POSITAL
FRABA

MULTITURN COUNTER MODULE
OPERATION MANUAL

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MULTITURN COUNTER MODULE
OPERATION MANUAL

BASIC FUNCTION

Overview

The POSITAL MT Module PCB is designed to count up to 43 bit revolutions without the need of a battery or a transmission gear and can be used to combine it with a high resolution ST base sensor[1]. The MT module provides MT and ST data via an SPI slave interface. The ST data are of low resolution and are needed to for the synchronization between ST and MT PCBs.

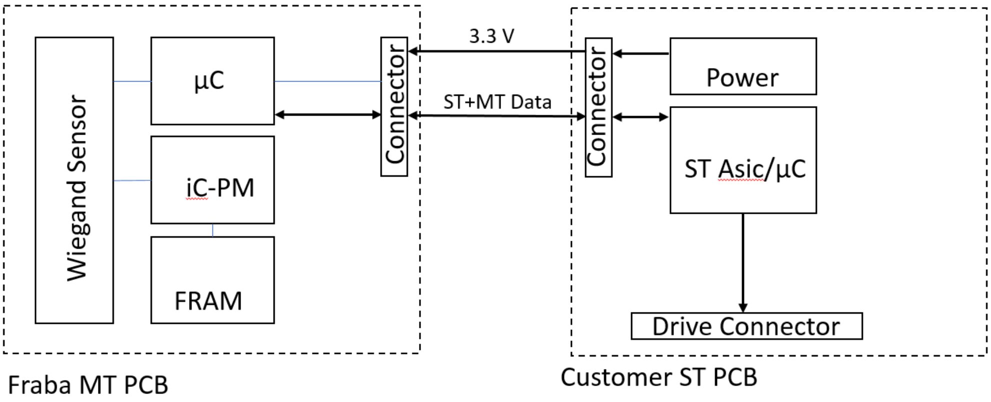


Figure 1: Basic Functional Concept

Counting Direction

Rotational direction is as viewed from the bottom of the MT-PCB. This means that CCW will result in upwards counting of ST and MT values, and CW will result in downwards counting of ST and MT values.

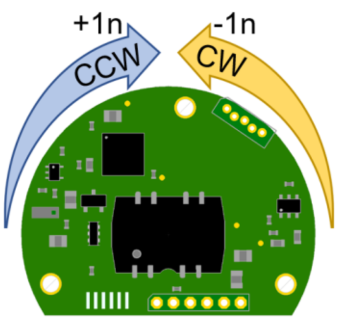


Figure 2: Counting Direction

Multiturn Error Detection

During powered operation, the internal singleturn count is used to calculate position data - the multiturn (Wiegand) rotation count, which is stored in the FRAM, is only used to calculate position data when the system reboots after powering down.

The multiturn (Wiegand) rotation count is continuously compared with the count derived from the internal singleturn system. When it is clear that the multiturn (Wiegand) system is not counting correctly, an error is flagged in the Status bits of the SPI communication (see relevant section below for details).

[1] Devices and processes for energy harvesting by Wiegand wire within position encoders are protected by several worldwide patents (such as WO 2004/046735 A1) and require licensing by the inventors and applicants. Use of the Multiturn Counter Module is restricted by application type. Please contact POSITAL for more details.

MULTITURN COUNTER MODULE
OPERATION MANUAL

SPECIFICATIONS:

Counter Characteristics

Item No.	Parameter	Symbol	Min.	Typ.	Max.	Unit	Conditions
101	Multi-turn Counting Range				40 bit	Turn	
102	Allowed Acceleration		0		80.000	Rad/s²	
103	Rotational Speed		0		12.000	rpm	
104	Software Version			2.02			

Electrical Characteristics (@ Ambient Temperature: 25°C)

Item No.	Parameter	Symbol	Min.	Typ.	Max	Unit	Conditions
201	Main power supply voltage	R	3	3.3	3.6	V	@25°C, DC
202	Current Consumption Counter PCB (Without ST PCB)	IC		35	50	mA	-40 to 105°C
203	Serial Communication Format	SPI 3.3 V TTL					
204	Communication Rate			5		Mbaut	
205	Power-on standby time				0.5	s	Time needed before PCB is ready to operate
206	ST Data bit			8			
207a	ST Data accuracy		-1.5		+1.5	degrees	@25°C, 100 r/min
207b	Worst case ST position error		-14		+14	degrees	@12000 r/min, @ -40/105°C
208	Communication cycle			100		μs	SPI Communication
209	Error bit			9		Bit	

Mechanical Characteristics

Item No.	Parameter	Symbol	Min.	Typ.	Max.	Unit	
601	Mass PCB	Mpcb		5		gr	
602	Mass Magnet	Mmag	--	1.26	--	gr	
603	Dimensions						See PCB Outline, see Magnet ouline

