MagAlpha MA780

Low-Power Angle Sensor with Integrated Wakeup and Interrupt Logic

DESCRIPTION

The MA780 is a low-power angle sensor that detects the absolute angular position of a permanent magnet, such as a diametrically magnetized cylinder on a rotating shaft. With its power-cycling ability, this sensor is suitable for applications requiring low average power. The timing can be controlled via an on-chip clock or external controller. Flags are available for detecting a definable amount of angle change.

The MA780 supports a wide range of magnetic field strengths and spatial configurations. Both end-of-shaft and off-axis (side-shaft mounting) configurations are supported.

On-chip, non-volatile memory (NVM) provides storage for configuration parameters, including the reference zero-angle position, power-cycling parameters, and the filter window affecting the output resolution.

The MA780 is available in a QFN-16 (3mmx3mm) package.

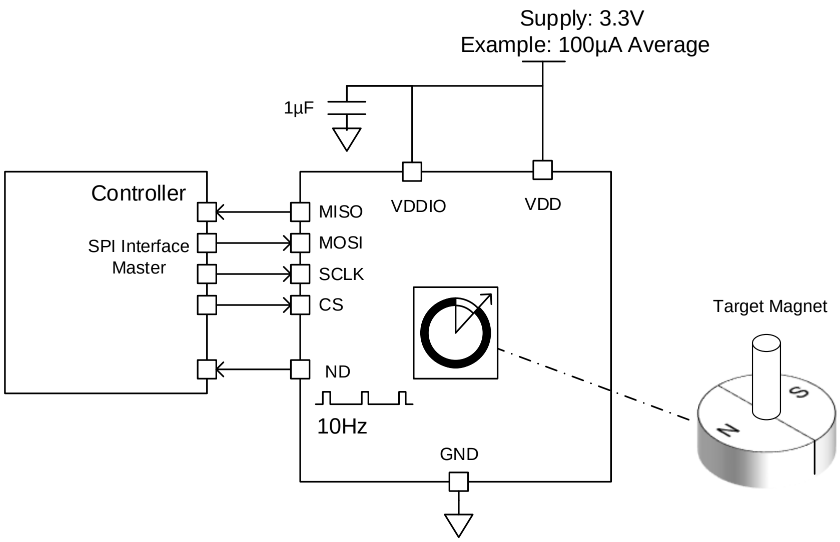
FEATURES

- 8-Bit to 12-Bit Resolution Absolute Contactless Angle Encoder
- 1µA Current Consumption in Idle Mode
- 10mA Current Consumption in Active Mode
- Internal or External Power-Cycling Control
- Warning on Change Flags
- SPI Serial Interface for Digital Angle Readout and Chip Configuration
- 3.3V Supply
- -40°C to +125°C Operating Temperature
- Available in a QFN-16 (3mmx3mm) Package

APPLICATIONS

- General-Purpose Angle Measurement
- Battery-Powered Devices
- Multi-Turn Encoders
- Low-Power Rotary Knob Interfaces

TYPICAL APPLICATION



ORDERING INFORMATION

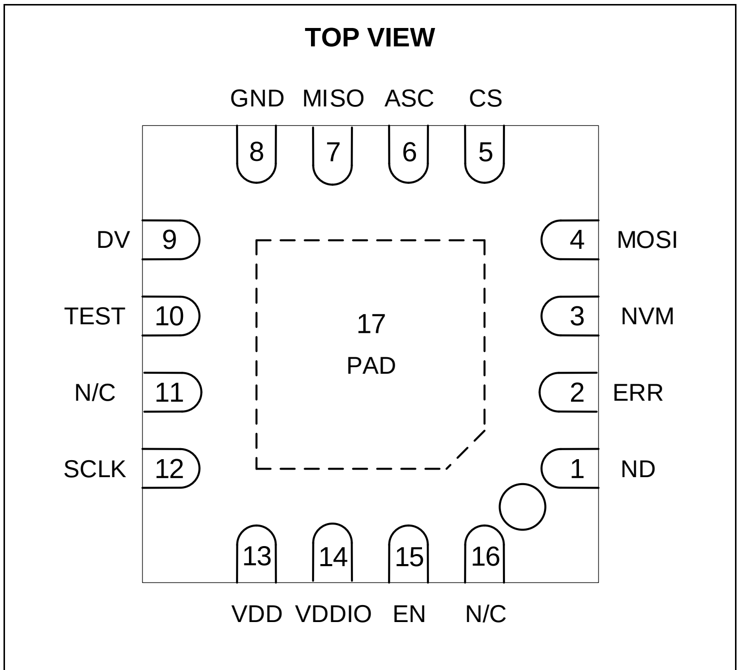
Part Number*	Package	Top Marking
MA780GQ	QFN-16 (3mmx3mm)	*See Below*

* For Tape & Reel, add suffix –Z (e.g. MA780GQ–Z).

TOP MARKING

BEA: Product code of MA780GQ
Y: Year code
LLL: Lot number

PACKAGE REFERENCE



QFN-16 (3mmx3mm)

ABSOLUTE MAXIMUM RATINGS [1]

Supply voltage ....-0.5V to +4.6V
Input pin voltage (V_I) ....-0.5V to +6.0V
Output pin voltage (V_O) ....-0.5V to +4.6V
Continuous power dissipation (T_A = 25°C) [2]
.... 2.0W
Junction temperature ....125°C
Lead temperature ....260°C
Storage temperature .... -65°C to +150°C

ESD Rating

Human-body model (HBM) 2kV
Charged-device model (CDM) 2kV

Recommended Operating Conditions

Supply voltage (V_{DD})………………..3.0V to 3.6V
I/O supply voltage (V_{DDIO})…………..1.8V to 3.6V
Operating temperature (T_{OP})….-40°C to +125°C
Applied magnetic field (B)……….30mT to 60mT

Thermal Resistance [3]

	θ_{JA}	θ_{JC}	
QFN-16 (3mmx3mm)	50	12	°C/W

Notes:

1) Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature, T_J (MAX), the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX) - T_A) / θ_{JA}.
3) Measured on JESD51-7, 4-layer PCB.

ELECTRICAL CHARACTERISTICS

V_{DD} = 3.3V, B = 45mT to 100mT, T_{OP} = -40°C to +125°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Supply Current						
Supply current when active	I_{ACTIVE}			10		mA
Supply current when idle	I_{IDLE}	Below 85°C		1		µA
Absolute Output – Serial						
Effective resolution		±3σ deviation of the noise distribution	8		12	bits
Noise RMS		1σ of the noise distribution	0.015		0.2	deg
Refresh rate		Active mode	850	980	1100	kHz
Data output length			16		16	bits
Response Time						
Power up time		After setting VDD at 3.3V		600		µs
Start-up time	$t_{START-UP}$	From idle to data valid with FW = 0		35		µs
Latency (4)		Constant speed propagation delay during t_{ACTIVE}. Equals the FW time constant (τ) + 3µs	4		16000	µs
Filter cutoff frequency (4)	f_{CUTOFF}	Depends on FW	5		160000	Hz
128MHz internal high frequency CLK error (affects TACT and filter settling time)		Room temperature	-13		+12	%
Cycle time error		Room temperature	-5		+5	%
Accuracy						
INL at 25°C		At room temperature across the full field range		0.7		deg
INL between -40°C to +125°C (5)		Across the full temperature range and field range		1.1		deg
Output Drift						
Temperature-induced drift at room temperature (5)				0.015		deg/°C
Temperature-induced variation (5)		From 25°C to 85°C		0.5		deg
		From 25°C to 125°C		1.0		deg
Induced magnetic field (5)				0.02		deg/mT
Induced supply voltage (5)				0.3		deg/V
Digital I/O						
Input high voltage	V_{IH}		2.5		5.5	V
Input low voltage	V_{IL}		-0.3		+0.8	V
Output low voltage (5)	V_{OL}	I_{OL} = 4mA			0.4	V
Output high voltage (5)	V_{OH}	I_{OH} = 4mA	2.4			V
Falling-edge slew rate (4)	t_F	CL = 50pF		0.7		V/ns

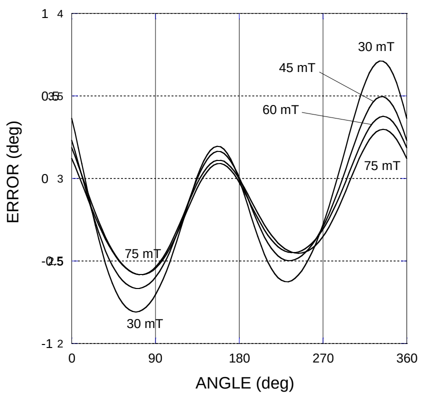
Notes:

4) Guaranteed by design.
5) Guaranteed by characteristic testing.

TYPICAL CHARACTERISTICS

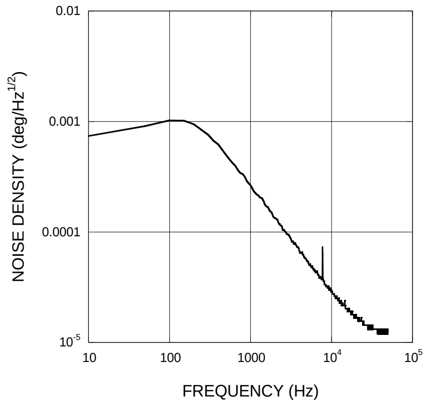
V_{DD} = 3.3V, T_{OP} = 25°C, unless otherwise noted.

Error Curves at 25°C



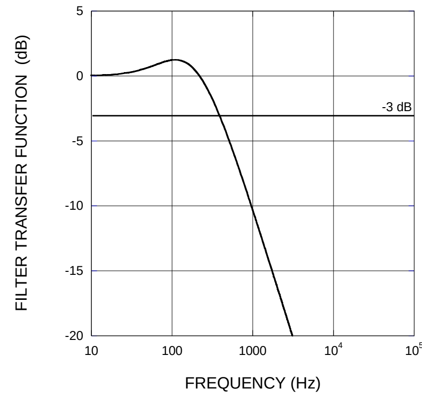
Noise Spectrum at 50mT

FW = 10

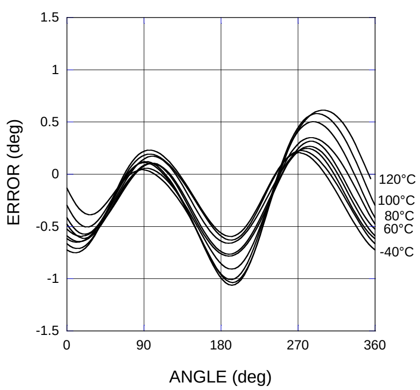


Filter Transfer Function

FW = 10

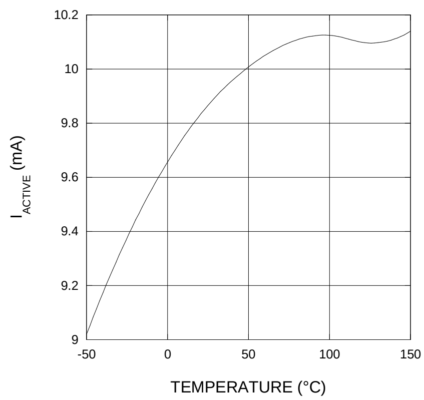


Error Curves at 45mT



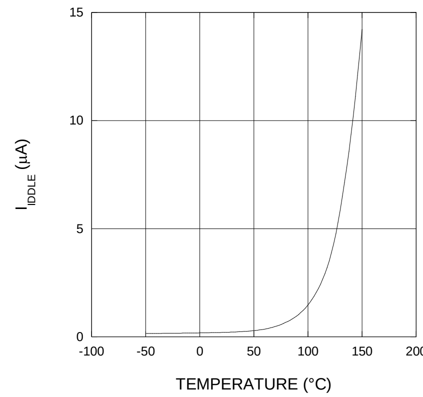
Supply Current

Active mode, V_{DD} = 3.3V



Supply Current

Idle mode, V_{DD} = 3.3V



PIN FUNCTIONS

Pin #	Name	I/O	Description
1	ND	O	**New data.** In ASC mode, ND indicates that new data is ready to be read. ND also indicates if the displacement exceeds the defined threshold.
2	ERR	O	**Error flag.**
3	NVM	O	**Non-volatile memory.** NVM indicates if the chip is busy accessing the non-volatile memory.
4	MOSI	I	**Data in (SPI)**
5	CS	I	**Chip selection (SPI).**
6	ASC	I	**Auto-sampling cycle**. Connect ASC to GND if it is not being used.
7	MISO	O	**Data out (SPI).** MISO is pulled low when CS is set to logic 1 (e.g. SPI is inactive).
8	GND	N/A	**Supply ground.**
9	DV	O	**Data valid.** DV indicates whether the digital filter has been stabilized in active mode.
10	TEST	N/A	**Connect to ground.**
11	N/C	N/A	**No connection.** Leave N/C disconnected.
12	SCLK	I	**Clock (SPI).**
13	VDD	N/A	**3.3V supply.**
14	VDDIO	N/A	**1.8V to 3.3V supply for the IO.** Allows communication at a voltage between 1.8V and 3.3V.
15	EN	I	**Enable.** EN switches the sensor to active mode. Connect EN to GND if it is not being used.
16	N/C	N/A	**No connection.** Leave N/C unconnected.

