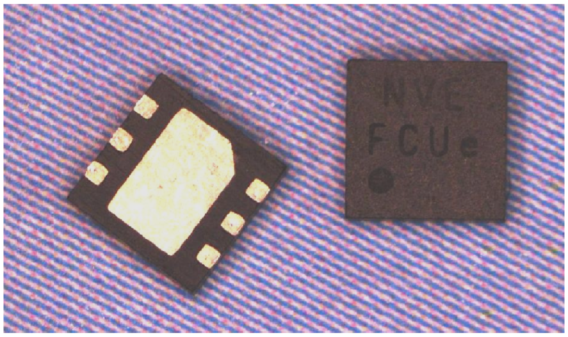
SM324-10E TMR Smart Magnetometer



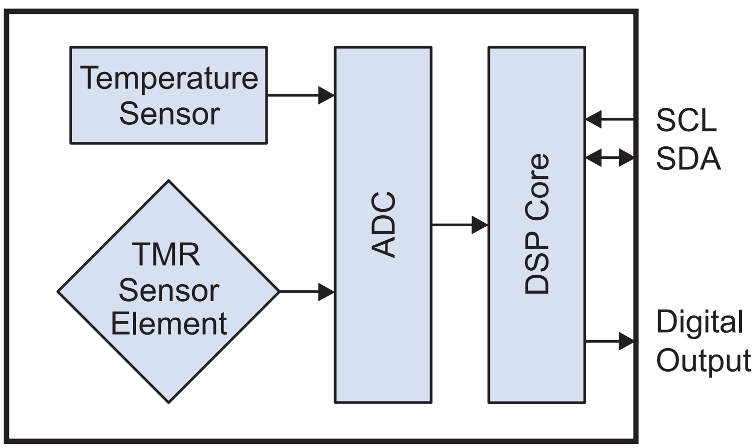
Features

- Can detect magnets more than 50 mm away
- In-plane sensitivity—more usable than Hall sensors
- Internal temperature compensation
- I²C field measurement plus on/off digital output
- Ultraminiature 2.5 x 2.5 x 0.8 mm TDFN6 package

Key Specifications

- 0 to ±20 Oe magnetic field operating range
- Ultra-accurate— ±0.3% of full scale at 25°C
- 1.5 mA typical supply current
- 300 samples/second
- −40°C to +125°C operating range

Block Diagram



Applications

- Proximity sensors
- Noncontact current sensing
- Automotive applications
- Robotics
- Internet of Things (IoT) end nodes

Description

The SM324 Smart Magnetometer provides ultraprecise magnetic field measurements.

The sensor combines a precise Tunneling Magnetoresistance (TMR) sensor element with sophisticated digital signal processing. The digital signal processing improves accuracy and allows application-specific calibration. Calibration coefficients are stored in an internal nonvolatile memory.

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, and lower noise than Hall.

An I²C interface provides data as well as a programming interface. A digital output provides precise, programmable magnetic thresholds.

Designed for harsh industrial or automotive environments, the SM324 has robust ESD protection and full −40°C to +125°C operating temperature range.

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Absolute Maximum Ratings

Parameter	Min.	Max.	Units
Supply voltage	–0.4	3.63	Volts
Input/ Output voltages (SCL, SDA, Digital Out)	–0.5	V_{DD}+0.5	Volts
Storage temperature	–50	130	°C
ESD (Human Body Model)	4000		Volts
Applied magnetic field		Unlimited	Oe

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Operating Specifications

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Operating temperature	T_{MIN}; T_{MAX}	–40		125	°C	
Supply voltage	V_{DD}	1.68		3.6	V	
Supply current (V_{DD} = 3.3 V)	I_{DD}		1.5	2.5	mA	Active; T_{MIN} to T_{MAX}
			20	250	nA	Idle Mode; ≤ 85°C
			50	750	nA	Idle Mode; ≤ 125°C
Power-Up and Power-Down						
Power-on reset low voltage	V_{BOR}	0		0.2	V	
Power down time (duration below V_{BOR})	t_{BOR}	3			µs	
Power-on reset rising slope	SR_{VDD}	10			V/ms	
Start-up time	t_{ST1}			1	ms	V_{DD} ramp time to active communication
	t_{ST2}			2.5	ms	V_{DD} ramp time to active operation
Wake-up time	t_{WU1}			0.5	ms	Idle to active communication
	t_{WU2}			2	ms	Idle to active operation
Internal Temperature Sensor						
Temperature resolution	T_{RES}		0.003		°K/LSB	T_{MIN} to T_{MAX}
Magnetic Measurements						
Operating magnetic field strength	H			20	Oe	
Conversion rate	f_{CON}	270	300		S/s	
Accuracy				±0.3	%FS	25°C
				±1		T_{MIN} to T_{MAX}
Hysteresis				0.1	%FS	T_{MIN} to T_{MAX}
Output resolution				24	bits	
Digital Output						
Update rate	f_{UPDATE}		300		S/s	During repeated 0xAA commands
Sink current	I_{SOURCE}		10		mA	V_{DD} = 3.3V
Source current	I_{SINK}		10		mA	V_{OL}< 0.5V; V_{OH}> 2.8V
Low-level analog output voltage	V_{OL}	0		50	mV	I_L = –50 µA
High-level analog output voltage	V_{OH}	V_{DD}–0.05		V_{DD}	V	I_L = 50 µA
Nonvolatile Memory						
Write time			5	16	msec	
Endurance		1000	10000		cycles	
Thermal Characteristics						
Junction-to-ambient thermal resistance	θ_{JA}		320		°C/W	
Package power dissipation			500		mW	
I²C Interface						
Data transfer rate	DR			400 k	Baud	Standard mode
				3.4 M		I²C fast mode
Bus voltage	V_{BUS}	3		V_{DD} + 0.5	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
Capacitive load	C_B			400	pF	
I/O capacitance	$C_{I/O}$			10	pF	