Environmental Conditions

Item No.	Parameter	Symbol	Min.	Typ.	Max	Unit	Conditions
301	Ambient operating temperature	T_a	-20		+105	°C	
302	Storage temperature	T_s	-20		+105	°C	
303	Relative humidity	rF			90%		+ 40°C, 96 hours, No condensation
304	Shock resistance	S_r			200	G	half sine 6 ms, EN 60068-2-27
305	Permanent shock resistance	S_{rp}			20	G	half sine 16 ms, EN 60068-2-29
306	Vibration resistance	V_r			20	G	10 Hz – 2000 Hz, EN 60068-2-6
307	EMC						No special EMC protection
308	External Magnetic Field				20	mT	Assuming Design requirements (section 9) are fulfilled

Electrical Connection

There are two connection options on the PCBA (see Figure 3 for location):

- 6x 1.8mm pitch through-holes
- 6x 0.93mm pitch SMD pads

In the following table the connection assignments are summarized:

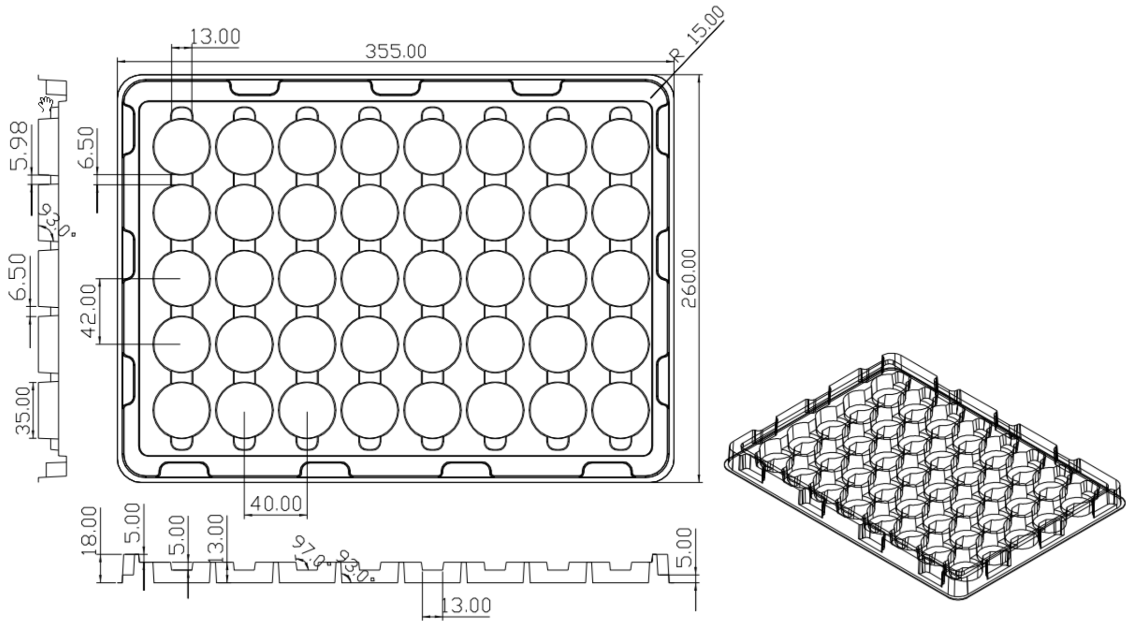
Pin number	Through hole	SMD
1	SPI_MOSI	SPI_MOSI
2	VCC=3.3V	VCC=3.3V
3	SPI_MISO	SPI_MISO
4	GND	GND
5	SPI_CLK	SPI_CLK
6	SPI_CS	SPI_CS

Ordering Information

Article Name	Article Number
KCD-FS00B-4008-PF1B-070	10048869
WS-Magnet-SmCo-DIA-8x2.5-A2	10034032

Packaging Information

320 pcs packed in 8x stacked plastic tray (article no: 10046745), sealed in ESD bag with one empty tray on top. SPQ: 320 MT-PCBs



Remarks

RoHS 2 (2011/65/EU)
Silicone free - a very small amount is in Sensor manufacture
Care must be taken to avoid direct contact between magnet and Wiegand sensor