FUNCTIONAL BLOCK DIAGRAM

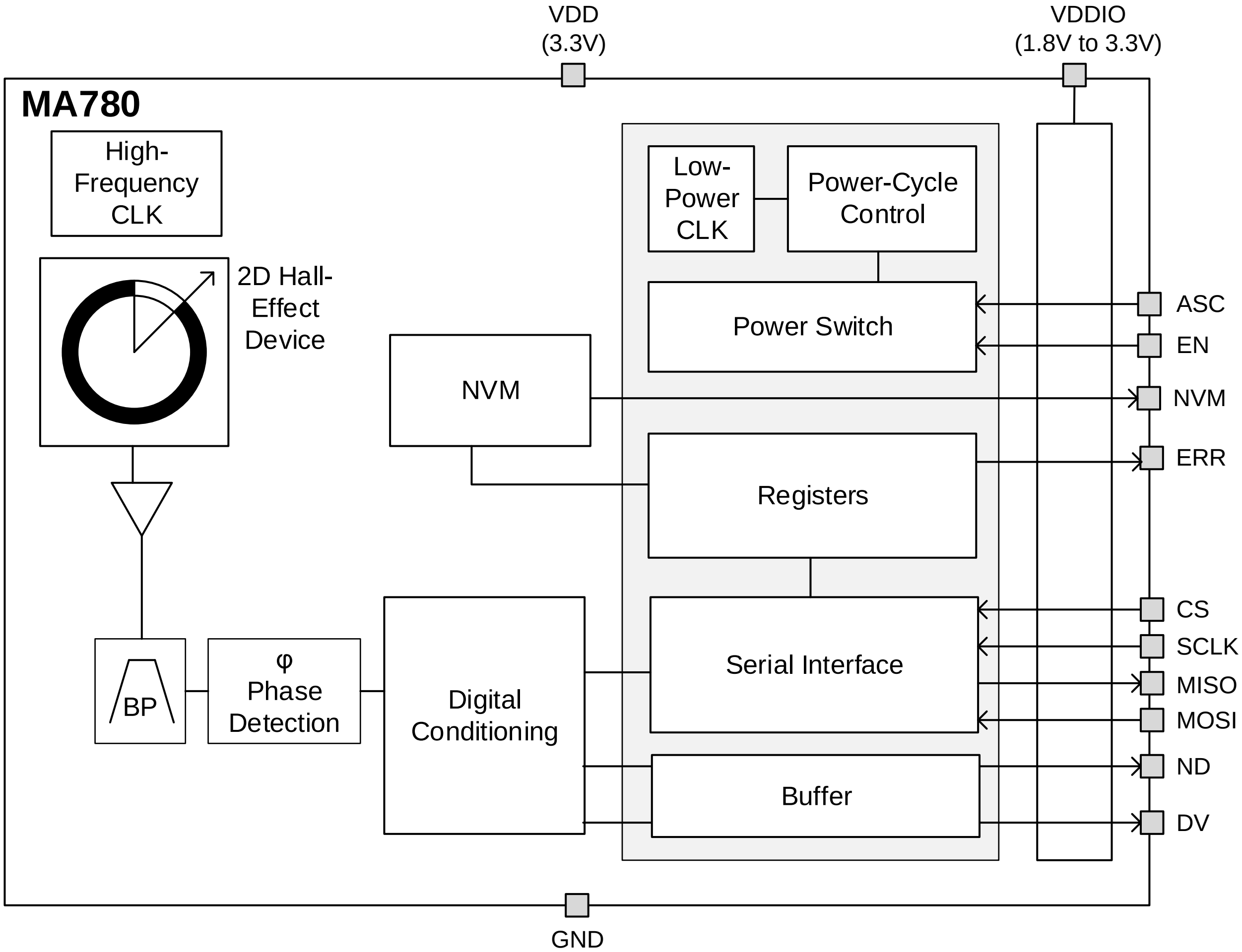


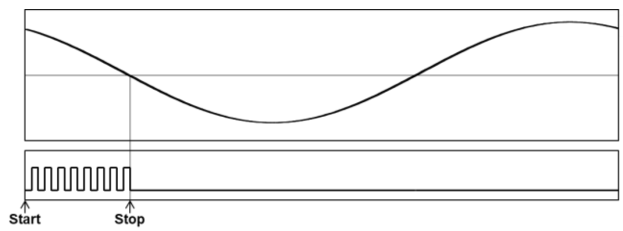
Figure 1: Functional Block Diagram (Only Grey Zone Operates in Idle Mode)

OPERATION

Sensor Front-End

The magnetic field is detected with integrated Hall devices located in the center of the MA780's package. The angle is measured using the Spinaxis™ method, which directly digitizes the direction of the field without complex arctangent computation or feedback loop based circuits (interpolators).

The Spinaxis™ method is based on phase detection, and generates a sinusoidal signal with a phase that represents the angle of the magnetic field. The angle is then obtained by a time-to-digital converter, which measures the time between the zero crossing of the sinusoidal signal and the edge of a constant waveform (see Figure 2). The time-to-digital is the output from the front-end to the digital conditioning block.



Top: Sine Waveform
Bottom: Clock of Time-to-Digital Converter
Figure 2: Phase Detection Method

The output of the front-end delivers a digital number proportional to the angle of the magnetic field at the rate of 1MHz in a straightforward and open-loop manner.

Digital Filtering

The front-end signal is further treated to achieve the final effective resolution. The filter transfer function can be calculated with Equation (1):

$$H(s) = \frac{1}{1+\tau s} \tag{1}$$

Where τ is the filter time constant, which depends on the filter window (see the Electrical Characteristics section on page 4 for the value of τ)

To save power, front-end and digital filtering are disabled in idle mode. However, the SPI block works continuously, meaning the angle can be read at any time.

Sensor – Magnet Mounting

The sensitive volume of the MA780 is confined in a region less than 100µm wide, and has multiple integrated Hall devices. This volume is located both horizontally and vertically within 50µm of the center of the QFN-16 package. The sensor detects the angle of the magnetic field projected in a plane parallel to the package's upper surface. This means that the only relevant magnetic field is the in-plane component (X and Y components) in the middle point of the package.

When looking at the top of the package, the angle increases when the magnetic field rotates clockwise (by default). Figure 3 shows the zero angle of the unprogrammed sensor, where the cross indicates the sensitive point. Both the rotation direction and the zero angle can be configured.

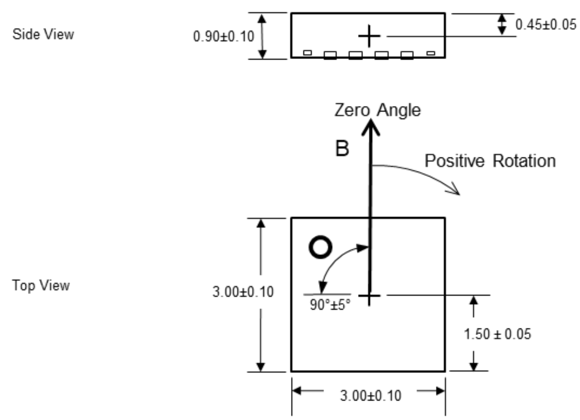


Figure 3: Detection Point and Default Positive Direction

This type of detection provides flexibility for the design of an angular encoder. The sensor only requires the magnetic vector to be placed within the sensor plane with a field amplitude of at least 30mT.

The MA780 can work with fields smaller than 30mT, but the linearity and resolution performance may deviate from the specifications. The most straightforward mounting method is to place the MA780 sensor on the rotation axis of a permanent magnet (e.g. a diametrically magnetized cylinder) (see Figure 4).

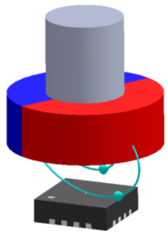


Figure 4: End-of-Shaft Mounting

The recommended magnet is a Neodymium alloy (N35) cylinder with dimensions of Ø5x3mm, inserted into an aluminum shaft with a 1.5mm air gap between the magnet and the sensor (surface of package). For good linearity, the sensor should be positioned with a precision of 0.5mm.

If the end-of-shaft position is not available, the sensor can be positioned away from the rotation axis of a cylinder or ring magnet (see **Error! Reference source not found.**).

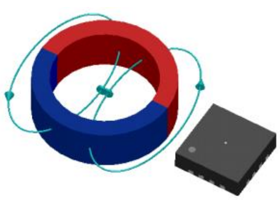


Figure 5: Side-Shaft Mounting

In this case, the magnetic field angle is no longer directly proportional to the mechanical angle. The MA780 can be adjusted to compensate for this effect, and to recover the linear relation between the mechanical angle and the sensor output. With multiple pole-pair magnets, the MA780 indicates multiple rotations for each mechanical turn.

Low-Power Operation

The MA780 has three power modes:

<u>Active</u>: The sensor runs without interruption, and the power consumption is at I_{ACTIVE} (see the Electrical Characteristics section on page 4).

<u>Idle</u>: The sensor's front-end is powered down. The SPI communication interface and memory blocks are working. The power consumption is at I_{IDLE} (see the Electrical Characteristics section on page 4).

<u>Automatic sampling cycle (ASC)</u>: The device automatically switches between active and idle mode.

Table 1 lists the supply current for each mode.

Table 1: Supply Currents

Power Mode	Supply Current
Active	I_{ACTIVE}
ASC	Between I_{IDLE} and I_{ACTIVE}
Idle	I_{IDLE}

Figure 6 shows a complete power cycle.

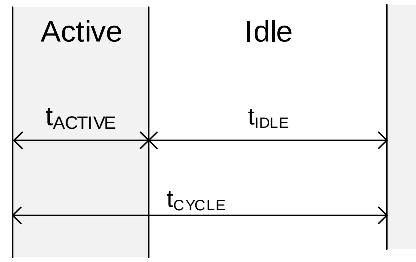


Figure 6: One Power Cycle

The MA780 can be operated in different ways by combining the three power modes.

Continuous ASC

In ASC mode, the on-chip, low-power clock is continuously running to control the sensor's power cycle, according to the active and cycle time stored in the register.

Figure 7 shows the minimum configuration.

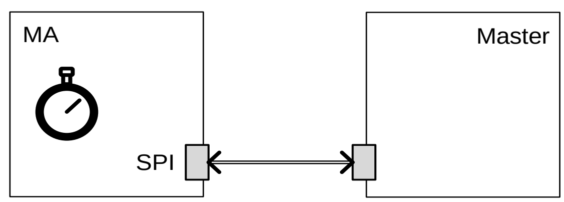


Figure 7: Minimum Configuration for Continuous ASC Mode

In this configuration, the master can check the MA780 by SPI at any time, the same way it does in active mode (see Figure 8). The difference is that the average power consumption is lower, and the refresh rate is determined by a user-configured parameter (t_{CYC}).

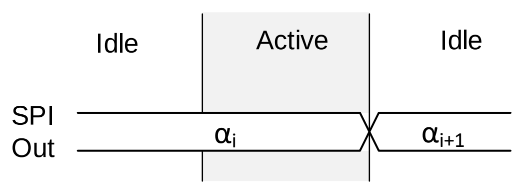


Figure 8: Signal Timing in ASC Mode

The SPI output is updated at the end of the active period.

The new data (ND) signal can be used in different ways, depending on the sensor's configuration (see Figure 9).

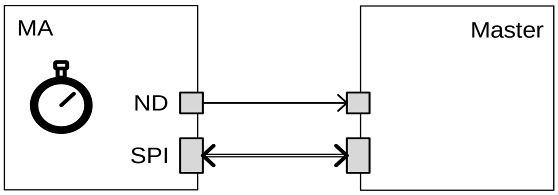


Figure 9: Typical ND Configuration in Continuous ASC Mode

For example, ND can be used to indicate the end of an active period. By default, the ND signal rises after each active phase, indicating that a new value is available in the output buffer. ND is reset after reading the angle (See Figure 10).

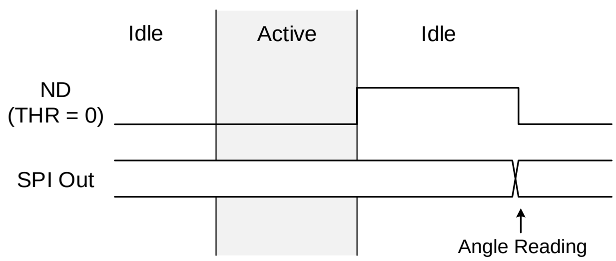


Figure 10: Using the ND Pin as a Flag for Data Updates (THR = 0)

If the threshold is configured to a non-zero value, the ND pin becomes a warning-on-change (WOC) signal. The reference value used to detect a change can either be a fixed value, or can be configured by the user at each WOC via Register 10 (see Figure 11).