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SM324 Overview

The SM324 is a non-contact magnetometer designed for proximity or current sensing.

The heart of the SM324 is a tunneling magnetoresistance (TMR) sensor. With a tiny 2.5 x 2.5 mm TDFN package and typical 1.5 mA active supply current and 50 nA idle current, the SM324 is the smallest, lowest-power magnetometer in its class.

Factory calibration for gain and offset, plus temperature correction and digital linearization provide extraordinary accuracy of ±0.3% of full scale. Combined with a high-sensitivity TMR element, absolute accuracy is 0.12 Oe at 25°C, or 0.4 Oe from −40°C to 125°C.

The unique TMR element also yield negligible hysteresis of less than 0.1%, or 0.04 Oe from −40°C to 125°C.

SM324 Operation

A block diagram is shown below:

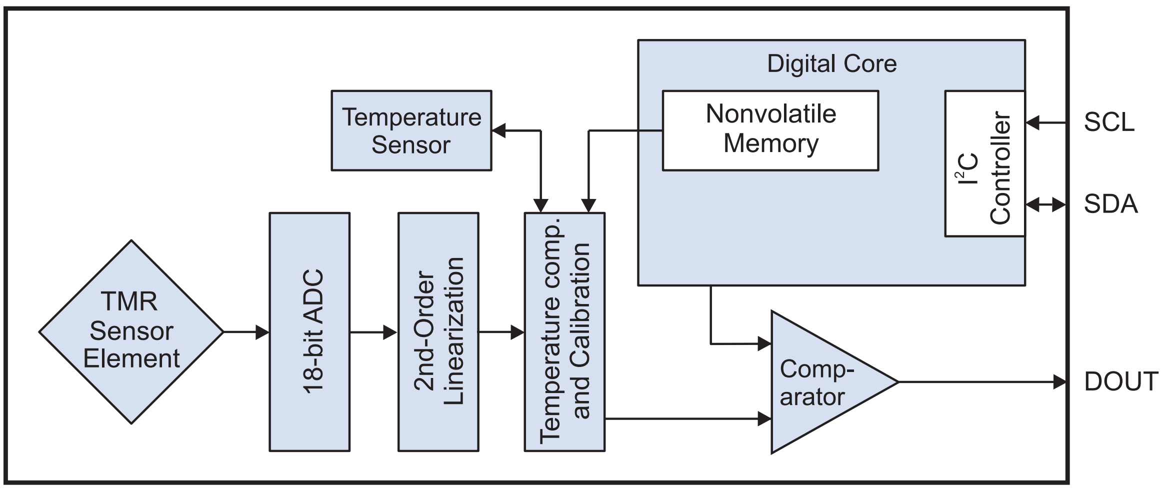

Figure 1. Detailed block diagram.

A robust 18-bit ADC, second-order linearization, and temperature compensation provide ultra-precise magnetic field measurements.

The digital core provides three bytes (24 bits) of mathematical precision.

Two outputs are available: an industry-standard I²C output for interfacing directly to microcontrollers and FPGAs, and a simple digital output for threshold detection of proximity, fault, overcurrent, and saturating magnetic fields.

Several other parameters can be programmed into the SM324 through the I²C interface.

User Defined Memory
Twenty-six 16-bit blocks of nonvolatile memory are available for part identification or general purpose use. This number can be overwritten if needed. Note that the nonvolatile memory is subject to endurance limitations and should only be used for occasionally updated data.

Sensor Offset
The sensor core of the SM324 is factory calibrated for highest accuracy, and a programmable three-byte parameter, OFFS, is available for user adjustments to environments with non-zero magnetic fields. OFFS has a signed sign/magnitude form value with where the most-significant bit is the sign (1 = negative), and the range is ±50% of the ±20 Oe full-scale range.

Internal Temperature Sensor
The SM324 utilizes an internal temperature sensor to allow for compensation of temperature effects. The thermometer is factory calibrated and a user-programmable three-byte variable, TEMP, is available for additional temperature offset calibration. Similar to the OFFS parameter, TEMP has a sign/magnitude form where the most-significant bit is the sign (1 = negative), and the range is ±50% of the 165°C full-scale range.

