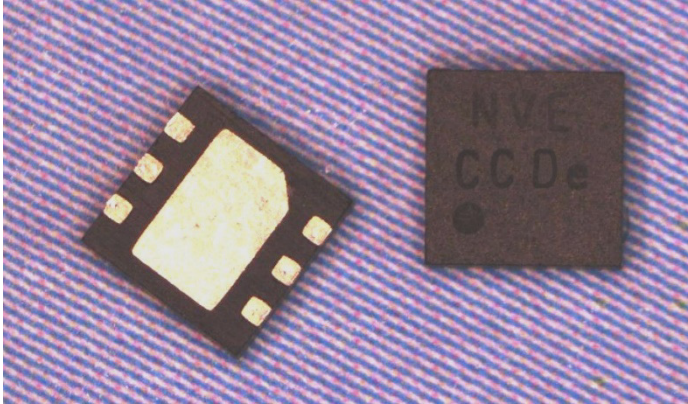


SM225 TMR Smart Magnetometer



Features

- Wide 0 to 150 Oe / 0 to 15 mT linear range
- Can detect magnets more than 50 mm away
- 3.3 volt or 5 volt compatible four-wire SPI interface
- Factory calibrated
- Analog field measurement plus on/off digital output
- Internal temperature compensation
- In-plane sensitivity—more usable than Hall effect
- 2.2 V to 3.6V supply
- Ultraminiature 2.5 x 2.5 x 0.8 mm TDFN6 package

Key Specifications

- 10bit output resolution
- -40°C to +125°C operating range
- 2% FS accuracy for 0 to 125°C
- 15 kSps sample rate for fast response
- 5 mA typical supply current

Applications

- Current sensing
- Proximity sensing
- Automotive applications
- Cylinder position sensing
- Security and intrusion detection

Description

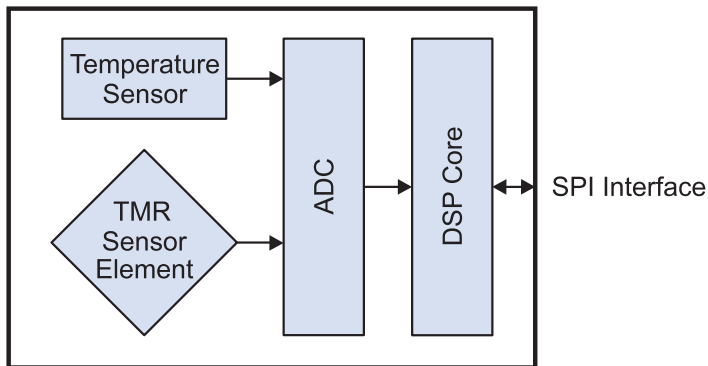
SM225 Smart Magnetometers provide precise magnetic field measurements. The sensors combine precise Tunneling Magnetoresistance (TMR) sensor elements with easy-to-use digital signal processing.

Unlike awkward, old-fashioned Hall-effect sensors, TMR is sensitive in-plane for optimal current sensing and easy mechanical interfaces. TMR also provides more sensitivity, higher precision, higher speed, and lower noise than Hall.

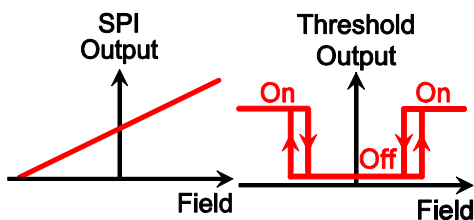
A four-wire SPI interface provides magnetic field data, as well as a way to set parameters. A virtual comparator allows programmable thresholds.

The device is factory calibrated for high accuracy, and calibration coefficients are stored in internal nonvolatile memory.

Simplified Block Diagram



Transfer Functions



Boundary Ratings

Parameter	Min.	Max.	Units
Supply voltage	-12	4.2	Volts
Input and output voltages (MISO, MOSI, SS, SCLK)	-0.5	$V_{cc}+2.5$ up to 5.8	Volts
Storage temperature	-55	150	°C
ESD (Human Body Model)		2000	Volts
Applied magnetic field		Unlimited	Oe

Operating Specifications (T_{min} to T_{max} : $2.2 < V_{DD} < 3.6$ V unless otherwise stated)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Operating temperature	T _{min} ; T _{max}	−40		125	°C	
Supply voltage	V _{DD}	2.2		3.6	V	
Supply current	I _{DD}		4	7	mA	Max. at V _{DD} = 3.6V
Power-on Reset supply voltage	V _{POR}		1.4		V	
Brown-out power supply voltage	V _{BOR}	0.75	1	1.36	V	
Start-up time	T _{STA}		15		ms	
Magnetics						
Linear range		−150		150	Oe	(1 Oe = 0.1 mT in air)
Resolution	δH		0.1			
Accuracy (% of linear range)				±4	% FS	−40 to 125°C
				±2		0 to 125°C
Precision and Speed						
Digital precision			10		bits	
Update rate			15		kSps	
Magnetic bandwidth			7.5		kHz	
Start-up time	T _{STA}		0.5	1	ms	
Internal Temperature Sensor						
Temperature accuracy (factory calibrated)				±2.5	°C	25 to 85°C
				±5	°C	−40 to 125°C
SPI Bus Characteristics						
Bus voltage	V _{BUS}	2.2		5.5	V	
Low level input threshold voltage	V _{IL}	0.8			V	
High level input threshold voltage	V _{IH}			2.2	V	
Low level output current	I _{OL}	3			mA	V _{OL} = 0.4V
I/O capacitance	C _{I/O}			10	pF	
SPI Setup and Hold Timing						
Data transfer rate	DR			2.5	Mbps	Full duplex
SCLK Rise time	t _R				ns	See figure 11
SCLK fall time	t _F				ns	
SCLK low time	t _{CL}	200			ns	
SCLK fall time	t _{CH}	200			ns	
SS to SCLK setup	t _{SE}	80			ns	
SCLK to MISO valid	t _{SDD}			170	ns	
SS to MISO tri-state	t _{SDZ}			170	ns	
SCLK to MOSI hold time	t _{SDH}	80			ns	
MOSI to SCLK setup	t _{SDS}	80			ns	
SCLK to SS hold time	t _{SH}	80			ns	
SS to MISO valid	t _{SEZ}			170	ns	
RAM Timing						
Address setup time	t _{ADDR}			10	μs	See figure 8
Data read time	t _{READ}			20	μs	
Nonvolatile Memory Characteristics						
Address setup time	t _{ADDR}			3	μs	See figure 9
Data read time	t _{READ}			10	μs	
Data write time	t _{NVM}			20	ms	
Endurance			10000		Cycles	