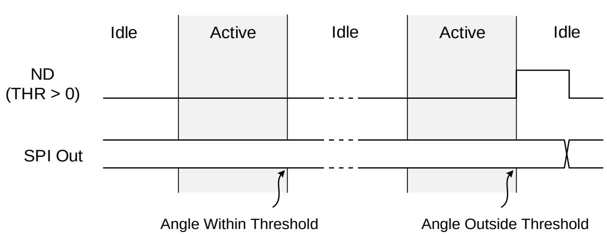


Figure 11: Using WOC (ND Configured to Non-Zero Threshold)

Externally Controlled

The master controls the power mode of the MA780 with digital input pins. Through the two digital input pins (EN and ASC), it is possible to switch between any power mode.

Switching Between Active and Idle Mode

Pulling the EN pin high wakes up the MA780. First, the DV signal indicates that the measurement is stable. The master can then send the MA780 back to idle mode while the angle remains in the MA780 output buffer. Meanwhile, the SPI interface stays active to allow data reading (see Figure 12 and Figure 13).

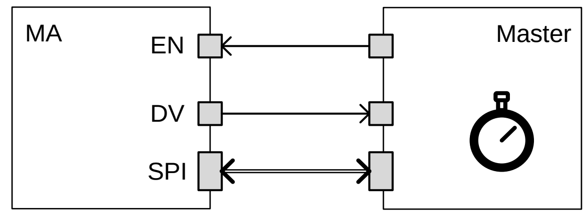


Figure 12: Typical Configuration in External Control

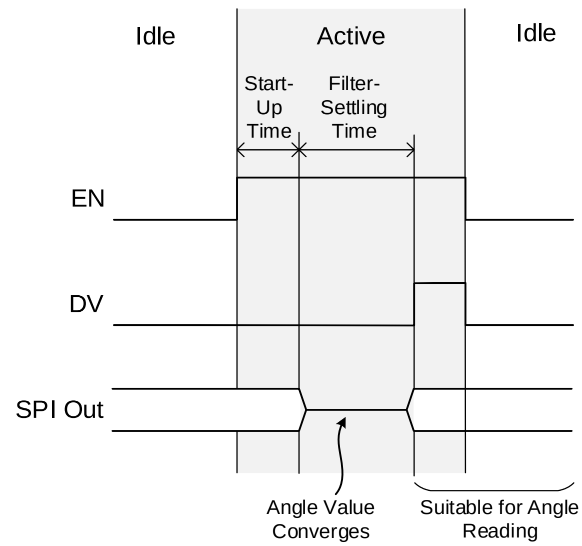


Figure 13: Signal Timing in External Control

Mixed Operation (Active and ASC Mode)

To switch between a low-power ASC mode and high-power active mode, drive the EN pin high or low, respectively. **Error! Reference source not found.** shows a typical configuration when switching between active mode and ASC mode.

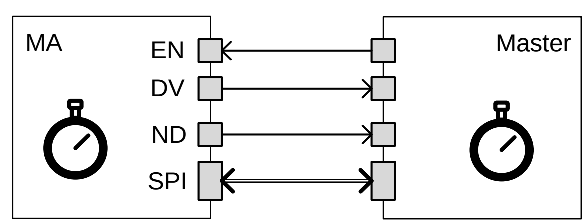


Figure 14: Typical Configuration when Switching Between Active Mode and ASC Mode

For example, if a certain angle change is detected in ASC mode, EN can be used to keep the sensor fully powered to make high-rate angle measurements.

Mixed Operation (ASC and Idle Mode)

In this scenario, the mode is switched by driving the ASC pin. ASC mode is activated when the ASC pin is high. In this configuration, the angle is updated when in ASC mode (see Figure 15).

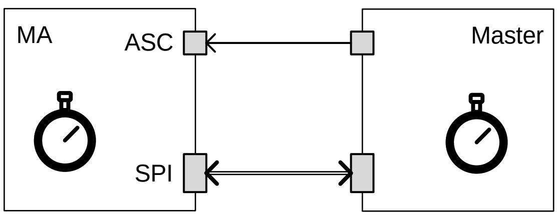


Figure 15: Typical Configuration when Switching Between Idle and ASC Mode

Power Supply

It is recommended to place a 1µF decoupling capacitor close to the sensor with a low-impedance path to GND (see Figure 16).

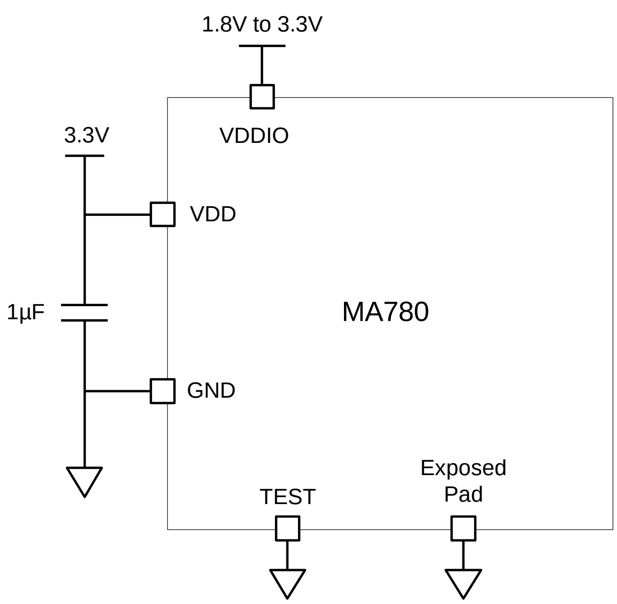


Figure 16: Electrical Mounting and Power Supply Decoupling

In general, the MagAlpha works well with or without the exposed pad connected. For optimal conditions (electrically, thermally, and mechanically), it is recommended to connect the exposed pad to ground.

Serial Interface

The sensor supports the SPI serial interface for angle reading and register programming.

SPI

The SPI is a 4-wire, synchronous, serial communication interface. The MagAlpha supports SPI Mode 3 and Mode 0 (see Table 2).

Table 2: SPI Specifications

	Mode 0	Mode 3
SCLK Idle State	Low	High
Data Capture	On SCLK rising edge	
Data Transmission	On SCLK falling edge	
CS Idle State	High	
Data Order	MSB first	

The SPI mode (0 or 3) is detected automatically by the sensor, and does not require any action from the user (see Table 3).

Table 3: SPI Standard

	Mode 0	Mode 3
CPOL	0	1
CPHA	0	1
Data Order (DORD)	0 (MSB first)	

The maximum clock rate supported on the SPI is 25MHz. There is no minimum clock rate. Real-life data rates depend on the PCB layout quality and signal trace length (see Figure 17, Figure 18, and Table 4 on page 12 for SPI timing).

All commands to the MagAlpha (whether for writing or reading register content) must be transferred through the SPI MOSI pin, and must be 16 bits long. See the SPI Communication section on page 13 for additional details.

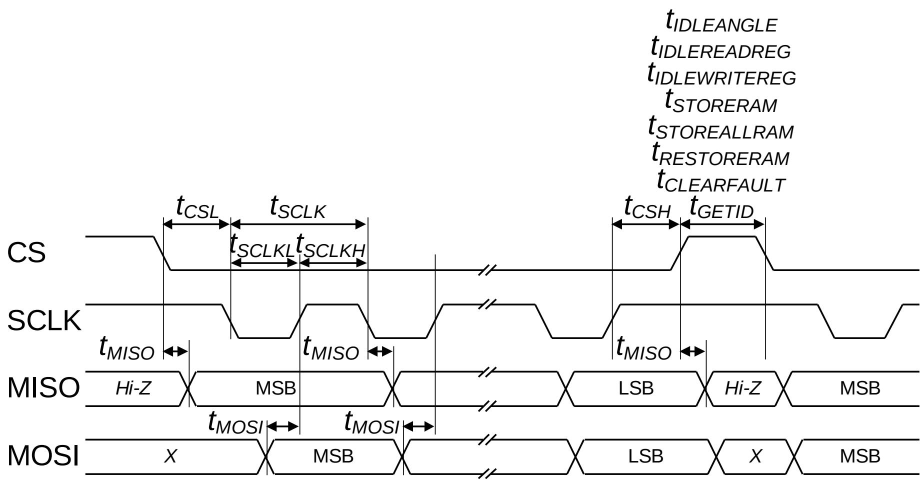


Figure 17: SPI Timing Diagram (for Mode 3)

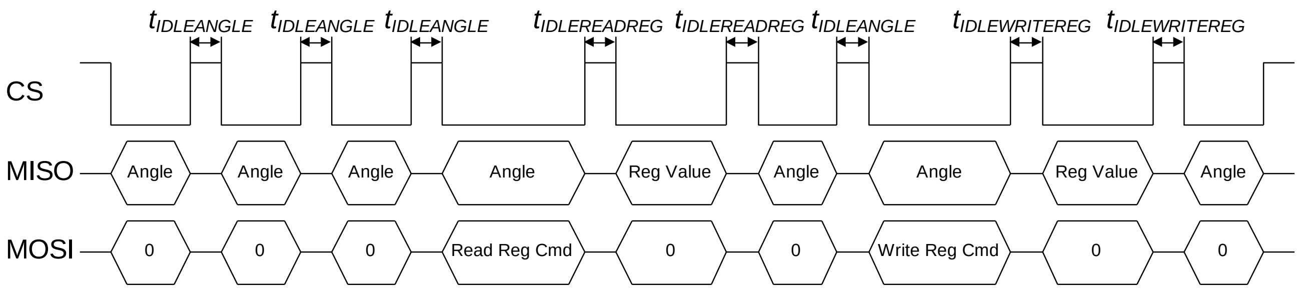


Figure 18: Minimum Idle Time

Table 4: SPI Timing

Parameter (6)	Description	Min	Max	Unit
$t_{IDLEANGLE}$	Idle time between two subsequent angle transmissions	120		ns
$t_{IDLEREADREG}$	Idle time before and after a register readout	120		ns
$t_{IDLEWRITEREG}$	Idle time before and after a register write	120		ns
$t_{STORERAM}$	Time required to store a register value to the NVM	23		ms
$t_{STOREALLRAM}$	Time required to store all register values to the NVM	704		ms
$t_{RESTORERAM}$	Time required to restore all register values from the NVM	240		us
$t_{CLEARFAULT}$	Time required to clear the fault flags (register 26)	40		ns
t_{GETID}	Idle time between a get ID command and the readout of the ID value	40		ns
t_{CSL}	Time between CS falling edge and SCLK falling edge	120		ns
t_{SCLK}	SCLK period	40		ns
t_{SCLKL}	Low level of SCLK signal	20		ns
t_{SCLKH}	High level of SCLK signal	20		ns
t_{CSH}	Time between SCLK rising edge and CS rising edge	20		ns
t_{MISO}	SCLK falling edge to data output valid		15	ns
t_{MOSI}	Data input valid to SCLK reading edge	15		ns

Note:

6) All values are guaranteed by design.

SPI Communication

The sensor supports the functions listed below:

- Read angle
- Read configuration register
- Write configuration register
- Store a single register value to NVM
- Store all register values to NVM
- Restore all register values from NVM
- Clear error flags

The sensor supports three types of SPI operation: SPI read angle, SPI read register, and SPI write register. Each operation has a specific frame structure, described below.

SPI Read Angle

Every 1µs, new data is transferred into the output buffer. The master device initiates this process by pulling CS low.

When a trigger event is detected, the data remains in the output buffer until the CS signal is de-asserted (see Table 5).

Table 5: Sensor Data Timing

Event	Action
CS falling edge	Start reading and freeze output buffer
CS rising edge	Release of the output buffer

Error! Reference source not found. shows a diagram of a full SPI angle reading.

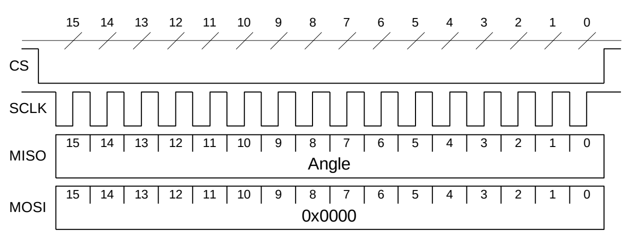


Figure 19: Diagram of a Full 16-Bit SPI Angle Reading

Figure 20 shows a partial SPI angle reading.