Digital Output for Threshold Detection

The SM324 has a programmable digital output that can be configured for threshold detection. The output is programmable using two 24-bit threshold parameters (THRSH1 and THRSH2). THRSH1 and THRSH2 are unsigned integers, each representing 0 to 100% of full scale, where 50% is zero field, 0 is the low end of the range (–20 Oe), and 0xFFFFFF is the high end of the range (+20 Oe).

Digital Threshold Updating
DOUT updates automatically with each sample in the Cyclic Mode, although the refresh rate is limited to eight samples per second in that mode. In normal mode, DOUT updates with each data request, so the sensor must be connected to a I²C Master continuously requesting data for the output to work.

Digital Threshold Modes
The digital output can be programmed as a high-field, low field, or window comparator function. The configuration of the output can also be reversed with a two-bit parameter, so either a high-field or low-field output can be generated. The figures below show the outputs for the three comparator modes, which are set by the CONFIG parameter.

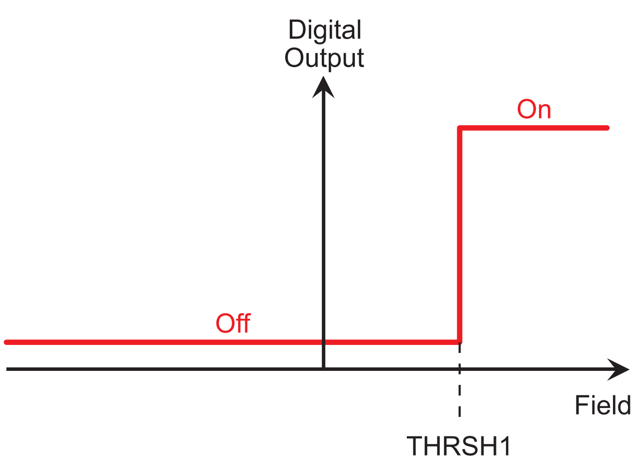

Fig. 2a. Normal mode (CONFIG = 01 bin).

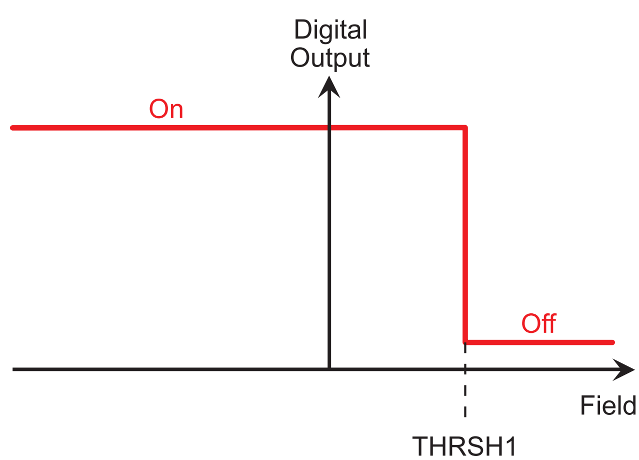

Fig. 2b. Inverted mode (CONFIG = 10 bin).

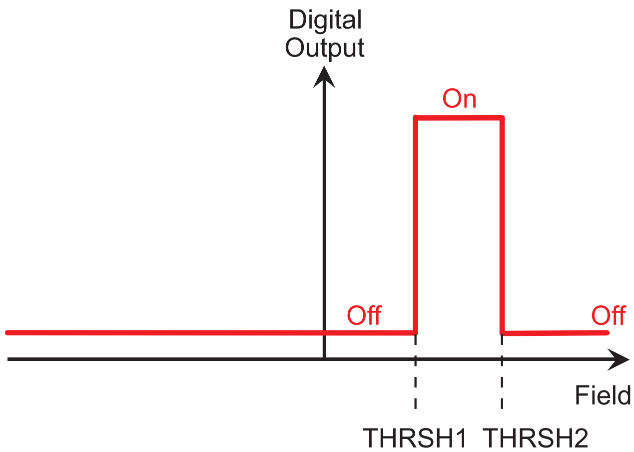

Fig. 2c. Window mode (CONFIG = 11 bin; THRSH2>THRSH1).

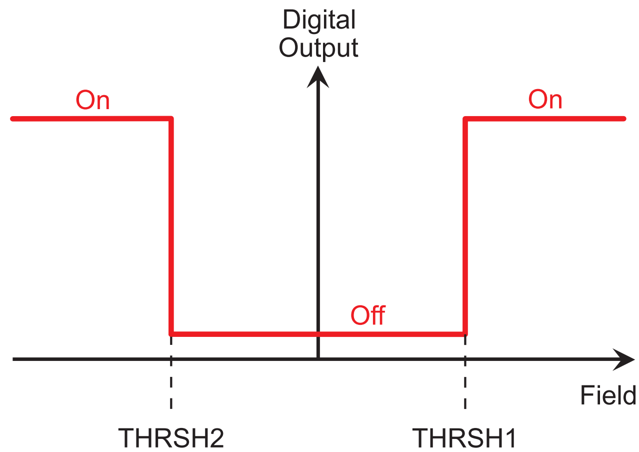

Fig. 2d. Inverted Window mode (CONFIG= 11; THRSH1>THRSH2).