DESIGN REQUIREMENTS

PCB

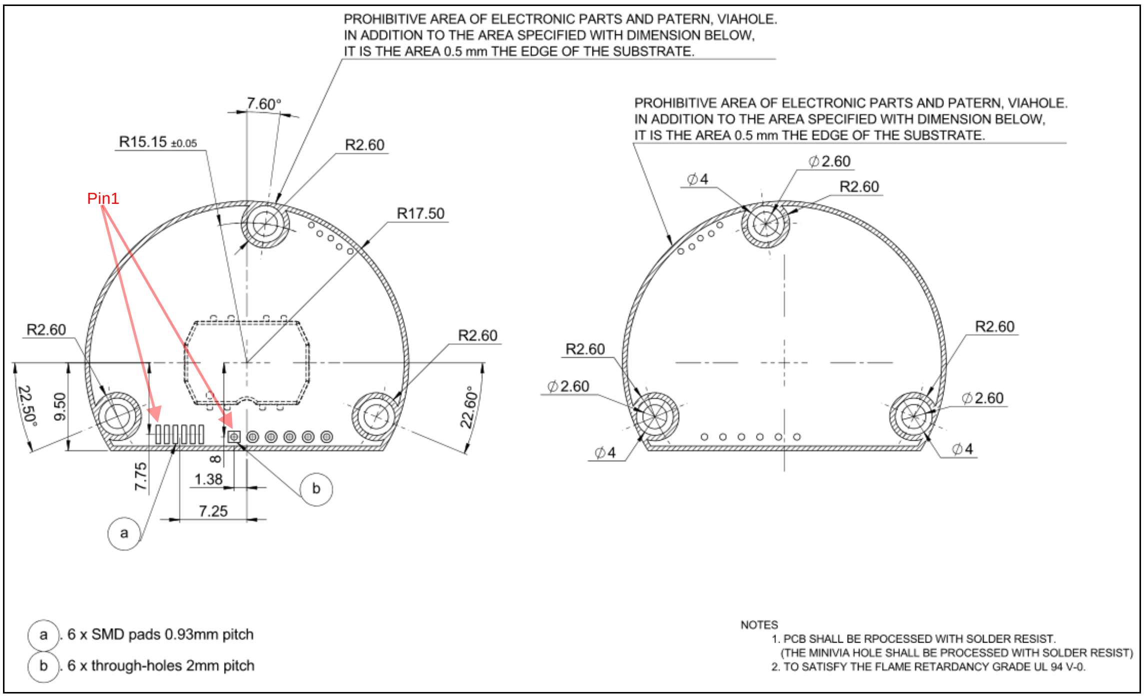


Figure 3: PCB Outline

Magnet

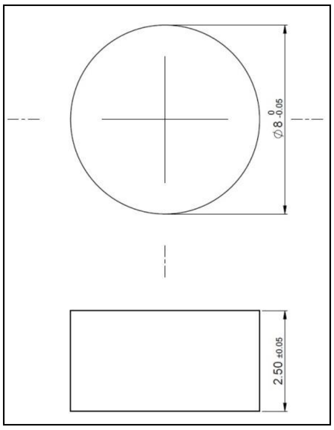


Figure 4: Magnet Outline (SmCo Φ8mm t2.5mm)