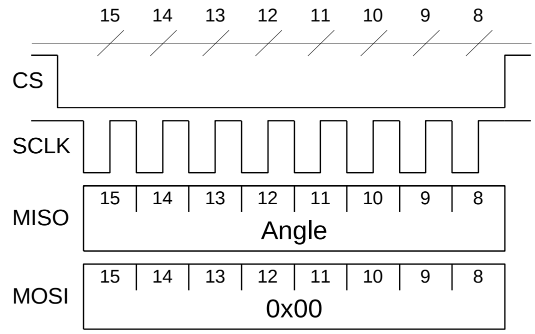
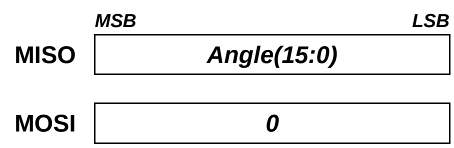


Figure 20: Diagram of a Partial 8-Bit SPI Angle Reading

A full angle reading requires 16 clock pulses. The sensor MISO line returns:



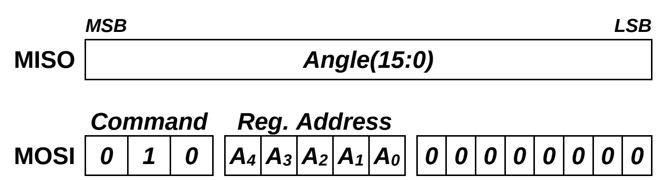
If less resolution is sufficient, the angle can be read by sending fewer clock counts (since the MSB is first).

In case of very fast reading cycles, the MagAlpha continues sending the same data until the data is refreshed (for the refresh rate, see the Electrical Characteristics section on page 4).

SPI Read Register

A read register operation is made of two 16-bit frames. The first frame sends a read request, which contains the 3-bit read command (010) followed by the 5-bit register address. The last 8 bits of the frame must all be set to 0. The second frame returns the 8-bit register value (MSB byte) with an 8-bit angle value.

First is the 16-bit SPI frame (read request):



The second is the 16-bit SPI frame (response):

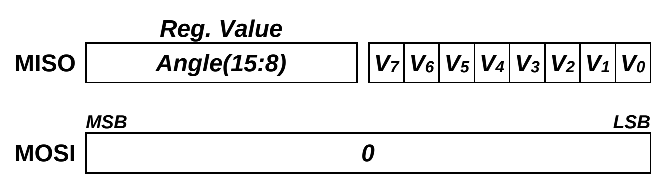


Figure 21 shows a complete transmission overview.

For example, to check the value of the ERRPAR parameter (parity error on register write command), read register 26 (bit 3) by sending the following first frame:

	MSB … LSB
MISO	*Angle(15:0)*

	Command			Reg. Address												
MOSI	*0*	*1*	*0*	*1*	*1*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

In the second frame, the MagAlpha replies:

	reg. value								
MISO	*Angle(15:8)*	*X*	*X*	*X*	*X*	*ERRPAR*	*X*	*X*	*X*

	MSB … LSB
MOSI	*0*

Figure 22 shows a complete read status overview.

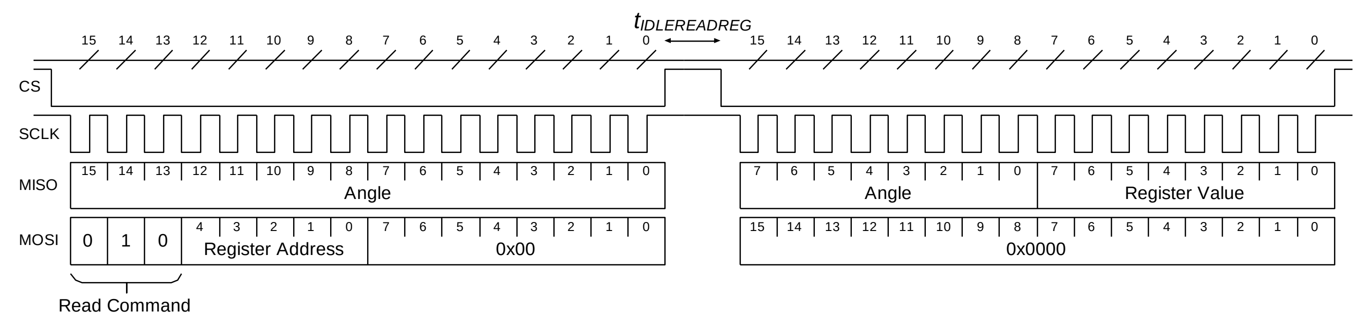


Figure 21: Two 16-Bit Frames Read Register Operation

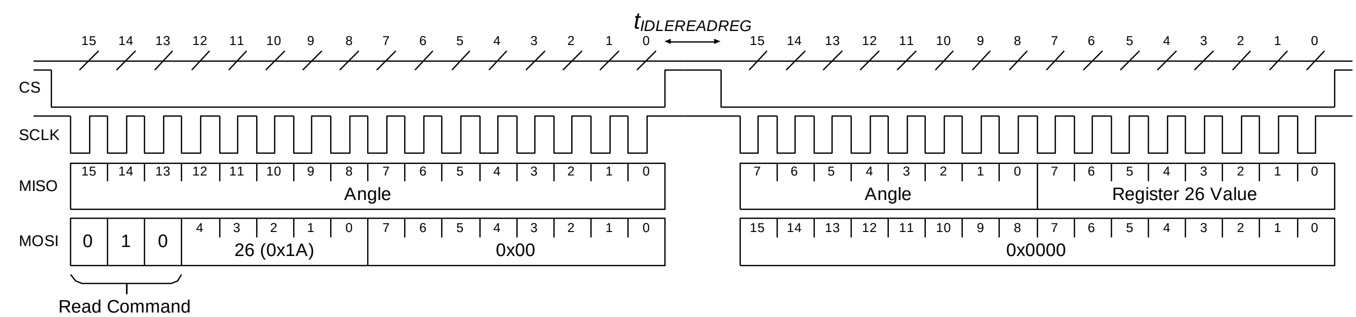


Figure 22: Read the Status Byte in Register 26

SPI Write Register

A write register operation is made of two 16-bit frames. The first frame sends a write request, which contains the 3-bit write command (100) followed by the 5-bit register address and the 8-bit value (MSB first). The second frame returns the newly written register value (acknowledge) with an 8-bit angle value.

The first 16-bit SPI frame (write request) is:

	MSB … LSB
MISO	*Angle(15:0)*

	Command			Reg. Address					Reg. Value							
MOSI	*1*	*0*	*0*	A_4	A_3	A_2	A_1	A_0	V_7	V_6	V_5	V_4	V_3	V_2	V_1	V_0

The second 16-bit SPI frame (response) is:

	Reg. Value								
MISO	*Angle(15:8)*	V_7	V_6	V_5	V_4	V_3	V_2	V_1	V_0

	MSB … LSB
MOSI	*0*

The readback register content can be used to verify the register configuration. Figure 23 shows a complete transmission overview.

For example, to set the value of the output rotation direction RD to counterclockwise (RD bit = logic 1), write register 9 by sending the following first frame:

	MSB … LSB		
MISO	*Angle(15:0)*		
	Command	*Reg. Address*	*Reg. Value*
MOSI	*1 0 0*	*0 1 0 0 1*	*1 0 0 0 0 0 0 0*

Send the second frame. If the register is written correctly, the reply is:

		Reg. Value
MISO	*Angle(15:8)*	*1 0 0 0 0 0 0 0*
	MSB … LSB	
MOSI	*0*	

Figure 24 shows a complete example.

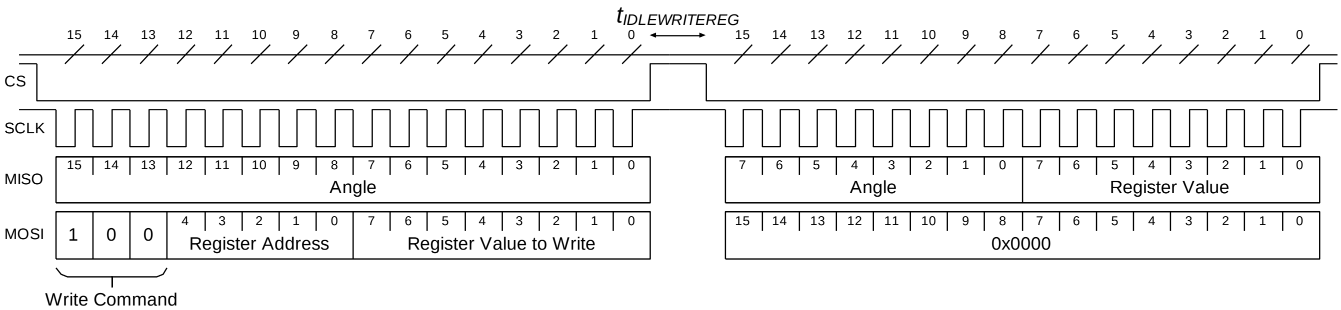


Figure 23: Overview of Two 16-Bit Frame Write Register Operation

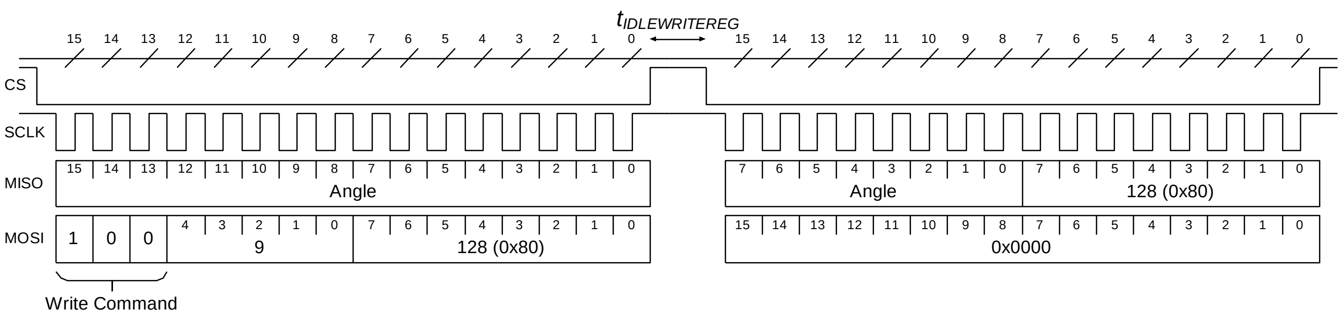


Figure 24: Write Output Rotation Direction (RD) to Counterclockwise (High), on Register 9, Bit 7

NVM Operations

The sensor contains a non-volatile memory (NVM) to store the chip configurations during shutdown. The values stored in the NVM are automatically loaded into the sensor's registers during start-up.

It is also possible to manually force the restoration of the NVM values to the registers by using the Restore All Register Values SPI command, described below.

The registers can be copied to the NVM using two SPI commands:

- Store a single register value to NVM
- Store all register values to NVM

The NVM is guaranteed to endure 1,000 write cycles at 25°C.

Users must first write the desired configuration to the RAM registers by using the read/write register commands (described above), and then call one of the store commands to save one or all registers to the NVM.

These commands are ignored if the NVM is busy executing a previously received command. To check that the NVM is available and ready to receive a new command, observe the NVM pin level.

The NVM pin is set to high when the non-volatile memory is busy. Store and restore commands are processed when the NVM pin is cleared (low) (see Figure 25).

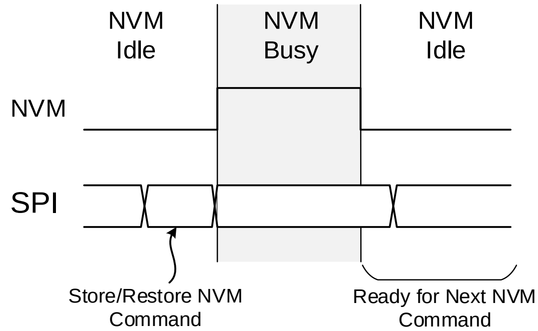


Figure 25: Signal Timing for NVM Access

SPI Store a Single Register Value to NVM

Store the current value of a specific register in the NVM. This command is ignored if the NVM is busy executing a previously received command (see Figure 26 and Figure 27).