These graphs are with respect to magnetic field, with zero field at the y-axis intercept in the center of the x-axis. The I²C output is unsigned, with zero field corresponding to 50%.

The Digital Threshold Modes are summarized in the following table:

CONFIG (Bin)	**DOUT**
01	0: Measurement < THRSH1 1: Measurement > THRSH1
10	0: Measurement > THRSH1 1: Measurement < THRSH1
11	Output determined by threshold settings. If THRSH1 > THRSH2 1: Measurement > THRSH1 OR Measurement < THRSH2 0: THRSH1 > Measurement > THRSH2 If THRSH2 > THRSH1 1: THRSH1 < Measurement < THRSH2 0: Measurement > THRSH2 OR Measurement < THRSH1

Table 1. Digital Output (DOUT) Threshold Configuration

The Window mode (CONFIG = 11) can be used to provide a response independent of polarity. For example, the default settings of CONFIG = 11, THRSH1 = 75% (0xC00000), and THRSH2 = 25% (0x400000) cause DOUT to be high if the field magnitude is more than 10 Oe (i.e., greater than +10 Oe or less than −10 Oe) as shown in the following diagram:

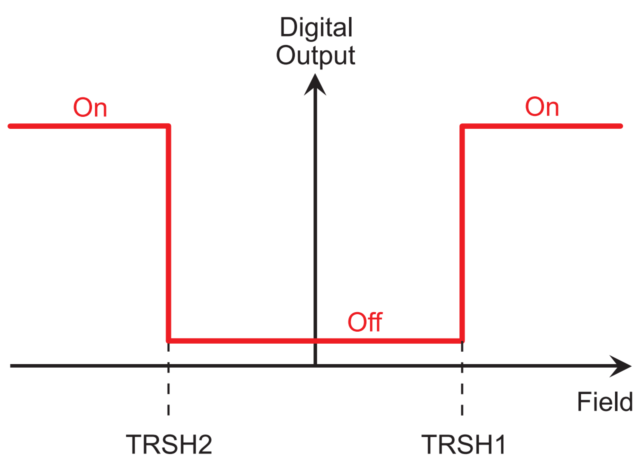

Fig. 2e. Default DOUT configuration (CONFIG = 11; THRSH1 = 75%; THRSH2 = 25%; for omnipolar DOUT).

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Directions of Sensitivity

Unlike Hall effect or other sensors, TMR sensors are sensitive to fields in the plane of the package, which is more convenient. The axis of sensitivity is in the pin 2 to pin 5 sensor axis, which is ideal for position sensing or current sensing so a current-sensing trace can be run under the sensor without crossing the pins.

Position Sensing

A typical proximity sensor using an SM324-10E sensor and magnet is shown below. With a 4 Oe operate point, the sensor actuates with a rare-earth magnet at more than 50 mm (two inches) from the sensor:

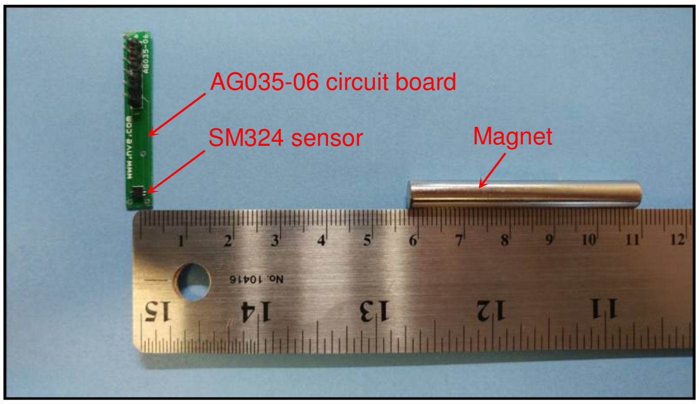

Figure 3. The SM324-10E sensor can be activated by a magnet more than 50 mm away.

Thresholds even lower than 4 Oe can be programmed for the SM324-10E, although care must be taken to account for the earth's magnetic field, which is approximately 0.5 Oe.