Magnetic System*

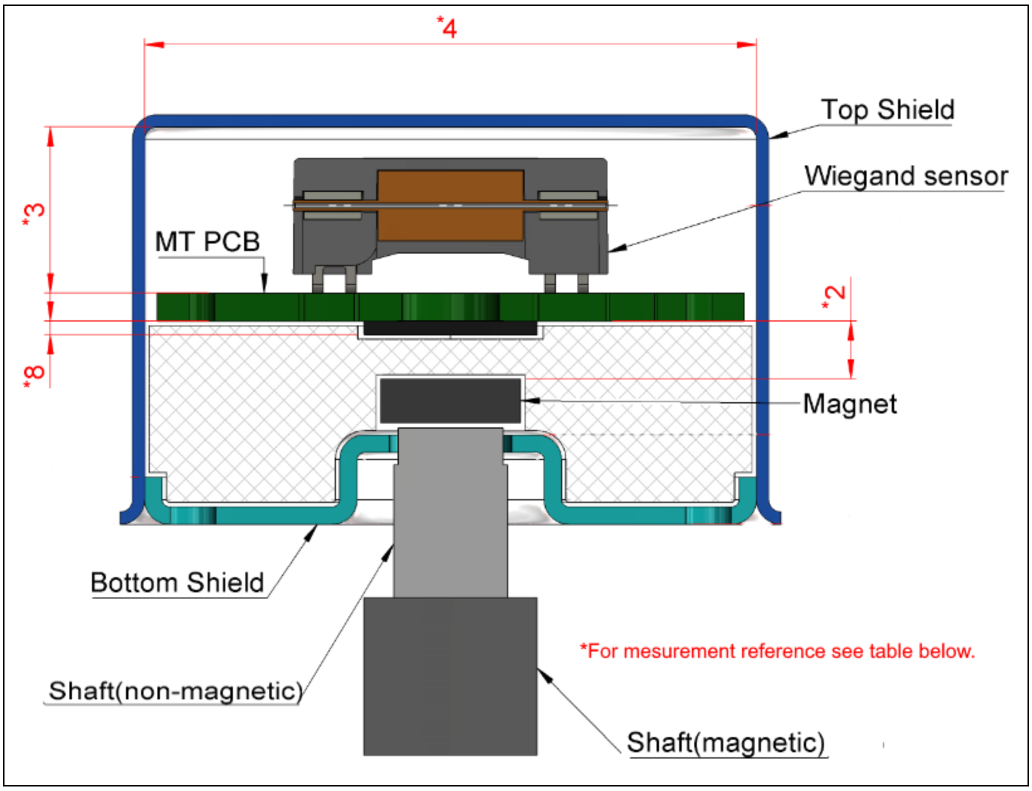


Figure 5: Kit Assembly Guidelines

Item No.	Parameter	Ref	Min.	Typ.	Max	Unit	Conditions
901	Axial Distance Magnet / MT-PCB (bottom)	2	4.25	4.5	5.005	mm	Corresponds to 7.98 mm - 8.735 mm distance magnet – wire (ref. 1)
901a	Magnetic Flux Density at Wire		8.5		9.5	mT	Based on specified magnet (@8.3mm distance)
901b	Magnetisation Angle of Magnet		-5		+5	deg	Angle between rotation axis and magnetization vector.
902	Axial Distance MT PCB (top) / Top Shield (bottom)	3	7.8			mm	
903	Top Shield Thickness		0.7			mm	
904	x/y position of MT-PCB to rotation axis		- 0.15		+0.15	mm	
905	MT-PCB thickness		1.08	1.2	1.32	mm	
907	Component Height on Bottom Side MT-PCB	8			1.2	mm	
908	Inner Diameter of Shield/Housing	4	35	35.8	36.6	mm	

(other dimensions to be confirmed)

*Disclaimer: Designs which deviate from the requirements could result in the need for custom firmware version optimized for MT functionality. (Dependent on evaluation)

SPI PROTOCOL

Overview

Pin name	Description	Data direction
SPI_XCS	Chip Select	ST-PCB --> MT-PCB
SPI_CLK	Clock (serial)	ST-PCB --> MT-PCB
SPI_MOSI	Data transmission	ST-PCB --> MT-PCB
SPI_MISO	Data transmission	MT-PCB --> ST-PCB

Parameter	Specification
Clock frequency	<5.0MHz
MOSI frames	2
MISO frames	7 or 9 (CMD dependent)
Bit width of frame	16 (MSB first)
CRC	CRC-16-CCITT (0x8810)
Communication cycle time	>100µs

Data table and chart taken from STM32F301x6 STM32F301x8 datasheet, p94-95

Parameter	MT-PCB
Clock frequency	<5.0MHz
CPHA	1
CPOL	1
Mode	Slave

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{SCK} $1/t_{c(SCK)}$	SPI clock frequency	Master mode	-	-	18	MHz
		Slave mode	-	-	18	
$t_{su(NSS)}$	NSS setup time	Slave mode, SPI presc = 2	4*Tpclk	-	-	ns
$t_{h(NSS)}$	NSS hold time	Slave mode, SPI presc = 2	2*Tpclk	-	-	
$t_{w(SCKH)}$ $t_{w(SCKL)}$	SCK high and low time	Master mode, f_{PCLK} = 36 MHz, presc = 4	Tpclk-2	Tpclk	Tpclk+2	
$t_{su(MI)}$ $t_{su(SI)}$	Data input setup time	Master mode	0	-	-	
		Slave mode	1	-	-	
$t_{h(MI)}$	Data input hold time	Master mode	6.5	-	-	
$t_{h(SI)}$		Slave mode	2.5	-	-	
$t_{a(SO)}$	Data output access time	Slave mode	8	-	40	
$t_{dis(SO)}$	Data output disable time	Slave mode	8	-	14	
$t_{v(SO)}$	Data output valid time	Slave mode	-	12	27	
$t_{v(MO)}$		Master mode	-	1.5	4	
$t_{h(SO)}$	Data output hold time	Slave mode	7.5	-	-	
$t_{h(MO)}$		Master mode	0	-	-	

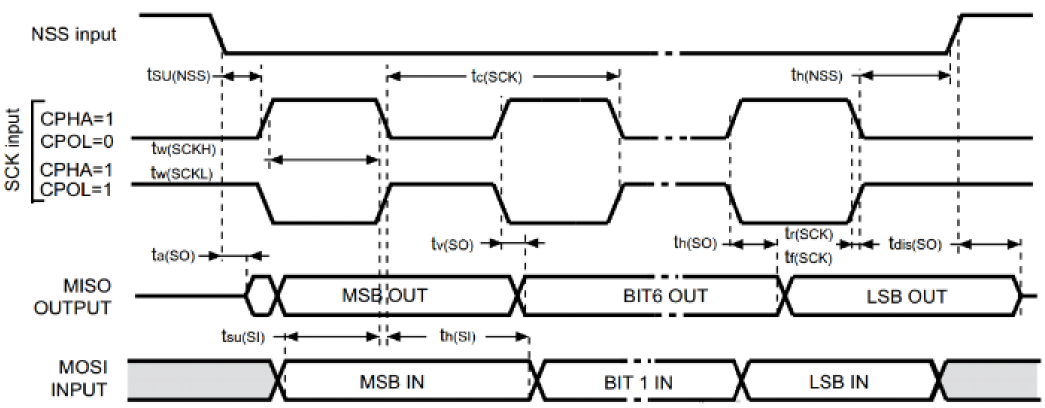


*Table and chart taken from STM32F301x6 STM32F301x8 datasheet, p94-95 (http://www.st.com)