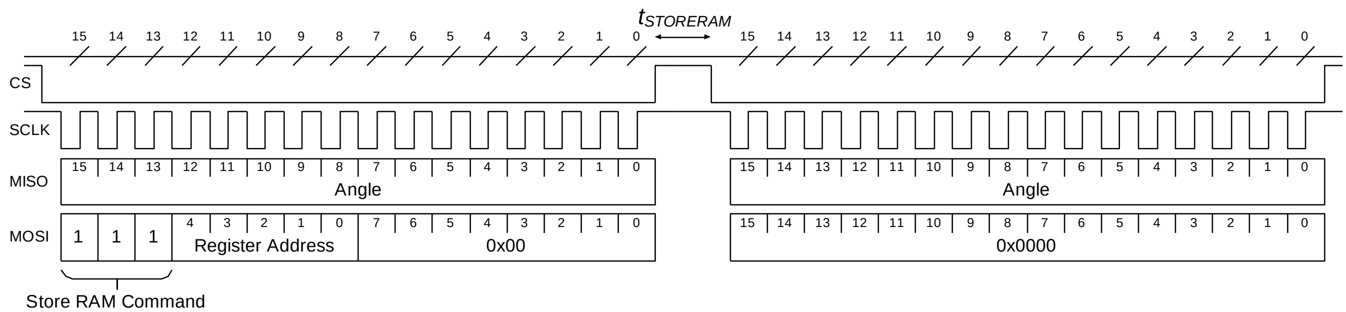


Figure 26: Overview of Two 16-Bit Frames Store Register to NVM Operation

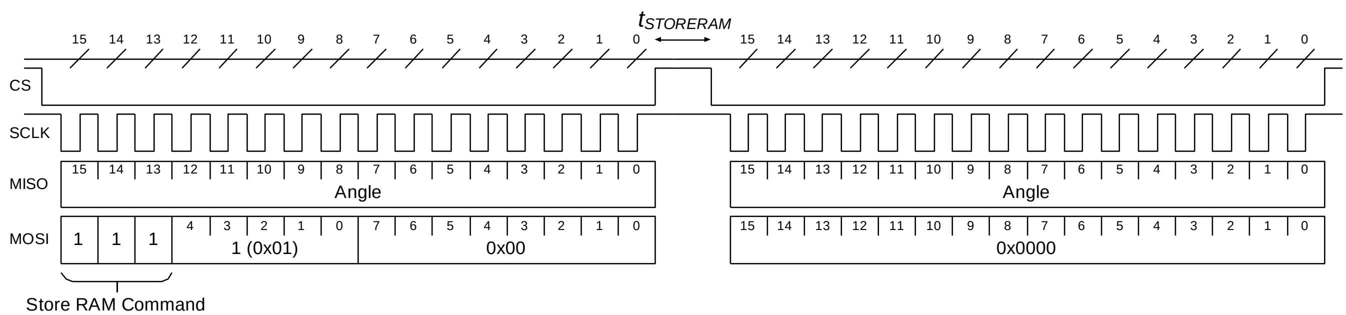


Figure 27: Store Register 1 Current Value to NVM

SPI Store All Register Values to NVM

Store the current value of all registers in the NVM (see Figure 28).This command is ignored if the NVM is busy executing a previously received command.

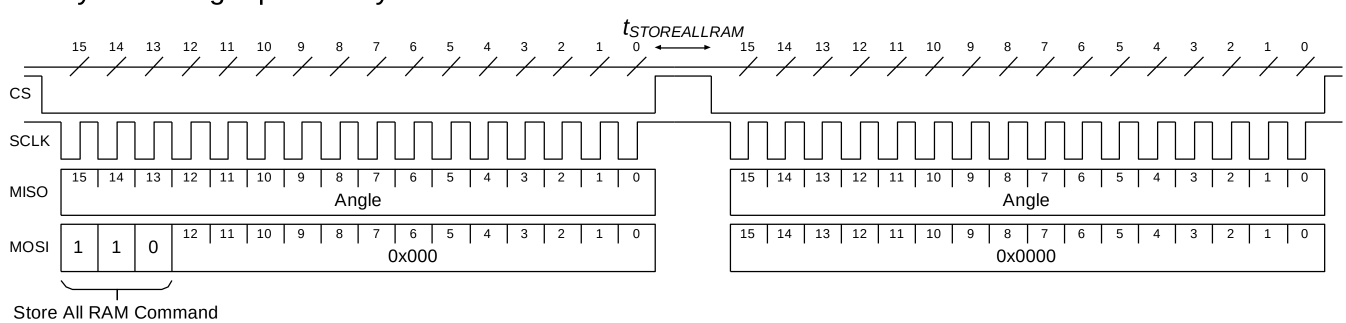


Figure 28: Overview of Two 16-Bit Frames Store All Register to NVM Operation

SPI Restore All Register Values from NVM

Restore the value of all registers from the non-volatile memory. This operation is done automatically (without user intervention) at each start-up (see Figure 29). This command is ignored if the NVM is busy executing a previously received command.

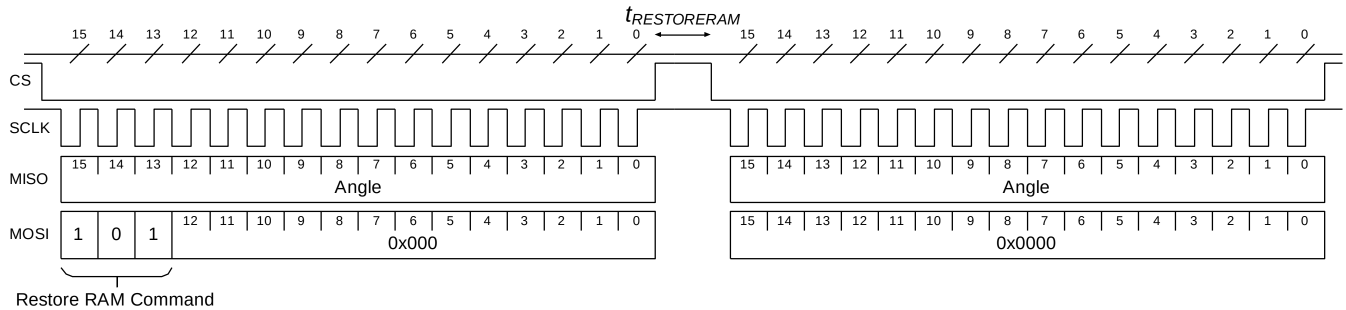


Figure 29: Overview of Two 16-Bit Frames Restore All Registers from NVM Operation

SPI Clear Error Flags

Clears the error flag on the ERR pin (reset to 0). Also clears the error flags in register 26 (see Figure 30).

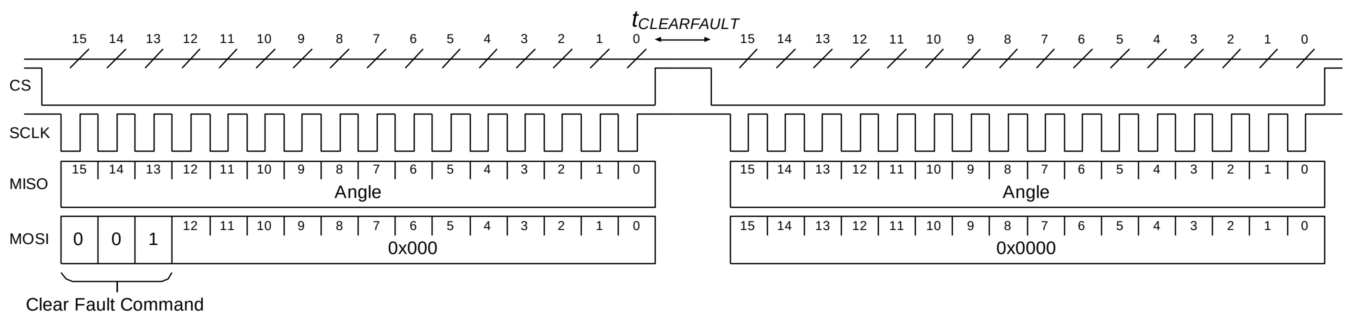


Figure 30: Overview of Two 16-Bit Frames Clear Error Flags Operation

Table 6 lists a summary of all SPI commands.

Table 6: SPI Command List Overview

Command Name	Command Bits [15:13]	Register Address Required	Register Value Required	Returned Value
Read Angle	000	No	No	16-bit angle
Read Register	010	Yes	No	8-bit angle + register value
Write Register	100	Yes	Yes	8-bit angle + register value
Store Single Register to NVM	111	Yes	No	16-bit angle
Store All Registers to NVM	110	No	No	16-bit angle
Restore All Registers from NVM	101	No	No	16-bit angle
Clear Error Flags	001	No	No	16-bit angle

REGISTER MAP

Table 7: Register Map (7)

No	Hex	Bin	Bit 7 MSB	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 LSB
0	0x0	00000	Z(7:0)							
1	0x1	00001	Z(15:8)							
2	0x2	00010	BCT(7:0)							
3	0x3	00011	-	-	-	-	-	-	ETY	ETX
4	0x4	00100	TCYC(7:0)							
5	0x5	00101	TCYC(15:8)							
7	0x7	00111	TACT(7:0)							
8	0x8	01000	THR(7:0)							
9	0x9	01001	RD	-	-	-	-	-	-	-
10	0xA	01010	REF(7:0)							
11	0xB	01011	ASCR	ASC	AUTACT	0	0	0	0	0
14	0xE	01110	FW(3:0)							
22	0x16	10110	0	0	0	MULTI(1:0)		0	0	1
26	0x1A	11010	-	-	-	-	ERRPAR	ERRMEM	ERRCRC	-

Note:

7) Register 26 contains error flag output bits (read-only).

Table 8: Default Factory Values

No	Hex	Bin	Bit 7 MSB	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 LSB
0	0x0	00000	0	0	0	0	0	0	0	0
1	0x1	00001	0	0	0	0	0	0	0	0
2	0x2	00010	0	0	0	0	0	0	0	0
3	0x3	00011	0	0	0	0	0	0	0	0
4	0x4	00100	0	1	1	0	1	1	1	0
5	0x5	00101	0	0	0	0	0	0	0	0
7	0x7	00111	1	0	0	0	0	1	1	1
8	0x8	01000	0	0	0	0	0	0	0	0
9	0x9	01001	0	0	0	0	0	0	0	0
10	0xA	01010	0	0	0	0	0	0	0	0
11	0xB	01011	1	1	1	0	0	0	0	0
14	0xE	01110	1	0	0	1	0	0	0	0
22	0x16	10110	0	0	0	0	0	0	0	1

Table 9: Programming Parameters

Parameters	Symbol	Number of Bits	Description	For Details, See
Zero setting	Z	16	Sets the zero position.	Table 10
Bias current trimming	BCT	8	For side-shaft configuration: reduce the bias current of the X or Y Hall device.	Table 12
Enable trimming X	ETX	1	Biased current trimmed in the X-direction Hall device.	Table
Enable trimming Y	ETY	1	Biased current trimmed in the Y-direction Hall device.	Table
Cycle time	TCYC	16	ASC mode: Time for active and idle cycle.	**Error! Not a valid result for table.**
On time	TACT	8	ASC mode: Active time.	Table 16
Threshold	THR	8	ASC mode: Threshold for change detection.	Table
Rotation direction	RD	1	Determines the sensor's positive direction.	Table 11 lists how to designate the rotation direction. **Table**
Reference	REF	1	ASC mode: Angle of reference for change detection.	Table 20
Auto-TACT	AUTACT	1	ASC mode: Automatically determines the active time.	Page 24
Auto-sampling cycle	ASC	1	Enables ASC mode.	Table
ASC register driven	ASCR	1	Allows ASC mode to be enabled via register setting.	Table
Filter window	FW	4	Size of the filter window. Determines the resolution, settling time, and latency.	Table 3
Multi-turns	MULTI	2	Sets the turn counter.	Table 7
Parity error	ERRPAR	1	Parity check for data sent to the device.	Page 22
Memory error	ERRMEM	1	Error when two successive NVM commands are too close in time.	Page 22
CRC error	ERRCRC	1	CRC check for loading data from the NVM.	Page 22

REGISTER SETTINGS

Zero Setting

The zero position of the MA780 (a_0) can be configured with 16 bits of resolution. The angle outputted by the MagAlpha (a_{OUT}) can be calculated with Equation (2):

$$a_{OUT} = a_{RAW} - a_0 \quad (2)$$

Where a_{RAW} is the raw angle provided by the MagAlpha front-end.

The parameter Z(15:0) is the zero-angle position coded on 16 bits (see Table 10).

Table 10: Zero Setting Parameter

Z(15:0)	Zero Position a_0 (deg)
0	0
1	0.005
2	0.011
…	…
65534	359.989
65535	359.995

Rotation Direction

When looking at the top of the package, the angle increases when the magnetic field rotates clockwise (CW) by default (see Figure 31).

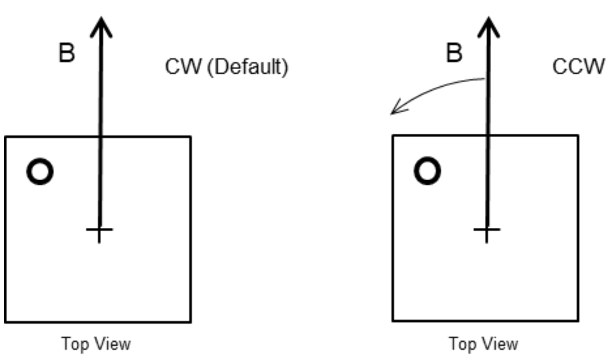


Figure 31: Positive Rotation Direction of the Magnetic Field

Table 11 lists how to designate the rotation direction.