Typical magnetic operate distances are illustrated below for an inexpensive ceramic disk magnet:

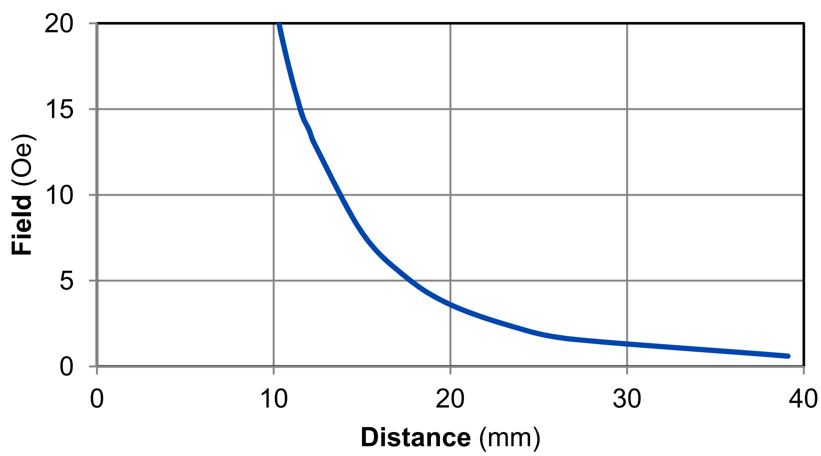

Figure 4. Field vs. distance from the center of the sensor
(NVE part number 12216; ferrite magnet; d=6 mm; t=4 mm; C1/Y10T; M_s=B_r=2175 G).

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.

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Current Sensing

In a typical current sensor configuration, a magnetic field provided by an off-chip current strap produces a magnetic field in the plane of the sensor. The digital output can be used for current threshold detection or overcurrent protection.

Typical current sensing configurations are shown below:

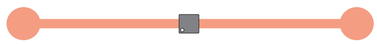

Figure 5a. 0.05" (1.3 mm) trace (0 – 5 A typ.).

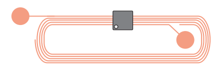

Figure 5b. Five turns of 0.0055" (0.14 mm) trace (0 – 1 A typ.).

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

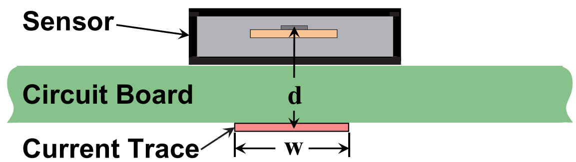

Figure 6. The geometry of current-sensing over a circuit board trace.

$$H = \frac{2I}{d}$$ ["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 more than five 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

Power-Up and Initialization

Parts power in the "normal" (single-reading) mode. In this mode, the sensor output and DOUT are updated when data is requested via I²C, so the sensor must be connected to a I²C Master continuously requesting data. If the "cyclic" (DOUT automatically updated) mode is desired, it should be invoked via the appropriate I²C commands on power-up.

Parameters such as I²C address, temperature and field offsets, digital output thresholds and configuration are stored in nonvolatile memory and retain their state through power cycle unless they are deliberately changed. As specified in "Operating Specifications—Power-Up and Power-Down," fast supply rise time is necessary to guarantee a power-on reset."

DOUT Update Modes

Two operational modes are available with the SM324. The "normal" mode allows the user to update DOUT and retrieve a single sensor reading via I²C. The part returns to a low power idle state when communication is complete.

Cyclic mode automatically updates the sensor read buffer and DOUT at a programmed interval. Field and temperature can be read via I²C during cyclic mode, and such reads will update the measurements and DOUT. Note that the minimum Cyclic Mode Interval is 125 ms, so without I²C data reads, DOUT is only updated a maximum of eight times per second in Cyclic Mode. Although data can be read, parameters cannot read or written in cyclic mode.

The mode can be set via I²C (see Table 2 below), and the cyclic interval is programmed using the CINT parameter (see Table 3):

Command	**Command Value** (hex)	**Notes**
Read User Memory	0x20-0x38	16-bit user defined data
Write User Memory	0x60-0x78	16-bit user defined data
Checksum	0x90	Perform memory update to CHECKSUM.
Single Measurement	0xAA	24-bit field plus 24-bit temperature measurement
Cyclic Measurement	0xAB	Cyclic 24-bit field and temperature measurements
2x Oversample Measure	0xAC	Complete 2x full continuous measurements and compute average values
4x Oversample Measure	0xAD	Complete 4x full continuous measurements and compute average values
8x Oversample Measure	0xAE	Complete 8x full continuous measurements and compute average values
16x Oversample Measure	0xAF	Complete 16x full continuous measurements and compute average values
Cyclic Measure Stop	0xBF	Stops cyclic measurements

Table 2. SM324 command options.

Parameter Value (binary)	**Cyclic Mode Update Interval**
000	Not assigned
001	125 msec
010	250 msec
011	500 msec
100	1000 msec
101	2000 msec
110	4000 msec
111	Not assigned

Table 3. CINT (Cyclic Interval) parameter values.

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Sensor Measurements and Offsets

Field and Temperature Measurements

The sensor provides field and temperature measurements with each reading.

The measurements are 24-bit unsigned integers. 0x000000 represents the minimum value which is −20 Oe for field and −40°C for temperature. 0xFFFFFF represents full scale, which is +20 Oe for field and +125°C for temperature.