Communication Overview

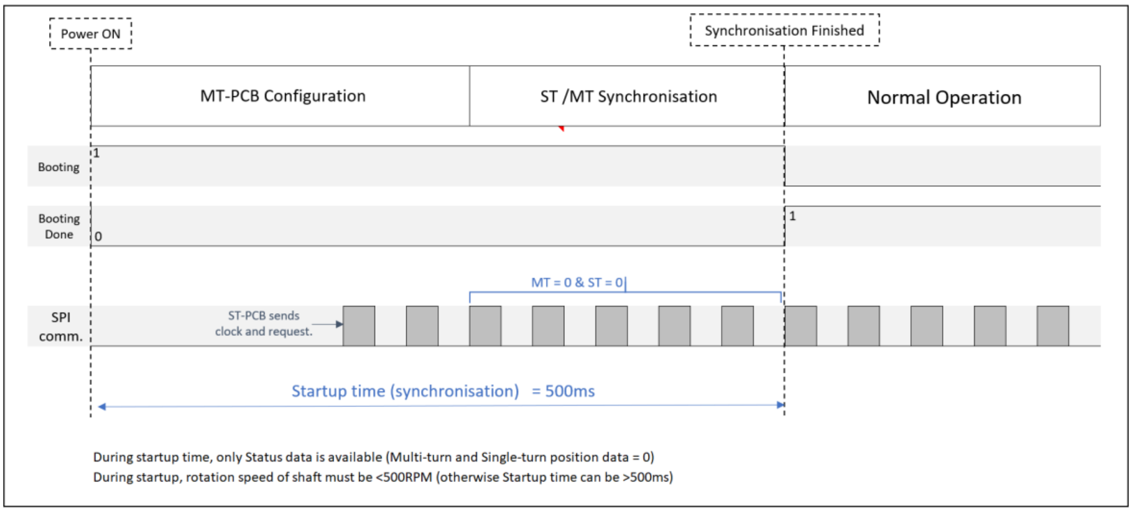


Figure 6: Start-up Sequence

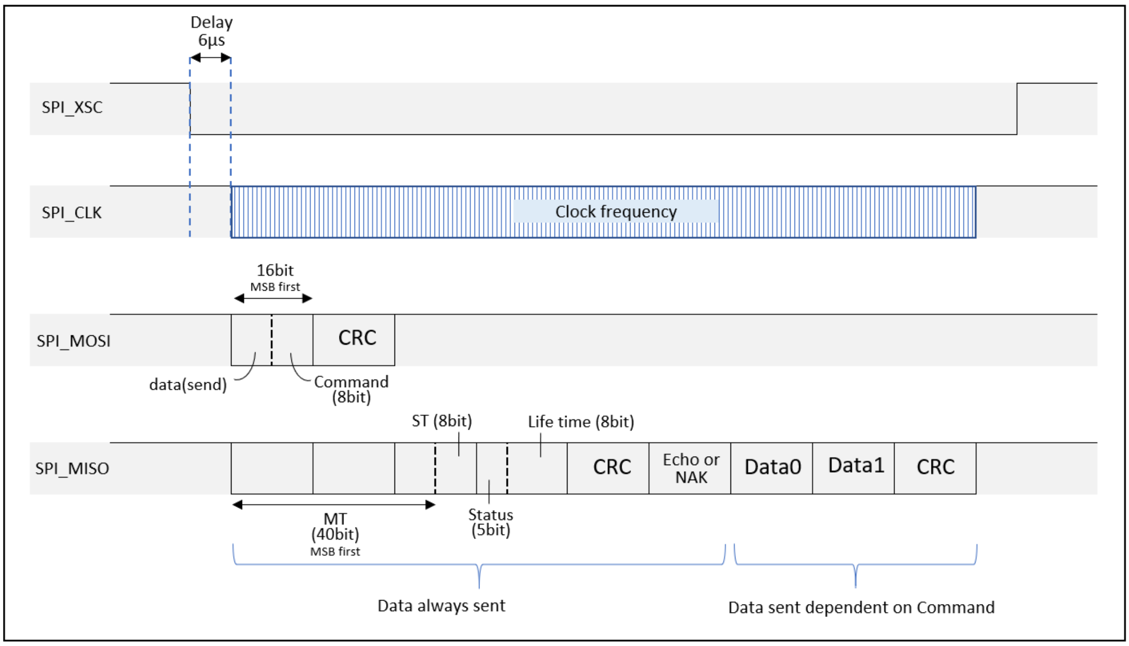


Figure 7: Timing Chart

Frame Overview

Command Name (Description)	Command	SPI_MOSI Frame		SPI_MISO Frame								
		1	2	1	2	3	4	5	6	7	8	9
EFR (Error Flag Read)	0x01	CMD = 0x0001	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	Error Flag		CRC
EFC (Error Flag Clear)	0x02	CMD = 0x0002	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CRC		
SWT (Start Wire Test)	0x03	CMD = 0x??03	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CRC		
RWT (Result Wire Test)	0x04	CMD = 0x??04	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	Wire Test Result Data		CRC
MTP (Multi-Turn Preset)	0x05	CMD = 0x**05	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CRC		
STP (Single-Turn Preset)	0x06	CMD = 0x0006	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CRC		
TMD (Temperature Data)	0x07	CMD = 0x0007	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CPU Temperature Data		CRC
IEP (Initialise EEPROM)	0x08	CMD = 0x0008	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	CRC		
FHV (FW HW Versions readout)	0x09	CMD = (Any)	CRC	MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	CMD ECHO	FW Version		CRC
NAK (Not Acknowledged)	Any	CMD = (Any)		MT[39:24]	MT[23:8]	MT[7:0] + ST[7:0]	STAT[5:0] + LT[7:0]	CRC	NAK (0x55AA)	CRC		

?? = Direction
** = Preset data
MT = Multi-turn position data
ST = Single-turn position data
STAT = Status data
LT = LifeTime data (LT incremented with every position value update)
Position data is always transmitted in MISO (except during Startup)
If MOSI transmission is not recognised, CMD ECHO will be NAK (0x55AA)
STP & MTP = For offset of internal ST/MT absolute position 0°

CRC (Cyclic Redudancy Check)

The SPI Protocol uses the 'CRC-16-CCITT reversed reciprocal' polynimial representation. The table below describes this polynomial.

CRC	
Polynomial	0x8810
Shift direction	Left
Initial Value	0x0000

Figure 8: CRC Polynomial Details

Some example commands and matching CRC (using the polynomial described above) are given below:

Command 0x0001	matching CRC = 0x8810.
Command 0x0103	matching CRC = 0x2770.
Command 0x0104	matching CRC = 0x8F20.

SPI PROTOCOL COMMANDS

Commands Overview

There are 9 commands implemented in the SPI protocol of the Multiturn counter Module. More detailed descriptions of each commands can be found in the following sections.

SPI_MOSI Frame 1

Command Name (Description)	Command	MSB bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	LSB bit0