Operating Specifications (...continued)

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Package Thermal Characteristics						
Junction-to-ambient thermal resistance	θ_{JA}		320		°C/W	
Package power dissipation			500		mW	

SM225 Overview

Direction of Magnetic Sensitivity

As the field varies in intensity, the digital output will turn on and off. Unlike Hall effect or other sensors, the direction of sensitivity is in the plane of the package. The diagrams below show two permanent magnet orientations that will activate the sensor in the direction of sensitivity:

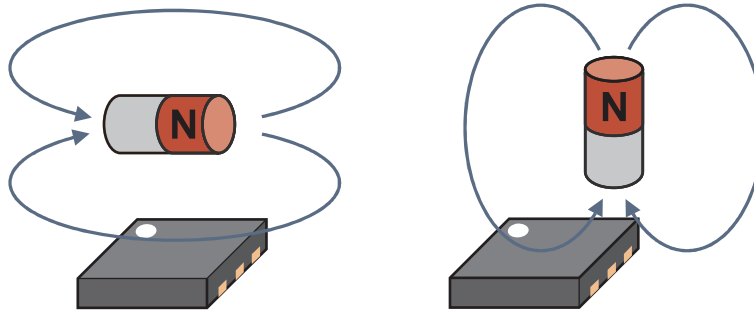


Figure 1. Direction of magnetic sensitivity.

These sensors are bipolar, meaning they can detect the polarity as well as magnitude of magnetic fields.

Typical Operation

Position Sensing

A typical proximity sensor using an SM225-10E sensor and magnet is shown below. With a 40e operate point, the sensor actuates with a rare-earth magnet at more than 50 mm (two inches) from the sensor:

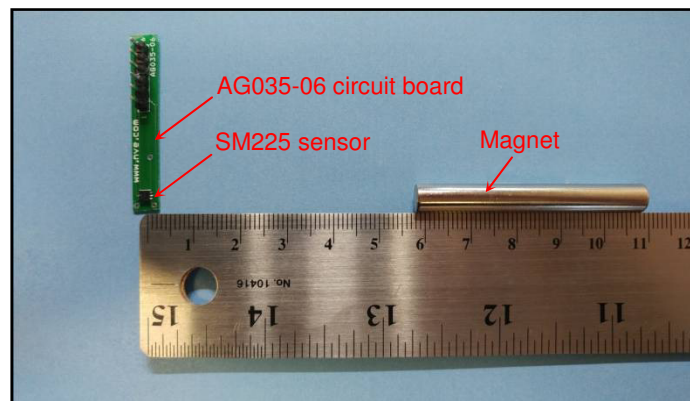


Figure2. The SM225-10E sensor can be activated by a magnet more than 50 mm away. Maximum sensitivity is in plane with the sensor, with the magnet axis in the pin 2/pin 5 sensor axis. The part is sensitive to either north or south fields.

Cautions for Low Fields

Thresholds even lower than 4 Oe can be programmed, although care must be taken to account for the earth's magnetic field, which is typically in the 0.5 Oe range.

Magnet Distances

Typical magnetic operate distances for the SM225 is illustrated in the following graph with an inexpensive ceramic disk magnet:

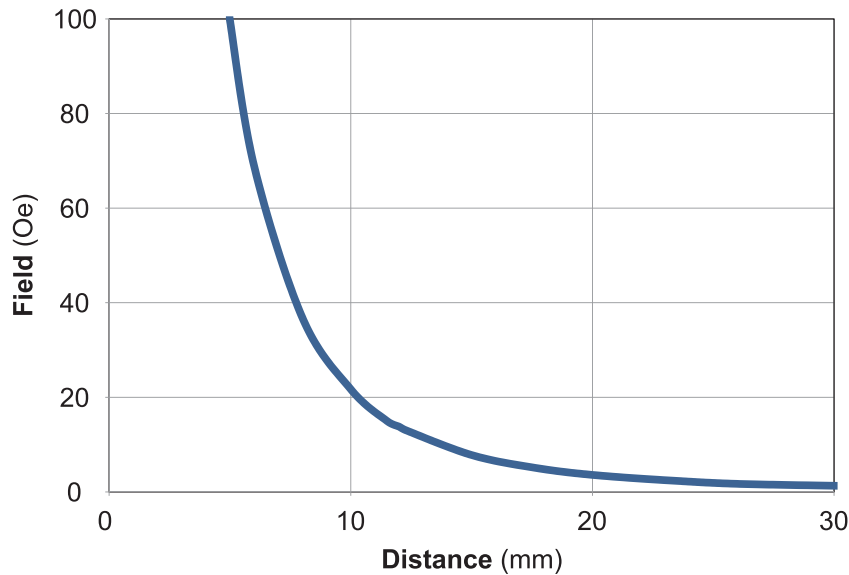


Figure 3. Field vs. distance from the center of the sensor
(NVE part number 12216; ferrite magnet; d=6 mm; t=4 mm; C1/Y10T; $M_s=B_r=2175$ G).