Saturation and Overflow

All measurements responses start with a status byte followed by the data. Bit 0 of the status byte indicates when the field is too high for an accurate measurement, i.e., the sensor is saturated. In this case, Bit 0 of the status byte will be set and the field will remain at or near 0xFFFFFF.

Offsets

Temperature and field offsets are factory calibrated, but can be reprogrammed if necessary. Offsets are in 24-bit Sign/Magnitude format, where the most significant bit (bit 23) is the sign (0 = positive; 1 = negative), and bits 22:0 are the magnitude. The offset range is ±50% of full-scale, where field full-scale is ±20 Oe;
and temperature full-scale is 165°C.

Measurements and offsets are illustrated below:

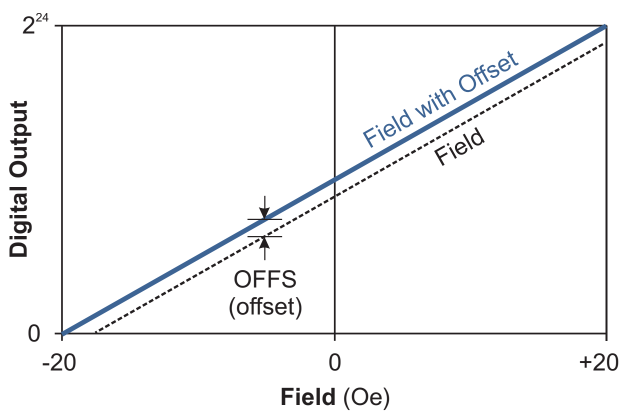

Fig. 7a. Sensor output versus field.

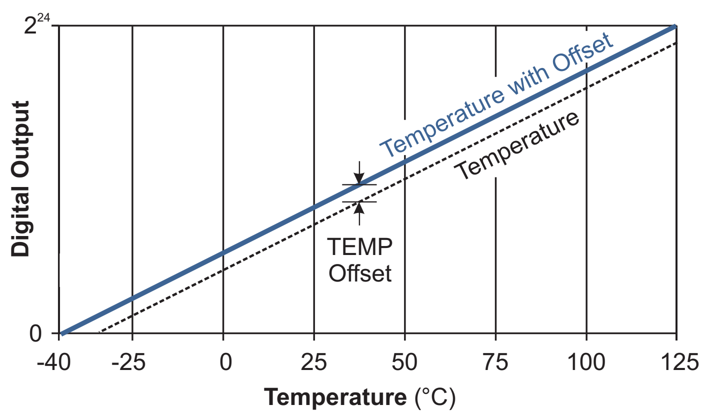

Fig. 7b. Sensor output versus temperature.

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I²C Interface

The I²C interface is an industry standard full-duplex 400 kHz connection with the sensor as the slave to an external master such as a microcontroller.

Consistent with industry practice, SDA and SCL are open-drain, and pull up resistors to V_{DD} are normally needed. The SDA / SCL pins should not be left floating for proper power-up/operation.

A schematic of a typical microcontroller interface is show in the Applications section.

I²C Address

The SM324 has a seven-bit address, which can be defined in the nonvolatile memory with the I^2C_{ADD} parameter. Allowable I²C addresses are 8 to 127. Addresses 4 to 7 are reserved for I²C High Speed Mode. The factory default I²C Slave Address is 16 (0x10 hex). A power cycle is required for a device to respond to an I^2C_{ADD} change.

Data Format

Each command follows the sequence shown below. All I²C read responses start with a status byte followed by the data. The data depends on the previous commands. Only the number of bytes that are needed for the command must be sent. An exception is the I²C High Speed Mode where three bytes must always be sent. After the execution of a command, the expected data can be read or if no data is returned by the command, the next command can be sent. You can read the same data more than once if the read request is repeated.

Command or I²C Memory Write Sequence

S	Addr	W	A	Command	A	P

S	Addr	W	A	Command	A	Data [15:8]	A	Data [7:0]	A	P

S	Addr	W	A	Memory Address	A	Data [15:8]	A	Data [7:0]	A	P

Read Sequence Following AA_{HEX} Command

S	Addr	R	A	Status	A	Field [23:16]	A	Field [15:8]	A	Field [7:0]	A	Temp [23:16]	A	Temp [15:8]	A	Temp [7:0]	N	P

Read Sequence Following 2-byte Memory Write Command

S	Addr	R	A	Status	A	Data [15:8]	A	Data [7:0]	N	P

Key:

S/P: Start/Stop
A/N: Acknowledge / Not Acknowledge
R/W: Read (0) / Write (1)

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Status Byte

A read status can be executed at any time with the following command sequence:

S	Addr	R	A	Status	N	P

The status byte contains the following bits:

Bit	7	6	5	4, 3	2	1	0
Meaning	0	Powered?	Busy?	00	Memory Error?	0	Saturation?

Power indication (bit 6): This bit is 1 if the sensor element is powered and 0 if not powered.