Table 1: Rotation Direction Parameter

RD	Positive Direction
0	Clockwise (CW)
1	Counterclockwise (CCW)

BCT Settings (Bias Current Trimming)

Side Shaft

When the MA782 is mounted on the side of the magnet, the relationship between the field angle and mechanical angle is no longer linear. This effect is related to the fact that the tangential magnetic field is usually smaller than the radial field. Calculate the field ratio (*k*) with Equation (3):

$$k = B_{RAD}/B_{TAN} \quad (3)$$

Where B_{RAD} and B_{TAN} are the maximum radial and tangential magnetic fields (see Figure 32).

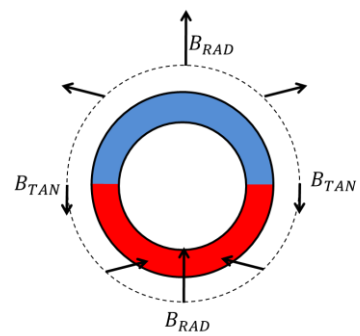


Figure 32: Side-Shaft Field

The *k* ratio depends on the magnet geometry and the distance to the sensor. Having a *k* ratio that does not equal 1 means the sensor output response is nonlinear with respect to the mechanical angle. The error curve has the shape of a double sine wave (see Figure 33). *E* is the amplitude of this error.

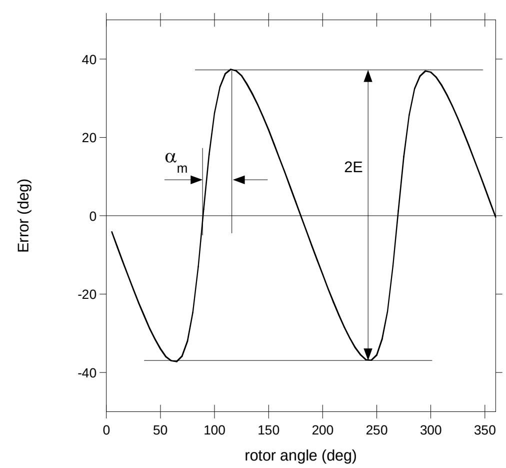


Figure 33: Error Curve in Side-Shaft Configuration (BCT = 0)

The X-axis or the Y-axis bias current can be reduced to recover an equal Hall signal for all angles and suppress the error. The parameters ETX and ETY control the direction in which sensitivity is reduced. The current reduction is set by the bias current trimming parameter (BCT(7:0)), which is an integer from 0 to 255.

In side-shaft configuration (when the sensor's center is located beyond the magnet's outer diameter), the *k* ratio exceeds 1. If the value of *k* is known, BCT(7:0) can be calculated with Equation (4):

$$BCT(7:0) = 258\left(1 - \frac{1}{k}\right) \qquad (4)$$

For optimal compensation, the sensitivity of the radial axis should be reduced by setting the BCT parameter. Figure 34 shows the optimum BCT value for a particular *k* ratio.

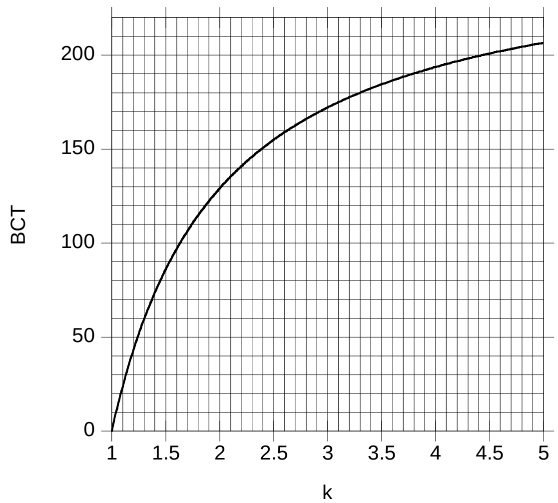


Figure 34: *k* Ratio and the Optimum BCT to Recover Linearity

Table 12 shows typical BCT values.

Table 12: Potential BCT Settings

E (deg)	Magnet Ratio *k*	BCT(7:0)
0	1.0	0
11.5	1.5	86
19.5	2.0	129
25.4	2.5	155
30.0	3.0	172
33.7	3.5	184
36.9	4.0	194
39.5	4.5	201
41.8	5.0	207

Determining k with the MagAlpha

It is possible to deduce the *k* ratio from the error curve obtained with the default BCT setting (BCT = 0). To do this, rotate the magnet more than one revolution and record the MagAlpha output. Then plot the error curve (the MagAlpha output minus the real mechanical position vs. the real mechanical position) and extract two parameters: the maximum error (*E*), and the position of this maximum with respect to a zero crossing (α_M) (see Figure 20). The *k* ratio can then be calculated with Equation (5):

$$k = \frac{\tan(E+\alpha_M)}{\tan(\alpha_M)} \qquad (5)$$

Alternatively, the value of *k* can be obtained using Figure 35.

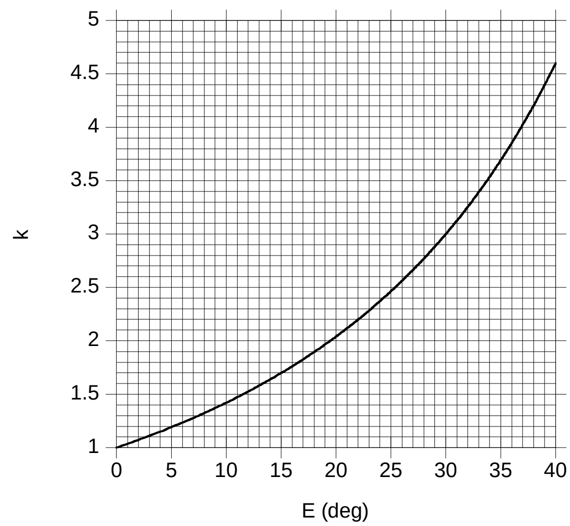


Figure 35: Relationship between the Error Measured with BCT = 0 and the Magnet Ratio *k*

Sensor Orientation

From the dot marked on the package, it is possible to know whether the radial field is aligned with the sensor coordinate X or Y (see Figure 36).

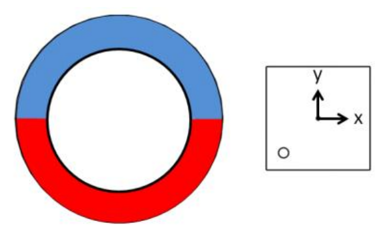


Figure 36: Package Top View with X and Y Axes

Determine which axis needs to be reduced (see the qualitative field distribution around a ring in Figure 32 on page 20).

Using Figure 36 as an example, the field along the sensor's Y direction is tangential and weaker, so the X-axis should be reduced (ETX = 1 and ETY = 0).

If both ETX and ETY are set to 1, the current bias is reduced in both directions the same way, without side-shaft correction (see Table 13). This reduces the sinusoidal signal and modifies the magnetic field thresholds.

Table 2: Trimming Direction Parameters

ETX	Enable Trimming of the X-Axis
0	Disabled
1	Enabled
ETY	**Enable Trimming of the Y-Axis**
0	Disabled

Status Byte

Register 26 contains information about the sensor's operational integrity.

ERRPAR

When using 17-bit communication on the SPI bus, the SPI write register command sent by the controller to the MA780 can be checked for parity (the other commands cannot). After the 16-bit command, the controller sends a parity bit on the MISO line. The MA780 checks the parity of the 17-bit word. If there is a parity error, the data that should be written to the RAM is discarded, and the ERRPAR bit is asserted (set to 1).

ERRMEM

The NVM pin indicates whether NVM is busy. If a command triggers an NVM access (read or write) in this period, it is ignored and the ERRMEM bit is asserted (set to 1).

ERRCRC

Restoring of register values from the NVM is secured by a CRC algorithm. Any mismatch between the generated CRC result with the previously stored value is flagged when the ERRCRC bit is asserted (set to 1).

Should any bit in the status byte be asserted, the ERR pin turns to logic 1. The status byte and ERR pin can be cleared by sending the SPI Clear Error Flags command.

Filter Window Size

The filter window (FW) determines the filter time constant, which affects the output bandwidth, resolution and latency (see Table 14).

Table 34: Filter Window Size (8)

Filter Window Size(0:3)	Time Constant (τ) (µs)	Filter Settling Time (µs)
0	1	1
1	2	3
2	4	7
3	8	15
4	16	31
5	32	63
6	64	127
7	128	255
8	256	511
9	512	1023
10	1024	2047
11	2048	4095
12	4096	8191
13	4096	8191
14	4096	8191
15	4096	8191

Note:

8) See the Electrical Characteristics section on page 4 for filter settling time accuracy.

The filter cutoff frequency can be calculated with Equation (6):

$$f_{\mathrm{CUTOFF}} = \frac{1}{2\pi\tau} \tag{6}$$

Latency

The latency is the difference between the true position of the mechanical angle and the angle reading available on the SPI interface. The angle latency during the sensor active time (t_{ACTIVE}) or when the sensor is always on is defined by the filter time constant (τ) + 3µs.

Resolution

When the MA780 enters active mode, the final resolution is not reached until the data valid flag is raised (DV pin outputs high). The time duration before the flag raises is a function of the window size. Figure 37 shows the flag after the resolution is given.

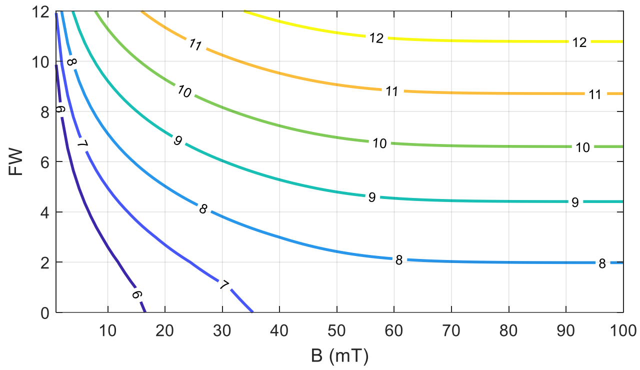


Figure 31: MA780 Resolution

Low-Power Operation

The MA780 power state is determined by the following truth table (see Table 15).

Table 4: Power State (9)

EN (Pin)	ASC (Pin)	ASC (Reg.)	ASCR (Reg.)	Mode
0	0	X	0	Idle
0	1	X	0	ASC
0	X	0	1	Idle
0	X	1	1	ASC
1	X	X	X	On

Note:

9) "X" means any state.

Settings for Power-Cycling Operations

Set the parameters below for different power cycling operations, described below.

Continuous ASC

The following parameters must be set for continuous ASC mode:

- EN = 0 (pin connected to GND)
- ASCR = 1
- ASC (register) = 1

Externally Controlled – Active-Idle Switching

Switching between active and idle mode is accomplished through commutation using the EN pin. Preset register 11 with the following values:

- ASCR = 1
- ASC (register) = 0

Externally Controlled – Active-ASC Switching

Switching between active and ASC mode is accomplished through commutation using the EN pin. Preset register 11 with the following values:

- ASCR = 1
- ASC (register) = 1

Externally Controlled – ASC-Idle Switching

Switching between ASC and idle mode is accomplished through commutation using the ASC pin. The following parameters must be set:

- EN = 0 (connected to GND)
- ASCR = 0

ASC Mode Parameters

The MA780 automatically cycles power according to user parameters TACT and TCYC. If the threshold is set to zero, the new data (ND) flag (ND output pin) can be used to inform to the controlling device that the sensor output was updated and is ready for reading. The user can also read the sensor angle at any time, regardless of the ND pin's flag state (see Figure 38).

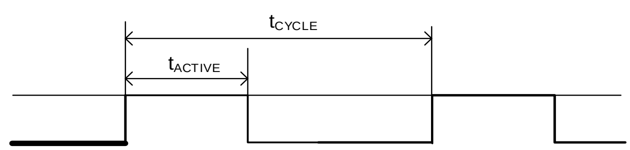


Figure 38: Timing of a Power Cycle

Active Time

The active time is a function of the filter window by default, and does not need to be set manually. This mode is recommended for most applications. By disabling AUTCT, the user can force an active time with the TACT parameter, which ranges from 40µs to 2056µs, by steps of 8µs (see Table 15). If TACT(0:7) exceeds 2, t_{ACTIVE} can be calculated with Equation (7) (in µs):

$$t_{ACTIVE}\ (\mu s) = 8 \text{ x } TACT(0:7) + 16 \qquad (7)$$

Table 16 lists potential times for t_{ACTIVE} (see the Electrical Characteristics on page 4 for active time accuracy).

Table 5: Active Time

TACT(0:7)	t_{ACTIVE} (µs)
0	Do not use
1	Do not use
2	Do not use
3	40
4	48
5	56
…	…
255	2056

The active time should be chosen such that the angle output is stable (the filter has settled). This means the active time should exceed the valid data time, estimated with Equation (8):

$$t_{ACTIVE}\ (\mu s) > t_{START-UP} + t_{SETTLING} \qquad (8)$$

In ASC mode (e.g. when EN = 0), the angle output is always updated at the end of the active time (see Figure 39). During the active time, the sensor returns the angle measured during the previous active time.