Larger and stronger magnets allow farther operate and release distances. For more calculations, use our axial disc magnetic field versus distance Web application at:

www.nve.com/spec/calculators.php#tabs-Axial-Disc-Magnet-Field.

Noncontact Current Sensing

SM225 sensors can measure the current through a circuit board trace by detecting the magnetic field generated by the current through the trace. The sensor is ideal for these applications because of the low fields generated. The threshold output can be used for current threshold detection or overcurrent protection.

Typical current sensing configurations are shown below:



Figure 4a. 0.05" (1.3 mm) trace
on top of PCB
(2.8 Oe/amp; 7 A max. current).

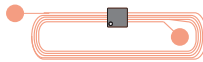


Figure 4b. Five-turn, 0.0055" (0.14 mm)
Trace on top of PCB
(14 Oe/amp; 1 A max. current).

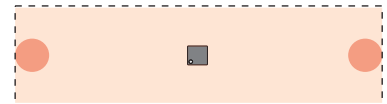


Figure 4c. 0.5" (13 mm) 2 oz. trace
on bottom of 0.062" (1.6 mm) thick PCB
(0.4 Oe/amp; 50 A max. current).

For the geometry shown below and narrow traces, the magnetic field generated can be approximated by Ampere's law:

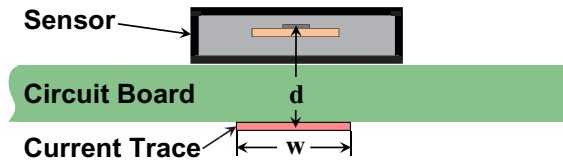


Figure 5. The geometry of current-sensing over a circuit board trace.

$$H = \frac{2I}{d} \quad [\text{"H" in oersteds, "I" in amps, and "d" in millimeters}]$$

For traces on the top side of the board, "d" is simply the distance of the sensor element from the bottom of the package, which is 0.5 millimeters.

Traces on the top side of the board are typically used for currents of five amps or less. Large traces on the bottom side of the PCB can be used for currents of up to 50 amps.

More precise calculations can be made by breaking the trace into a finite element array of thin traces, and calculating the field from each array element. We have a free, Web-based application with a finite-element model to estimate magnetic fields and sensor outputs in this application:

www.nve.com/spec/calculators.php#tabs-Current-Sensing

SM225 Operation

The SM225 is a high-speed noncontact magnetometer designed for proximity or current sensing. A detailed block diagram is shown below:

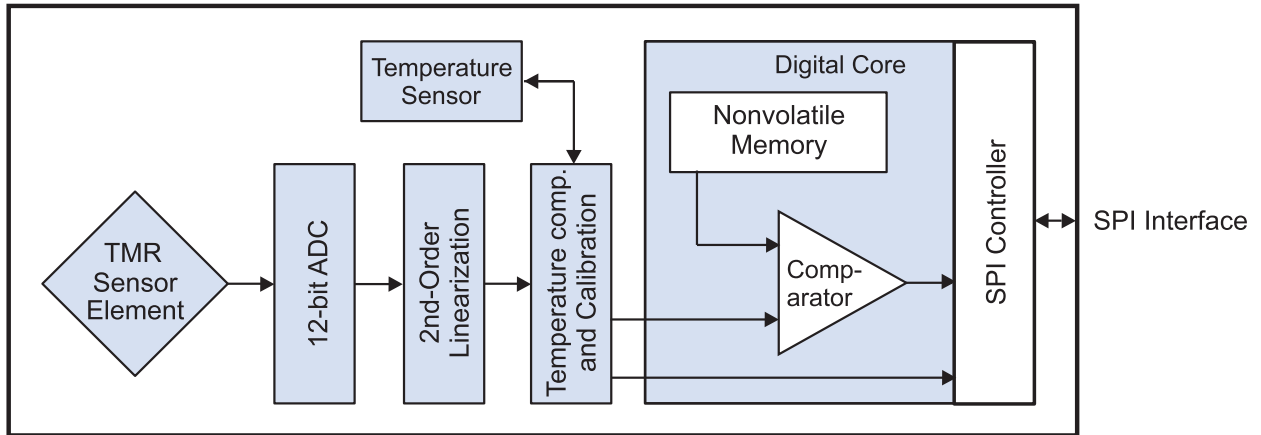


Figure 6. SM225 detailed block diagram.

ADC

The sensor output is digitized with a 12-bit ADC. The extra bits ensure precision and computational accuracy.

Digital Filter

A first-order Infinite Impulse Response (IIR) digital filter with a programmable cutoff frequency can be used for ultralow noise if high-frequency operation is required. The cutoff frequency is set by a filter constant, m , as follows:

$$f_{\text{CUTOFF}} = f_{\text{SAMPLE}} / (2\pi m)$$

Where f_{CUTOFF} is the filter cutoff frequency and f_{SAMPLE} is the sensor ADC sampling rate (approximately 20000/s). So for example, if $m = 10$, the cutoff frequency is approximately 300 Hz.

$m = 1$ disables filter so the output is simply updated with each sample. The factory default is the filter turned off.

Sensor Offset

The sensor core of the SM225 is factory calibrated for highest accuracy, and a programmable parameter, `sensor_offset`, is available for user adjustments to environments with non-zero magnetic fields. `sensor_offset` is a signed integer.

Internal Temperature Sensor

A factory-calibrated internal temperature sensor compensates for temperature effects, and optionally compensates for temperature effects on permanent magnets. Sensor temperature can also be read via the SPI interface.

Threshold Output

The SM225 has a programmable threshold output based on a “virtual comparator” metaphor. There are two threshold / hysteresis pairs (TRSH1 /HYST1 and TRSH2/HYST2). Normally, the threshold output is high if the field exceeds the threshold, but it can be inverted by setting the “TOUT_invert” bit.