Busy indication (bit 5): This bit is 1 if the device is busy, which indicates that the data for the last command is not available yet. No new commands are processed if the device is busy. Note that the device is always busy if the cyclic measurement operation has been started.

Memory integrity/error flag (bit 2): This bit indicates whether the checksum-based integrity test passed or failed. The bit is 0 if the integrity test passed and 1 if it failed. The memory error status bit is calculated only during the power-up sequence, so a newly written CHECKSUM will only be used for memory verification and status update after a subsequent power-on reset (POR).

Saturation (bit 0): This bit is 0 for any non-measurement command or if the last command was a measurement request and the computation is valid. This bit is 1 if the last command was a measurement request and the computation caused an internal saturation or is invalid.

Memory Register

The SM324 uses an internal nonvolatile memory to enable user programmable parameters such as I²C address, temperature and field offsets, digital output thresholds and configuration parameter, and cyclic mode interval. Each register is 16 bits and is written using the scheme described in the I²C interface section.

The memory address and number of bits for each parameter are also provided. Memory address bit 6 is a write bit, so writing to nonvolatile memory uses an address 0x40 higher than the address for reading.

Table 4 summarizes programmable parameters:

Parameter	Symbol	Read Address (hex)	Write Address (hex)	Bits	Default		Notes
					Hex	Value	
Device Identifiers							
User Memory		00-01; 20-38	40-41; 60-78	[15:0]	--	--	
I²C Address	I^2C_{ADD}	0x02	0x42	[6:0]	0x10	16 dec	Address changes require power cycle.
Offsets							
Temperature Offset (lower 16 bits)	TEMP	0x18	0x58	[15:0]	Factory Calibrated		Sign/Magnitude format; most significant bit is sign (1=negative); bits 22:0 are magnitude (±50% of full scale); full scale field = ±20 Oe; full scale temp. = 165°C.
Temperature Offset (sign bit + upper 7 bits)		0x19	0x59	[15:8]			
Field Offset (lower 16 bits)	OFFS	0x17	0x57	[15:0]			
Field Offset (sign bit + upper 7 bits)		0x19	0x59	[7:0]			
Mode Parameters							
Cyclic Interval	CINT	0x02	0x42	[14:12]	000_{BIN}	0	
Digital Output Configuration							
Threshold 1 (LSB)	THRSH1	0x13	0x53	[15:0]	0x0000	10 Oe	Unsigned (0–100% of full scale)
Threshold 1 (MSB)		0x15	0x55	[7:0]	0xC0		
Threshold 2 (LSB)	THRSH2	0x14	0x54	[15:0]	0x0000	−10 Oe	
Threshold 2 (MSB)		0x15	0x55	[15:8]	0x40		
Threshold Configuration	CONFIG	0x02	0x42	[8:7]	11_{BIN}	3	

Table 4. SM324 programmable parameters.

Supply Decoupling

V_{DD} should be bypassed with a 1 nF (0.001 µF) capacitor placed as close as possible to the supply pin. Note that a larger capacitor is not required, and could interfere with power-up timing.

Typical Circuit

A typical microcontroller interface is shown below:

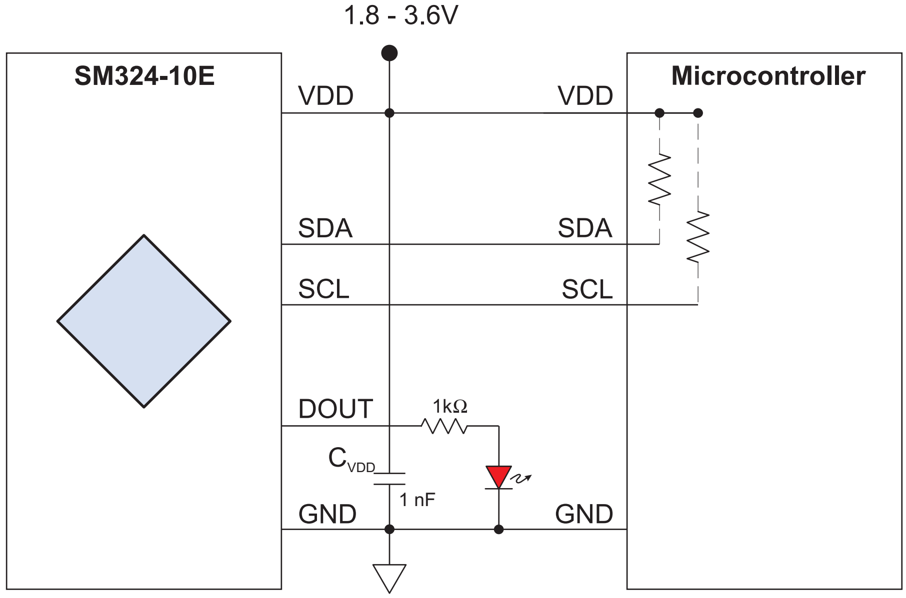

Figure 8. Typical microcontroller interface.