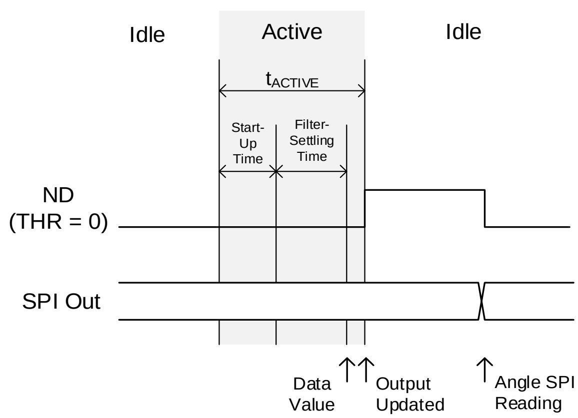


Figure 39: ASC Timing with THR = 0 and AUTACT = 0

The ND flag is reset on the first SCLK rising edge of the following action/commands:

- Read angle
- Store registers to NVM
- Restore registers from NVM
- Clear status byte

The ND flag cannot be reset with a read ID command, or by writing or reading the registers.

When AUTACT is enabled (default) the active time is automatically set to the optimum value, estimated with Equation (9):

$$t_{ACTIVE-AUTO}\ (\mu s) = t_{START-UP} + t_{SETTLING} \qquad (9)$$

This means that the sensor returns to idle mode as soon as valid angle information becomes available (see Figure 40).

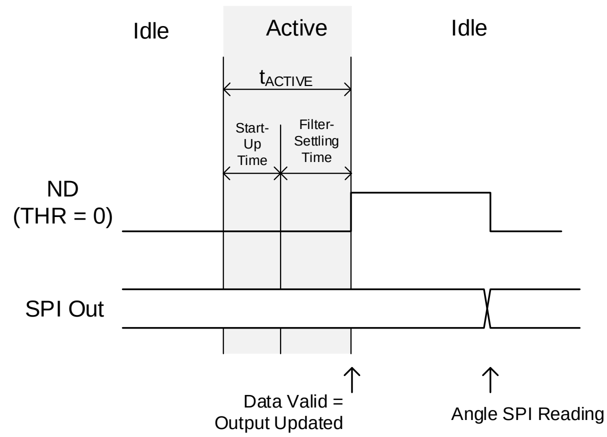


Figure 40: ASC Timing with THR = 0 and AUTACT = 1

Since the filter settling time depends on the filter window, the automatic active time is a function of the filter window size (see Table 14 on page 22).

If the window size exceeds 12, the automatic active time can be calculated with Equation (10):

$$t_{ON-AUTO}\ (\mu s) = t_{START-UP} + 8191\mu s \qquad (10)$$

If the active time is shorter than the filter-settling time (determined by the user settings for TACT and FW[3:0]), the ND signal is not updated. This is because the output angle value is not fully stabilized, and is not within the required resolution (the data valid signal [DV] is not yet set to logic high).

Cycle Time

The ASC cycle time is set by the TCYC parameter. The cycle time must be greater than the active time (see Table 17).

Table 6: Cycle Time

TCYC	Cycle Time (ms)
0	Continuously idle
1	Do not use
2	0.2
3	0.3
4	0.4
…	…
65535	6553.5

See the Electrical Characteristics section on page 4 for the cycle time accuracy.

Once the TACT and TCYC parameters are set, the average current consumption can be calculated with Equation (11):

$$i = i_{ACTIVE}\ \text{x}\ \frac{t_{ACTIVE}}{t_{CYCLE}} + i_{IDLE}\left(1 - \frac{t_{ACTIVE}}{t_{CYCLE}}\right) \quad (11)$$

Turn Counting

The MA780 can count 16, 64, or 256 turns. The counter value is coded on M = 4, 6, or 8 bits, respectively. The number of turns is indicated by M bits in the MSB of the 16-bit SPI output. As a consequence, the angle information is shifted by M bits, and the resolution is reduced by M bits.

	MSB	*LSB*
MISO	***Turn(M-1:0)***	***Angle(15:M)***

The number of turns to count is set by the MULTI(1:0) parameter, and stored in register 22 (see Table 18). When writing this register, only modify bits 3 and 4, and ensure that the other bits retain their default value stated in Table 8 (see page 18).

Table 7: Turn Counting

MULTI(1:0)	Number of Turns	M (Bit Used to Count Turns)
0	1 (default)	0
1	16	4
2	64	6
3	256	8

The counter value is stored in the non-volatile memory. In the idle state, the value is maintained until the next angle update. When updating the turn count, the sensor always assumes that the angle increment is smaller than 180 degrees. This means that if the shaft turns more than 180 degrees per idle time, the counter goes backwards. To prevent turn count errors, ensure that the angle change during the idle time is always less than 180 degrees.

If power is removed from the sensor, the counter always resets to zero. The zero setting only affects the angle; it does not reset the turn counter.

Threshold

If the parameter THR is zero, the ND flag is raised after each active time. To detect a certain angle change, THR must be configured to a non-zero value. The ND flag is reset at each SPI reading. This means that if the angle exceeds the threshold, the ND signal rises each time the angle is updated after an SPI reading.

The THR parameter is a relative angle coded on 8 bits. If THR exceeds 180 degrees, the lower and upper thresholds merge, and the range of angles located beyond the threshold disappears. This disables the ND flag (see Table 19).

Table 8: Threshold for Wakeup on Change

THR(6:0)	Threshold (deg)
0	0
1	1.41
2	2.81
…	…
127	178.59
128	180 (ND flag only at 180)
…	…
255	358.59 (no ND flag)

Reference

The reference value used to detect a change is coded on 8 bits, and stored in register 10. It refers to the absolute angle (see Table 20).

Table 9: Change Detection with Fixed Reference

REF(7:0)	Reference (deg)
0	0
1	1.41
2	2.81
…	…
255	358.59

Figure 41 shows the behavior of the ND signal when the angle output crosses the threshold.

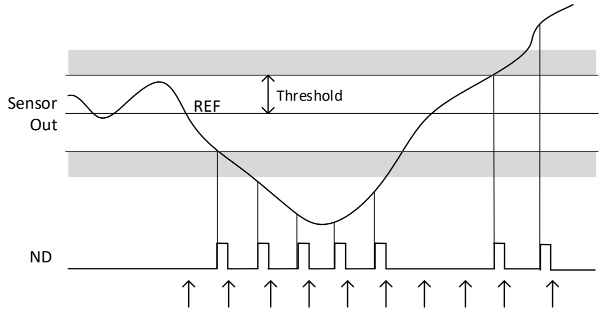


Figure 41: ND Signal with Changing Angle (Arrows = SPI Readings)

If the angle is set outside the set threshold in ASC mode with THR, the ND signal is asserted high after every active sample period. To detect relative motion and to avoid repeated assertion of the ND signal when the angle is outside the set threshold, update the reference position (REF) in register 10 with the current angle position each time the threshold is crossed.

TYPICAL APPLICATION CIRCUIT

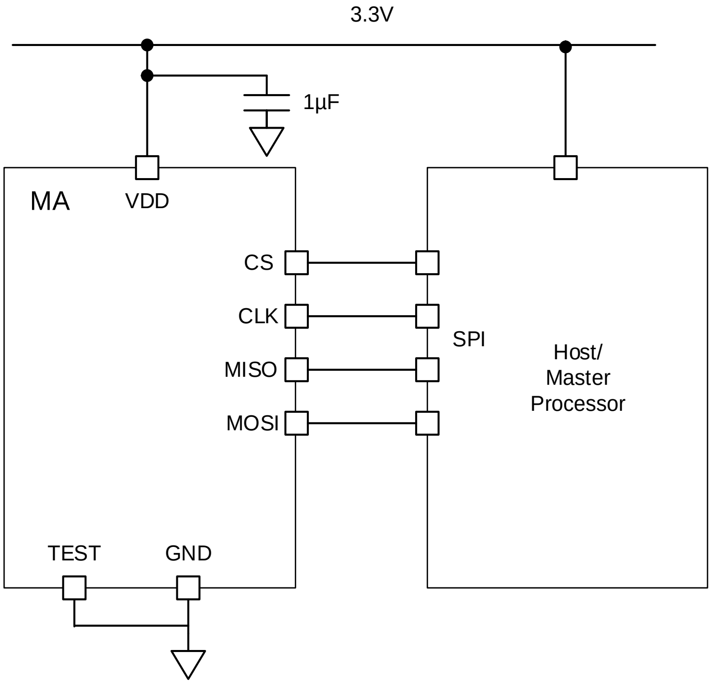
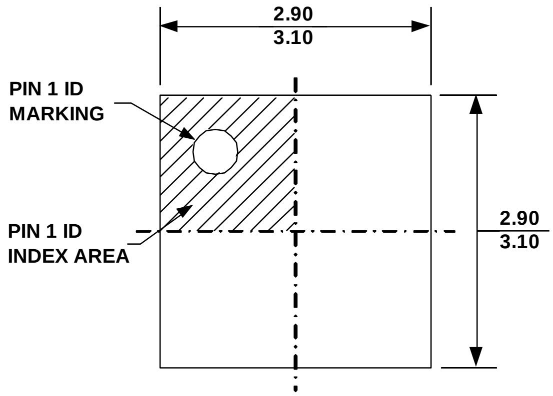


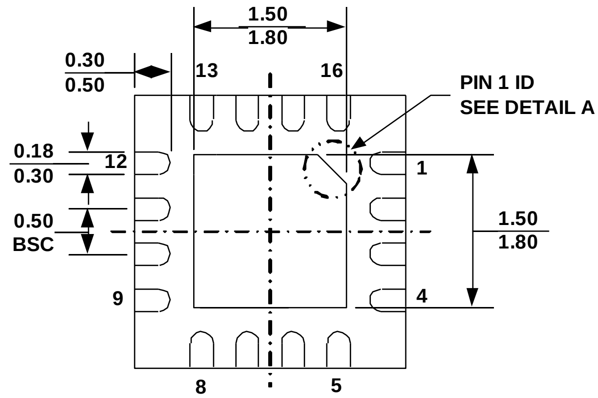
Figure 42: Typical Application Circuit Using SPI Interface

PACKAGE INFORMATION

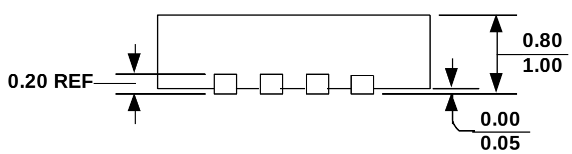
QFN-16 (3mmx3mm)



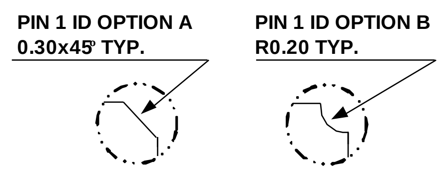
TOP VIEW



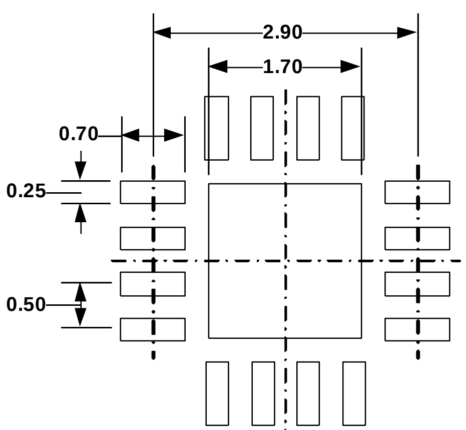
BOTTOM VIEW



SIDE VIEW



DETAIL A

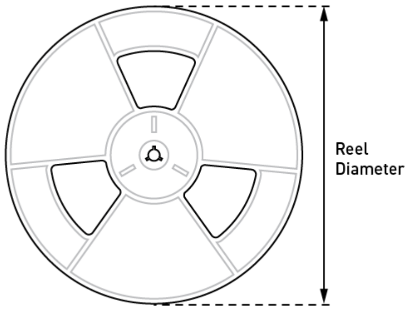


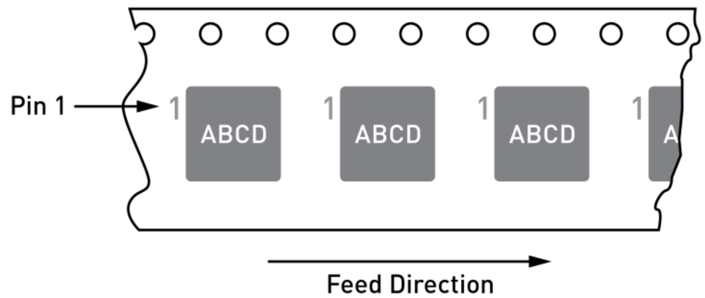
RECOMMENDED LAND PATTERN

NOTE:

1) ALL DIMENSIONS ARE IN MILLIMETERS.
2) EXPOSED PADDLE SIZE DOES NOT INCLUDE MOLD FLASH.
3) LEAD COPLANARITY SHALL BE 0.10 MILLIMETER MAX.
4) DRAWING CONFORMS TO JEDEC MO-220, VARIATION VEED-4.
5) DRAWING IS NOT TO SCALE.