The factory default is a an omnipolar threshold output with 100 Oe thresholds and 10 Oe hysteresis:

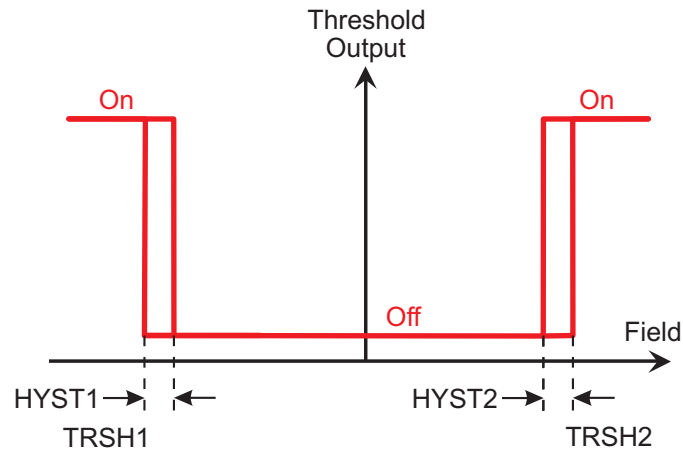


Fig. 7a. Factory default threshold output (TRSH2 = +100 Oe; TRSH1 = -100 Oe; HYST1 = HYST2 = 10 Oe).
The output turns on when the field magnitude exceeds the threshold, and operates the same with either magnet pole.

The thresholds can be configured to provide “omnipolar” or “bipolar” responses. Here are two examples of common settings:

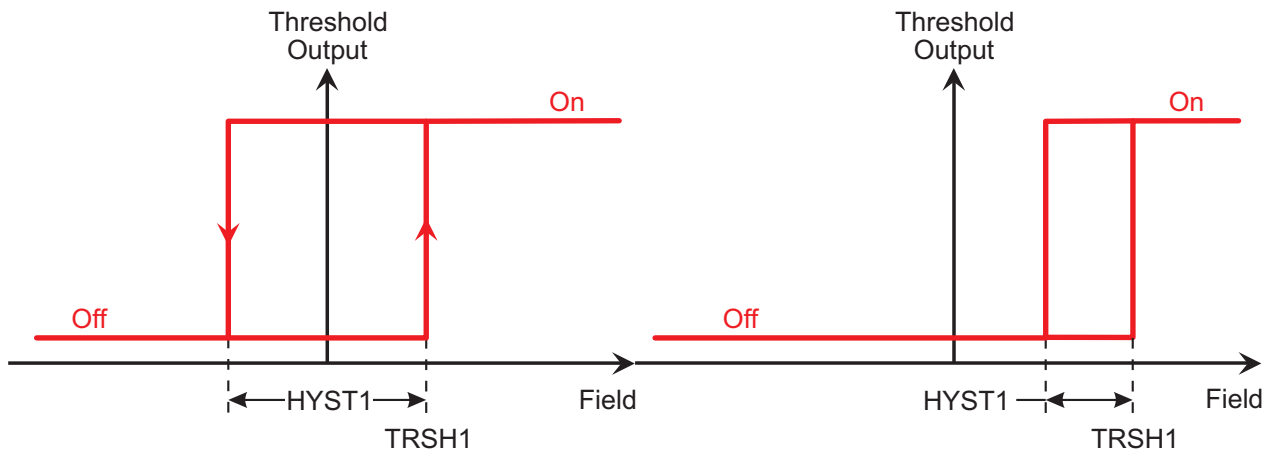


Fig. 7b. “Bipolar” symmetrical threshold output (HYST1 = 2 x TRSH1; TRSH2 not used).
The output turns on with a north magnetic pole and off with a south pole.

Fig. 7c. “Unipolar” threshold output (HYST1 < TRSH1; TRSH2 not used).
The output turns on with a north pole but not with a south pole, and turns off when the field is reduced.

Thresholds parameter constraints are as follows:

- TRSH2 should be greater than TRSH1.
- HYST1 and HYST2 should be positive or zero.
- Unused parameters can be set to 0xFFFF, or set the same as the other parameter.

A Simple SPI Interface

The SPI interface is an industry standard four-wire, full-duplex 2 megabit per second connection with the sensor as the slave to an external master such as a microcontroller. SPI data (MOSI and MISO) and the Clock (SCLK) are 2.2 volt to five-volt compliant. The sensor's magnetic field measurement is the default two byte response.

The SM225 uses an industry-standard "Mode 0" interface (data is sampled at the leading rising edge of the clock; CPOL=0 and CPHA=0). In accordance with industry standards, slave select (SS) is active-low, and bit order and byte order are from MSB to LSB.

Details are shown in the following diagrams:

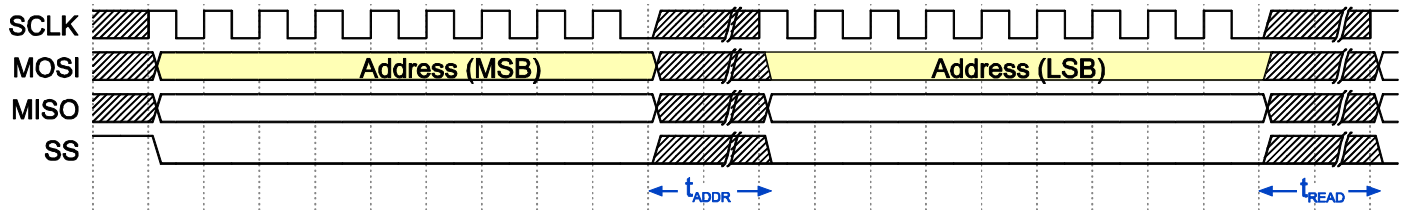


Figure 8a. Sending the address for a read.