The SM324 is configured as a Slave and the microcontroller should be configured as the Master. The SM324 I²C interface is compatible with 1.8 to five-volt nominal microcontrollers.

The SM324 SDA and SCL lines are open-drain, so the microcontroller's internal pull-up resistor should be activated in software. If an external pull-up is used with different power supplies, it should be connected to the lower supply voltage, which is usually the sensor (Slave) supply.

V_{DD} should be bypassed with a 1 nF (0.001 µF) capacitor placed as close as possible to the V_{DD} and GND pins.

A LED can be used to indicate the digital output. The appropriate series resistor depends on the supply voltage and LED type, and of course the LED cannot be operated at the low end of the sensor supply voltage range, such as 1.8 volts.

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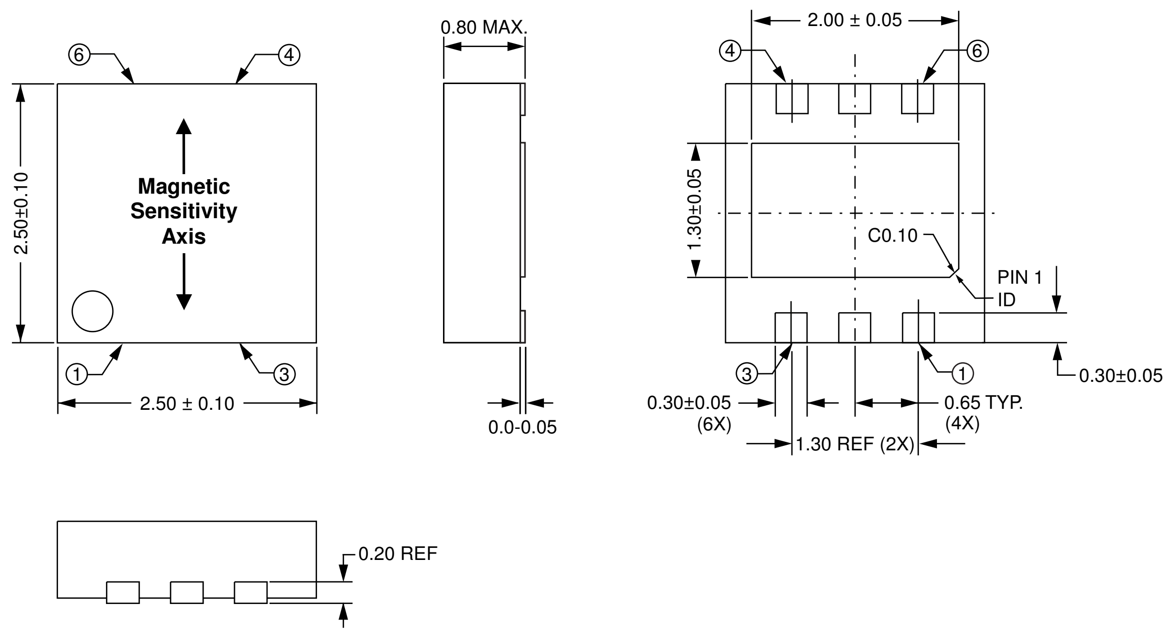
2.5 x 2.5 mm TDFN6 Package (approx. 15x actual size)



Pin	Symbol	Description
1	VDD	Power Supply (bypass with a 1 nF capacitor)
2	GND	Ground / V_{SS}
3	DOUT	Digital Output
4	SCL	I²C Clock (input)
5	SDA	I²C Data (bidirectional/open drain)
6	NC	Not internally connected

RoHS
COMPLIANT

Notes:

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

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Ordering Information

SM324 - 10E TR13

Product Family
SM = Smart Magnetometer

Precision
3 = 3-Byte resolution; TMR Sensor Element

Magnetic Orientation
2 = Cross-axis (sensitive to a field vector in the pin 2 to pin 5 direction)

Field Range
4 = 20 Oe Magnetic Field Range

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

Bulk Packaging
TR13 = 13" Tape and Reel Bulk Packaging

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Revision History

SB-00-077 Rev. B
February 2019

Change
- Added "Power-Up and Initialization" section and clarified Cyclic Mode (p. 9).
- Added charts showing field and temperature outputs (p. 10).
- More detailed descriptions of bit/byte concatenation (p. 11).
- Clearer Table 4 memory map; merged Table 5 into Table 4 (p. 13).
- Clarified direction of sensitivity (p. 15).
- Corrected minor specification inconsistencies.

SB-00-077 Rev. A
September 2018

Change
- Dropped "Preliminary" designation.
- Misc. style changes.
- Dropped fax number.

SB-00-077-PRELIM2
August 2018

Change
- Dropped "Product Preview" designation.
- Added 25°C accuracy specification.
- Added hysteresis specification.
- Misc. minor changes.

SB-00-077-PRELIM
July 2018

Change
- Initial release.

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An ISO 9001 Certified Company

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February 2019