EFR (Error Flag Read)	0x01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
EFC (Error Flag Clear)	0x02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
SWT (Start Wire Test)	0x03	0	0	0	0	0	0	0	Direction 0 = CCW 1= CW	0	0	0	0	0	0	1	1
RWT (Result Wire Test)	0x04	0	0	0	0	0	0	0	Direction 0 = CCW 1= CW	0	0	0	0	0	1	0	0
MTP (Multi-Turn Preset)	0x05	8bit Signed Multi-turn (-127 to 127)								0	0	0	0	0	1	0	1
STP (Single-Turn Preset)	0x06	8bit Unsigned Single-turn								0	0	0	0	0	1	1	0
TMD (Temperature Data)	0x07	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
IEP (Initialise EEPROM)	0x08	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
FHV (FW HW Versions readout)	0x09	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

Figure 9: Command Frame Details

Error Flag Read (EFR)

Error Flag Read is the most commonly used command during operation as it allows for all operational and critical information to be read in each communication cycle. Details of the frames output by the module are below:

SPI_MISO Frames 1 to 3

MSB bit47	bit46	bit45	bit44	bit43	bit42	bit41	bit40	bit39	bit38	bit37	bit36	bit35	bit34	bit33	bit32
upper 16bit Multi-turn Position Data [bit 39:24]															
bit31	bit30	bit29	bit28	bit27	bit26	bit25	bit24	bit23	bit22	bit21	bit20	bit19	bit18	bit17	bit16
middle 16bit Multi-turn Position Data [bit 23:8]															
bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
lower 8bit Multi-turn Position Data [bit 7:0]								8bit Single-Turn Position Data							

SPI_MISO Frame 4

	MSB bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	LSB bit0
Booting = Startup time ERR = Error Flag WTST = Wire Test EBSY = EEPROM busy	0	0	EBSY	0	ERR	WTST	Booting done	Booting	8bit LifeTime Data (system process counter for microprocessor)							

SPI_MISO Frames 7 and 8 (response to EFR)

MSB bit31	bit30	bit29	bit28	bit27	bit26	bit25	bit24	bit23	bit22	bit21	bit20	bit19	bit18	bit17	bit16
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0	0	0	0	0	0	EEWR 0 = no error 1 = error	EERD 0 = no error 1 = error	ECOM 0 = no error 1 = error	EVCC 0 = no error 1 = error	EMFL 0 = no error 1 = error	EMFH 0 = no error 1 = error	ETEMP 0 = no error 1 = error	EMT 0 = no error 1 = error	*EFLAG 00 = no error 01 = count overflow 10 = ECC error 11 = write error	

Error Flag Clear (EFC)

In the case of an error that has been resolved, Error Flag Clear can be used to clear the error flag (bit11) from the Status bits. Details and clear conditions of the error bits are shown below:

Error	Name	Details	Clear condition	Detected?
FRAM Error Flag	EFLAG	An error with the FRAM cannot be cleared is considered critical and immediate maintenance is needed bit [1:0] = 00 = no error bit [1:0] = 01 = count overflow bit [1:0] = 10 = ECC error bit [1:0] = 11 = write error	Cannot be cleared	During Startup & Main loop
Error Multi-turn data	EMT	An error occurs when hardware and software multi-turn count values differ at startup. When receiving EFC (0x02) -> multi-turn count value is updated with the multi-turn count value of IC-PM	Receive EFC, hardware and software counts become the same and the error state is cleared.	During Main loop
CPU Temperature too high	ETEMP	Junction temperature is greater than 125°C	Receive EFC, and temperature falls below 115°C	During Main loop
Magnetic Field too high	EMFH	Voltage at Hall sensor (ICPM) >95% saturation	Receive EFC, and saturation drops below error release level.	During Main loop
Magnetic Field too low	EMFL	Voltage at Hall sensor (ICPM) <10kA/m	Receive EFC, and voltage is above error release voltage.	During Main loop
Error Power Supply	EVCC	Supply voltage of ST probes is not OK (ICPM RDY is Low following startup - falling edge continuously monitored).	After power reset, receive EFC, and RDY = High	During Startup & Main loop
IC-PM/FRAM Comm. Error	ECOM	Default values are written into ICPM during startup and then read out again immediately afterwards. A difference triggers error	After power reset.	During Main loop
EEPROM Read Error	EMRD	EEPROM checksum wrong during startup (up to 3 READ attempts)	IEP command to initialize/reset EEPROM all error flags = 0, ST and MT Preset = 0	During Main loop
EEPROM Write Error	EMWR	EEPROM value written is read out again immediately afterwards. A difference triggers error. (NB: while writing to EEPROM all commands are ignored until write is complete.)	IEP command to initialize/reset EEPROM all error flags = 0, ST and MT Preset = 0	During Main loop

To clear errors relating to EEPROM operation (EMRD & EMWR), the Initialise EEPROM command is required.

Initialise EEPROM (IEP)

The Initialise EEPROM command is used to clear all data stored in the EEPROM. This includes:

- EMRD error flag
- EMWR error flag
- Single-Turn Preset (STP) value
- Multi-Turn Preset (MTP) value

Following this command it may be necessary to resend the STP and MTP data to maintain synchronization between the ST and MT PCBAs.

Temperature Data (TMD)

The Temperature Data command can be used to return the microcontroller junction temperature:

SPI_MISO Frames 7 and 8 (response to TMD)

MSB	bit31	bit30	bit29	bit28	bit27	bit26	bit25	bit24	bit23	bit22	bit21	bit20	bit19	bit18	bit17	bit16
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
	0	0	0	0	0	0	0	0	8bit CPU Temperature (T[°C] + 50)							

Firmware Version (FHV)

The Firmware Version command can be used to return the currently installed firmware version use by the microcontroller.

SPI_MISO Frames 7 and 8 (FWV)

MSB	bit31	bit30	bit29	bit28	bit27	bit26	bit25	bit24	bit23	bit22	bit21	bit20	bit19	bit18	bit17	bit16
	Main FW Version (e.g. 0x02)								Sub FW Version (e.g. 0x02)							
	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
	HW Version															

(e.g. FW version 2.02)

Start Wire Test (SWT) and Result Wire Test (RWT)

Following mechanical installation, one complete Wire Test function must be made to verify and ensure the performance of this system. During this test the Wiegand pulse peak voltages are measured, analyzed and stored.

The Pulse Peak average ($U_{P,Average}$) is calculated, using 1000 pulses for each trigger point. Additionally, the function also calculates a quality criteria of $U_{Pmin} = U_{P,Average} - 4\sigma$.

To test the Wiegand pulse quality, the MT-PCB has to be mounted according to specification. The test is only reliable if the top magnetic shield is closed during testing (Note: that the test routines have no way of checking if this is the case.)

Before starting the test, the PCB has to be powered up and the shaft has to rotate with the specified rotation direction and speed at a speed of ~2000rpm. The Wire Test begins when the Start Wire Test (SWT) command is received together with the defined rotation direction. The multiturn counter module scans the pulses continuously until the test is finished. The following steps must be completed before the test is concluded:

1. Start shaft rotating in the clockwise (CW) direction at 2000rpm
2. Send command 0x0103 (Start Wire Test, CW)
3. Allow shaft to rotate CW (>1000 times)
4. Start shaft rotating in the counterclockwise (CCW) direction at 2000rpm
5. Send command 0x0003 (Start Wire Test, CCW)
6. Allow shaft to rotate CCW (>1000 times)
7. Send command 0x0104 (Result Wire Test, CW)
8. Send command 0x0004 (Result Wire Test, CCW)

Note: Rotational direction is as viewed from the bottom of the MT-PCB.