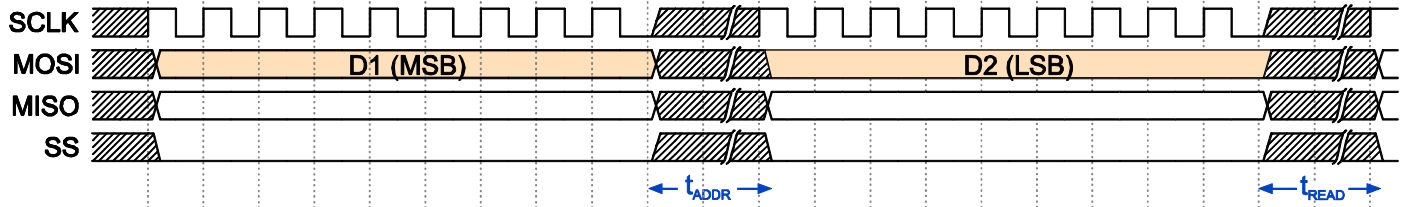


Figure 8b. Reading data.

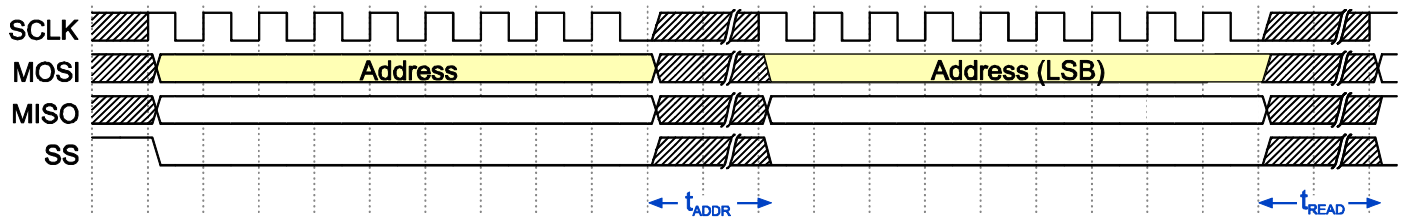


Figure 9a. Sending the address for a write.

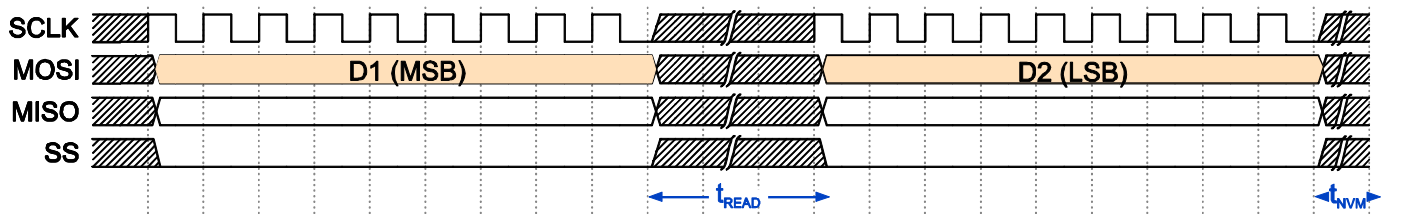


Figure 9b. Writing data.

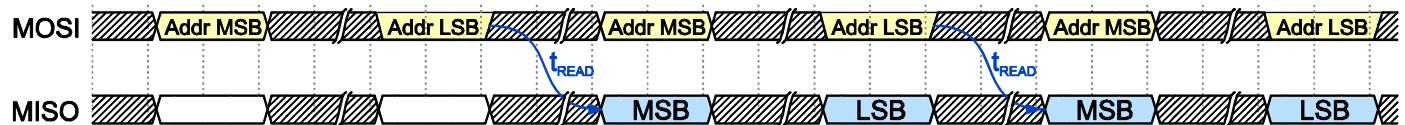


Figure 10. Continuous read.

SPI setup and hold timing constraints are shown in Figure 7:

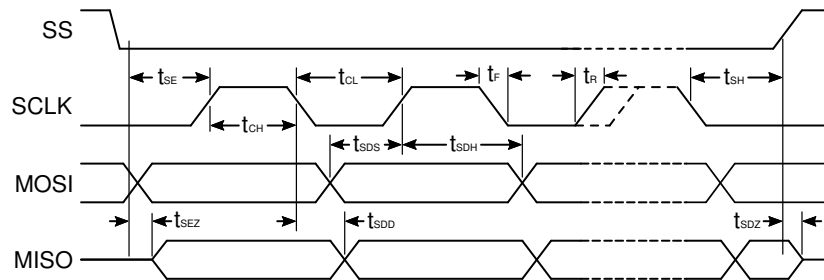


Figure 11. SPI setup and hold timing.

A schematic of a typical interface to a 3.3-volt or five-volt microcontroller is show in the Applications section.

Straightforward Reading and Writing

The sensor is reset on a falling edge of SS. All reads and writes are initiated by the master pulling the SS “LOW” and sending a two-byte address to the sensor with the MSB always zero. The sensor responds with two bytes of data.

As shown in figures 4 and 5, and the specification table, a 3 μ s delay (t_{ADDR}) is needed between address bytes; 10 μ s (t_{READ}) should be allowed before data can be read, and 20 ms (t_{NVM}) should be allowed for writing parameters to the nonvolatile memory.

The measured field is stored in Address 0 of the sensor, and reading the sensor is a simple two-byte sequence. The master writes the two zero bytes for the sensor output address, and reads the two-byte sensor output, which is expressed in tenths of an oersted. This can be repeated to continuously read the sensor as shown in Figure 6.