CARRIER INFORMATION





Part Number	Package Description	Quantity/ Reel	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MA780GQ–Z	QFN-16 (3mmx3mm)	5000	13in	12mm	8mm

APPENDIX A: DEFINITIONS

Effective Resolution (3σ Noise Level)

Smallest angle increment distinguishable from the noise. The resolution is measured by computing three times σ (the standard deviation in degrees) taken over 1,000 data points at a constant position. The bit resolution is calculated as: $\log_2 (360 / 6\sigma)$.

Refresh Rate

Rate at which new data points are stored in the output buffer.

Latency

The time elapsed between the instant when the data is ready to be read and the instant at which the shaft passes that position. The lag in degrees is $\mathrm{lag} = latency \cdot v$, where v is the angular velocity in deg/s.

Power-Up Time

Time until the sensor delivers valid data starting at start-up (V_{DD} < 3V).

Start-Up Time

Time until the sensor front-end delivers valid data to the digital treatment block when recovering from idle.

Filter Settling Time

Time for the filter to deliver a stable angle (i.e. when the error is smaller than the noise at the particular filter window setting).

Integral Nonlinearity (INL)

Maximum deviation between the average sensor output (at a fixed position) and the true mechanical angle.

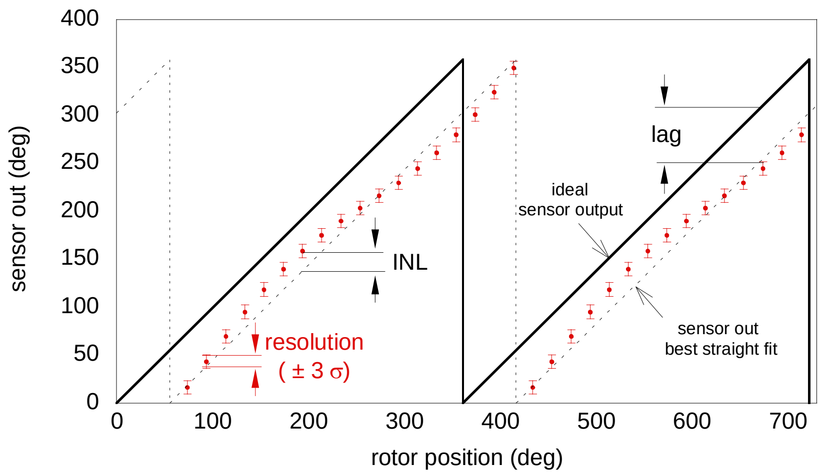


Figure A1: Resolution, INL, Lag

INL can be obtained from the error curve $\mathrm{err}(\alpha) = \mathrm{out}(\alpha) - \alpha$, where $\mathrm{out}(\alpha)$ is the average over 1000 sensor outputs, and α is the mechanical angle indicated by a high precision encoder (<0.001 deg). INL can be calculated with Equation (A1):

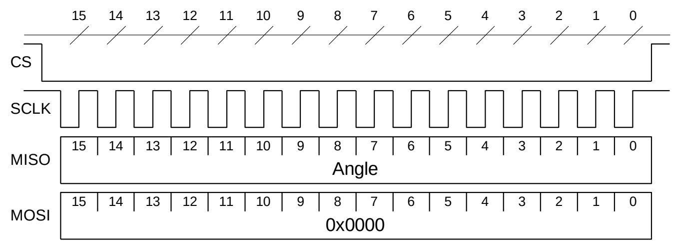
$$\mathrm{INL} = \frac{\max(\mathrm{err}(\alpha)) - \min(\mathrm{err}(\alpha))}{2} \quad \text{(A1)}$$

Drift

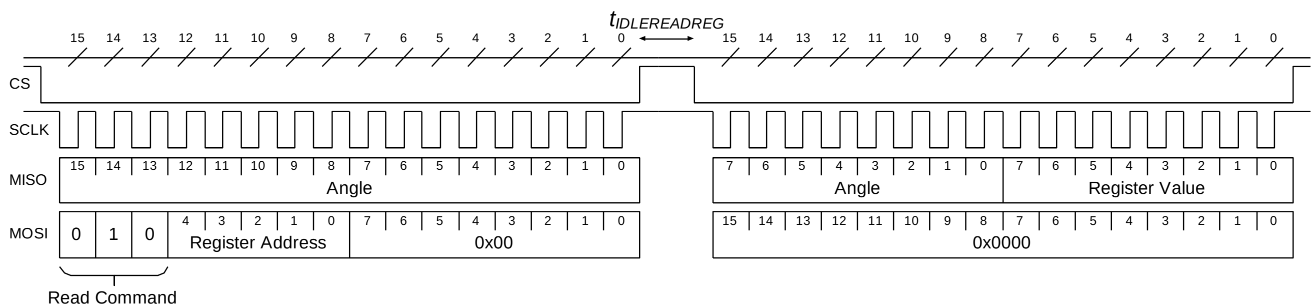
Angle variation rate when one parameter is changed (e.g. temperature, VDD) and all the others (e.g. shaft angle) remain constant.

APPENDIX B: SPI COMMUNICATION CHEATSHEET

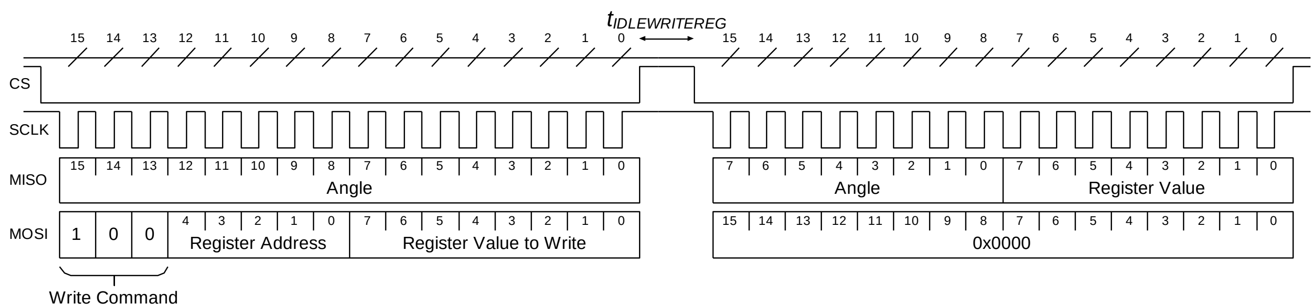
Read Angle (See the SPI Read Angle section on page 13.)



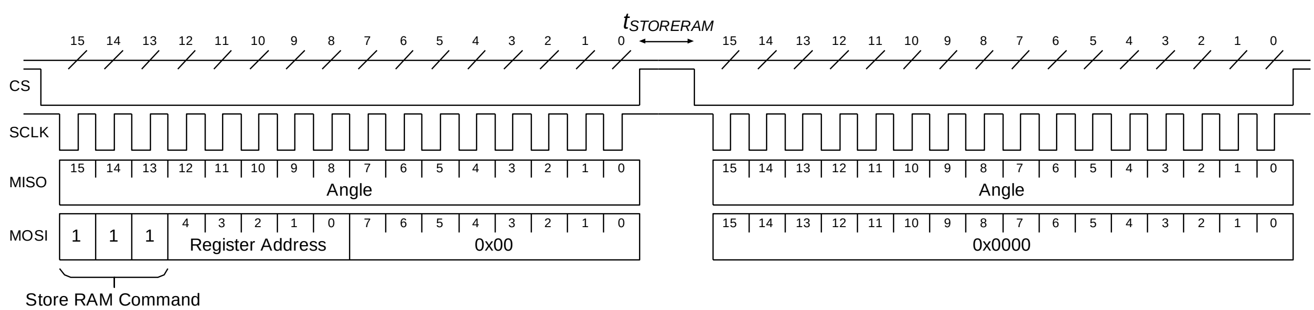
Read Register (See the SPI Read Register section on page 13.)



Write Register (See the SPI Write Register section on page 14.)

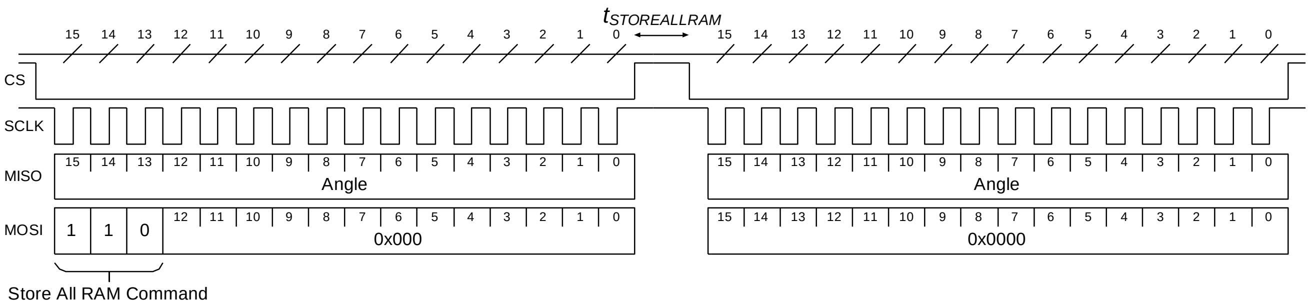


Store a Single Register Value to NVM (See the SPI Store a Single Register Value to NVM section on page 16.)

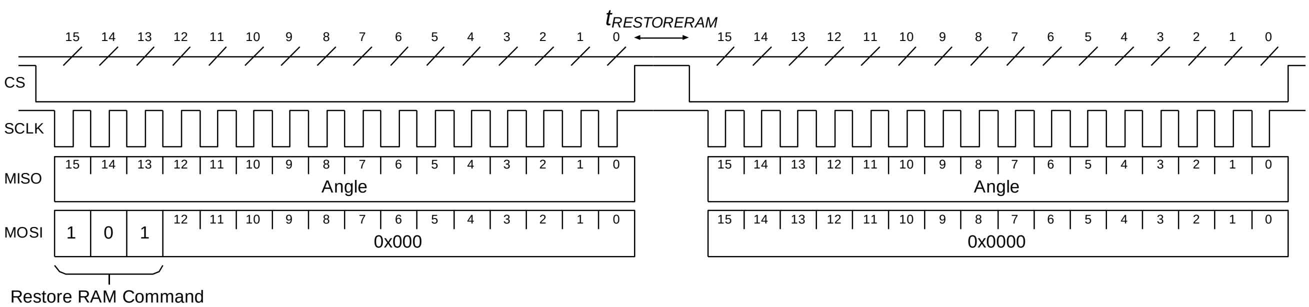


.

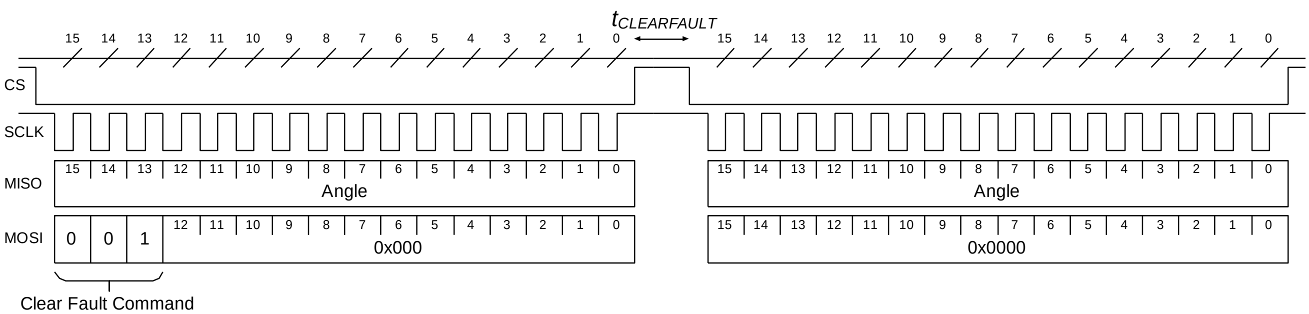
Store All Register Values to NVM (See the SPI Store All Register Values to NVM section on page 16.)



Restore All Register Values from NVM (See the SPI Restore All Register Values from NVM section on page 17.)



Clear Error Flags (See the SPI Clear Error Flags section on page 17.)



Revision History

Revision #	Revision Date	Description	Pages Updated
1.0	4/30/2020	Initial Release	-

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