The results of the wire test in each direction will be returned as follows:

SPI_MISO Frames 7 and 8 (response to RWT)

MSB	bit31	bit30	bit29	bit28	bit27	bit26	bit25	bit24	bit23	bit22	bit21	bit20	bit19	bit18	bit17	bit16
	(Average Pulse Voltage - 4σ) x 10								Average pulse voltage x 10							
	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The following conditions should be used for performing the Wire Test.

Parameter	Symbol	Min.	Typ.	Max.	Unit	Conditions
Wire Test Criteria	$U_{P,min}$	5.3	6	8	V	Valid for each trigger/direction with $U_{P,Average} - 4\sigma_i >= U_{P,min}$. Analysis for each of the 4 trigger points with 2*1000 pulses each @ 25°C @ 6.8 ± 1%, nF load.
Test Rotation Speed		1500	2000	2500	r/min	

Multi-Turn Preset (MTP) and Single-Turn Preset (STP)

The Multi-Turn Preset command can be used to define a preset value (+/-127 turns) to the Multi-turn Position Data. The adjusted multi-turn position value will be output during the subsequent communication cycle. This information is stored in the EEPROM as an offset and used during the Startup Time (Synchronisation) to adjust the output Multi-turn position data.

Single-Turn Preset command can be used to synchronise the 0/360° position of the internal (multiturn counter module) and external (Single-turn PCBA) systems. The adjusted single-turn position value will be output during the subsequent communication cycle. This information is stored in the EEPROM as an offset and used during the Startup Time (Synchronisation) to adjust the output Multi-turn and Single-turn position data. The functionality of this command is depicted below:

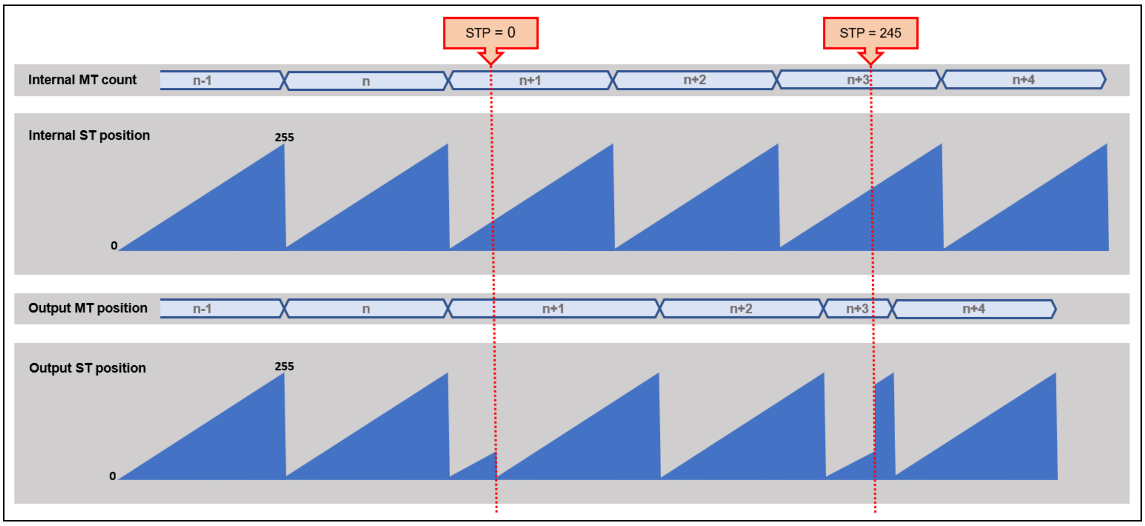


Figure 10: Single-Turn Preset Functionality

EEPROM Busy Timing

The following commands involve an EEPROM WRITE cycle. While a EEPROM WRITE cycle is ongoing the EEPROM busy (EBSY) flag stays High. The EEPROM busy flag should be monitored before sending commands involving an EEPROM WRITE cycle - such commands sent during this time will be NAK (Not Acknowledged).

Item No.	Command	EBSY time			Unit
		Min.	Typ.	Max.	
1001	Multi-Turn Preset (MTP)	-	-	15*	ms
1002	Singe-Turn Preset (STP)	-	-	15*	ms
1003	Initialise EEPROM (IEP)	-	-	15*	ms
1004	Error Flag Clear (EFC)	-	-	15*	ms

* A single EEPROM WRITE cycle can take 5ms, a maximum of 3 cycles are attempted before an error is given.

POSITAL FRABA

MULTITURN COUNTER MODULE
OPERATION MANUAL

REVISION HISTORY

Rev.:	Date	BY	Remarks
1.0	27.08.2019	TBE	Initial Version
1.1	07.02.2020	TBE	Added EEPROM Busy timing table
1.2	13.03.2020	TBE	Added disclaimer to p.8
1.3	04.08.2020	TBE	Removed ‘Output Inversion’, CRC table on p.11 Adjusted minimum temperature 301/302
1.4	22.12.2020	TBE	Added ‘pin 1’ marking to Fig 3. Updated Fig 5

Editor: TBE

Reviewer: MLO

Date: 22.12.2020

Mod