Memory Map

Data and parameter memory addresses are shown in the following table:

	Symbol	Default	Range	Read Address	Write Address	Description
Sensor (calibrated)	Sensor	-	-1500 – +1500	0x00	-	1500 = 150 Oe / 15 mT
Temperature	Temperature	-	-40– 125	0x02	-	°C
Threshold output	TOUT	-	0 – 1	0x03	-	Virtual comparator
Threshold 1	TRSH1	-1000	-1500– +1500	0x10	0x30	1000 = 100 Oe / 10 mT; TRSH2 > TRSH1; HYST1, HYST2 ≥ 0; 0xFFFF to disable
Hysteresis for TRSH1	HYST1	100	-1500 – +1500	0x11	0x31	
Threshold2	TRSH2	+1000	-1500 – +1500	0x12	0x32	
Hysteresis for TRSH2	HYST2	100	-1500 – +1500	0x13	0x33	
Threshold invert	TOUT_invert	0	0 – 1	0x14	0x34	HIGH to invert TOUT
Sensor offset	sensor_offset	0	-1500– +1500	0x15	0x35	
Digital filter constant	<i>m</i>	1	1 – 127	0x16	0x36	$f_{\text{CUTOFF}} = f_{\text{SAMPLE}} / (2\pi m)$; $f_{\text{SAMPLE}} = 15\text{kSps}$ $m = 1$ disables filter
Lot code	YY	N/A	R	N/A (ASCII)	0x80	ASCII date code in the form YYWWXX, where: YY = year; WW = work week; XX = internal code. The left-most character is in address 80 and the right-most in 82.
	WW				0x81	
	XX				0x82	

Table 1. SM225 Memory Locations.

Power-Up and Initialization

All parameters are nonvolatile so they can be set once (via SPI), and remain for the life of the product if desired.

Minimizing Magnetic Interference

Several precautions can be taken for applications that need maximum accuracy:

- Components such as resistors and capacitors can be slightly magnetic, and should be located away from the sensor if possible.
- Moving the bypass capacitor away from the sensor may lead to noise problem.
- If components must be located near the sensor, ultra-small components such as 0201 (0603 metric) contain less ferromagnetic material than larger components.
- Nonmagnetic resistors and capacitors can be used for extremely sensitive applications. Nonmagnetic 1 μF capacitors may not be available, but a 0.1 μF bypass capacitor can be used in applications not subject to significant noise.

Minimizing Noise

Several steps minimize noise:

- V_{DD} should be bypassed with a 1 $\mu\text{F}/6.3\text{ V}$ capacitor placed as close as possible to the V_{DD} and GND pins. 10 μF can be used in noisy environments or if the capacitor can't be located close to the sensor. Inadequate bypassing can cause noise or anomalous device behavior.
- Use a circuit board ground plane.
- If the sensor is not being used for current over trace sensing, ground the sensor's center pad for better grounding.

Applications

Typical Microcontrollers Interface

A typical microcontroller interface is shown below:

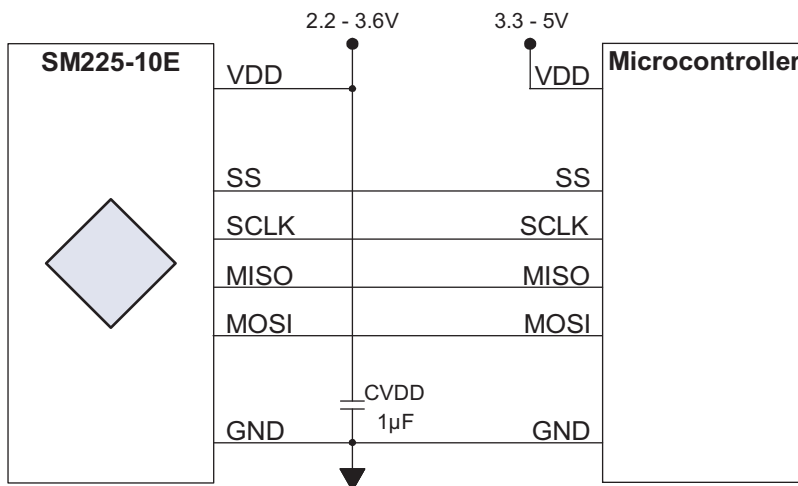


Figure 12. Typical microcontroller interface.

The SM225 is configured as a Slave and the microcontroller should be configured as the Master. The SM225 SPI interface is compatible with 3.3 or five-volt microcontrollers.

Typical Read and Write Communications Pseudocode

```
//SPI clock set elsewhere (2 MHz max.)
//SPSR = SPI Status Register; SPIF = SPI Status Register Interrupt flag
//SS set low (active) elsewhere
{
    case COMM_GET_MEM:          //Routine to READ memory
    SPDR=0x00; //'0' for the first address byte (MSB, always zero)
    while(! (SPSR & (1<<SPIF))); //Waits for transmission
    _delay_us(3); //Allow 3 microseconds between address bytes

    SPDR=buffer[1];             //Second address byte (LSB)
    while(! (SPSR & (1<<SPIF))); //Waits for transmission
    _delay_us(10); //Allows 10 microseconds for the address to be sent

    SPDR=0x00;
    while(! (SPSR & (1<<SPIF))); //Waits for transmission to complete
    _delay_us(10); //Allows 10 microseconds for data to be sent
    MSB=SPDR;                  //Reads the first byte of data (MSB)

    SPDR=0x00;
    while(! (SPSR & (1<<SPIF)));
    _delay_us(10); //Allows 10 microseconds for data to be sent
    LSB=SPDR;                  //Reads the second byte of data (LSB)

    buffer[0]=MSB; //Stores data in the buffer
    buffer[1]=LSB;

    *output_len=2; //Number of bytes to transmit
    break;

    case COMM_SET_MEM:          //WRITE memory routine (to set sensor parameters)
    SPDR=0x00; //'0' for the first address byte (MSB, always zero)
    while(! (SPSR & (1<<SPIF))); //Waits for transmission
    _delay_us(3); //Allow 3 microseconds between address bytes

    SPDR=buffer[1];             //Second address byte (LSB)
    while(! (SPSR & (1<<SPIF))); //Waits for transmission
    _delay_us(10); //Allows 10 microseconds for the address to be sent

    SPDR=buffer[2]; //Read first data byte (MSB)
    while(! (SPSR & (1<<SPIF)));
    _delay_us(10); //Allows time for the data to be sent

    SPDR=buffer[3]; //Read second data byte (LSB)
    while(! (SPSR & (1<<SPIF)));
    _delay_ms(20); //Allows 20 MILLIseconds to write to nonvolatile memory

    break;
}
```


Illustrative Arduino Code for Continuous Read

```

/*****
Continuously read an NVE SM225 Smart Magnetometer
Arduino Uno connections: pin 10=SS; pin 11=MOSI; pin 12=MISO; pin 13=SCLK
*****/

#include<SPI.h>
int sensor;

void setup() {
  pinMode(10, OUTPUT); //Pin 10 = Sensor SS
  SPI.begin ();

  //Set clock rate at 2 MHz; MSB first, and Mode 0
  SPI.beginTransaction(SPI_Settings(2000000, MSBFIRST, SPI_MODE0));
  digitalWrite(10, LOW); //Enable sensor
}

void loop() {
  sensor= (SPI.transfer (0))<<8; //Send 0 for address MSB; receive sensor MSB
  delayMicroseconds (3); //Allow 3 us between address bytes
  sensor|= SPI.transfer (0); //2nd address byte (LSB); receive sensor LSB
  delayMicroseconds (10); //Allow 10 us for next data
}

```

Illustrative Arduino Code to Set Thresholds

```

/*****
Sets SM225thresholdsand hysteresis.
Arduino Uno connections: pin 11=MOSI; pin 12=MISO; pin 13=SCLK; pins 9 & 10=SS
*****/
#include<SPI.h>
int sensor; //Sensor reading
char addr; //Sensor memory address
const int parameter[] = { //Sensor parameters starting at address 0x30:
    -1000, //Threshold 1 (-100 Oe / -10 mT)
    100, //Hysteresis for Threshold 1 (10 Oe / 1mT)
    1000, //Threshold 2 (100 Oe / 10 mT)
    100, //Hysteresis for Threshold 2 (10 Oe / 1mT)
};

void setup() {
    pinMode(10, OUTPUT); //Pin 10 = Sensor SS
    SPI.begin ();

    //Set clock rate to 2Mbps/s; MSB first; Mode 0
    SPI.beginTransaction(SPI_Settings(2000000, MSBFIRST, SPI_MODE0));

    digitalWrite(10, HIGH); //Disable to reset the sensor
    digitalWrite(10, LOW); //Re-enable sensor

    for(addr=0x30; addr<= 0x33; addr++){ //Threshold and hysteresis memory addresses

        //Write address
        SPI.transfer (0); //Address MSB(always 0)
        delayMicroseconds (3); //Allow 3 us between address bytes
        SPI.transfer (addr); // Address LSB
        delayMicroseconds (10); //Allow 10 us for next address to settle

        //Write parameter to sensor
        SPI.transfer (parameter[addr-0x30]<<8); //parameter MSB
        delayMicroseconds (3); //Allow time between bytes
        SPI.transfer (parameter[addr-0x30]&0xFF); //parameter LSB
        delay (20); //Delay 20 ms to allow writing to nonvolatile memory

    } //Next address

```

In Case of Difficulty

Random data, or measurements outside the allowable range.

- The SPI clock may be too fast (the SM225 maximum clock rate is specified as 2.5 Mbps).
- Ensure the Master is operating in the correct mode (Mode 0).

Random data, or measurements outside the allowable range on the first readings after the sensor is selected.

- The sensor is reset on a falling edge of SS. Toggling SS HIGH, then LOW will ensure the sensor is reset.

MSB/LSB bytes are reversed.

- The MSB should be read first. SPI devices use different byte orders, but the SM225 follows the most common convention of MSB first.

Angle data is shifted by one or more bits.

- This is usually because the sensor has not completed internal shifting of bits into the correct positions. Ensure there is enough settling time between writing the address and reading the data (10 μ s minimum).

Garbled data on Master startup.

- Data can be left in the sensor if the Master microcontroller is reset and the sensor is not. This can be corrected by doing a “dummy read” as part of the microcontroller startup sequence, or toggling SS HIGH then LOW to reset the sensor.

Parameters do not appear to be written correctly.

- Ensure that the Write bit is set in the second (LSB), i.e., the second address byte is a “1.”
- Ensure there is adequate settling time before reading or using a written parameter (10 milliseconds minimum). Parameters are stored in nonvolatile memory, not RAM, and writing to nonvolatile memory is much slower.

Evaluation Support

Breakout Board

The AG959-07E breakout board provides easy connections to an SM225-10E sensor with a six pin connector. It also has a recommended 1 μ F bypass capacitor:

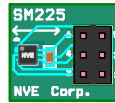


Figure 16. AG959-07E breakout board (actual size)
0.5" x 0.6" (12 mm x 15 mm)

Evaluation Kit

This simple evaluation board includes an SM225-10E Smart Magnetometer and a microcontroller that interfaces to the SM225 via SPI and to a PC via USB.

The sensor can be activated with a magnet or an on-board current trace. A Windows-based user interface provides two-way communication with the sensor to display the sensor outputs and change sensor programmable parameters. A microcontroller PWM output on the board provides an analog representation of the measured field.

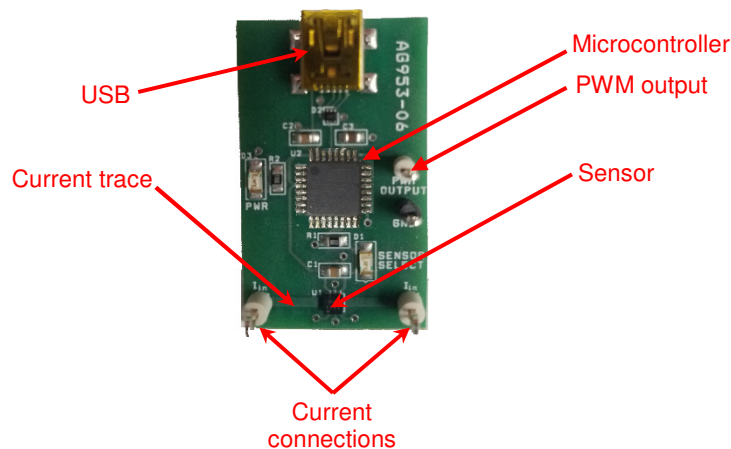


Figure 14. AG953-07E: SM225 Smart Magnetometer Demonstration/Evaluation Kit board
1" x 1.625" (25 mm x 41 mm)(actual size)

Socket Board

The AG954-07E provides a TDFN6 socket for easy interface to smart sensors such as the SM225-10E without soldering:

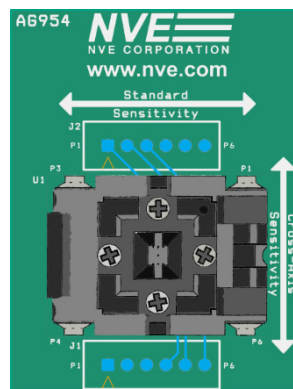
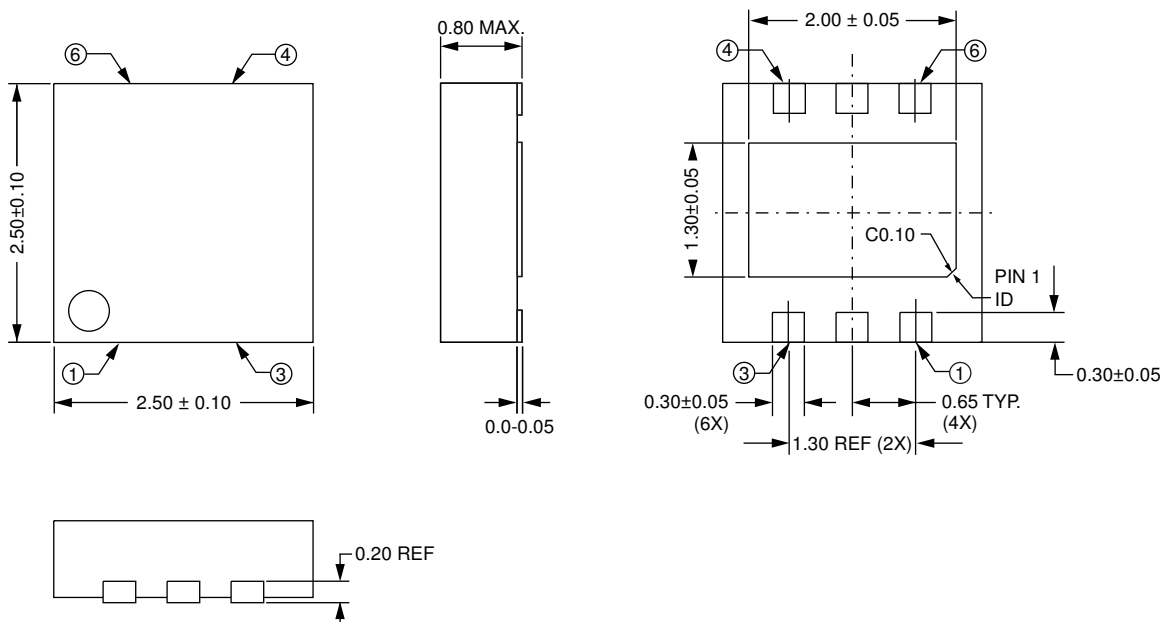


Figure 15. AG954-07E: TDFN socket board
1.5" x 2" (38 mm x 50 mm)(actual size)

2.5 x 2.5 mm TDFN6 Package



Pad	Symbol	Description
1	SS	Sensor Select Input (low to select)
2	MOSI	Sensor SPI Data Input
3	MISO	Sensor SPI Data Output
4	GND	Ground/ V_{ss}
5	SCLK	SPI Clock Input
6	VDD	Power Supply (bypass with a 1µF capacitor)
Center pad		Internal leadframe connection; connect to GND to minimize noise; leave unconnected for current over trace sensing.

Notes:

- Dimensions in millimeters.
- Soldering profile per JEDEC J-STD-020C, MSL 1.



Ordering Information

SM225 - 10E TR13

Product Family

SM = Product Family (Smart Magnetometers)

Base Part Number

2 = TMR element with 2-byte data

2 = Magnetic Orientation (cross-axis, i.e., sensitive to a field vector in the pin 2 / pin 5 direction)

5 = Magnetic Field Linear Range (0 to 150 Oe / 0 to 15 mT)

Part Package

10E = RoHS-Compliant 2.5 x 2.5 mm TDFN6 Package

Bulk Packaging

TR13 = 13" Tape and Reel Package

Revision History

SB-00-079-RevC

August 2019

Change

- Corrected pin one location on Figure 1 (p. 5).
- Replaced bare circuit board with breakout board (p. 20).

SB-00-079-RevB

June 2019

Change

- Changed Digital Filter Constant memory locations to 0x16 read / 0x36 write.

SB-00-079-RevA

May 2019

Change

- Initial release.

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