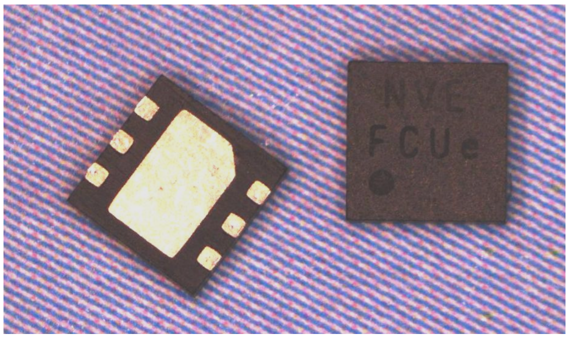
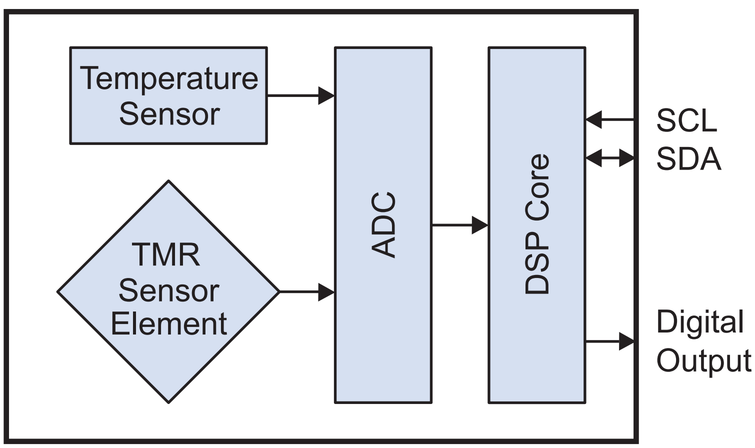
SM324-10E TMR Smart Magnetometer



Block Diagram



Features

- Precise TMR sensor element
- Wide magnetic field operating range
- Can detect magnets more than 50 mm away
- In-plane sensitivity—more usable than Hall sensors
- Low power
- Internal calibrated temperature sensor
- Internal temperature compensation
- I^2C field measurement plus on/off digital output
- 24 bit output resolution
- Ultraminiature 2.5 x 2.5 x 0.8 mm TDFN6 package

Key Specifications

- ±1.0% FS accuracy
- 0 to 20 Oe magnetic field operating range
- 300 Hz sample rate
- 1.5 mA typical supply current
- −40°C to +125°C operating range

Applications

- Current sensors
- Proximity sensors
- Automotive applications
- Robotics
- Internet of Things (IoT) end nodes

Description

The SM324 Smart Magnetometer provides precise 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 I^2C interface provides data as well as an external programming interface. A digital output provides precise, programmable 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

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 20 50	2.5 250 750	mA nA nA	Active State, Idle Mode ≤ 85°C 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	Hz	
Accuracy		1.0			%FS	T_{min} to T_{max}
Output Resolution				24	bits	
Digital Output						
Update rate	f_{MAX}		300		Hz	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 Characteristics						
Write time			5	16	msec	
Endurance		1000	10,000		cycles	
Package Thermal Characteristics						
Junction-to-ambient thermal resistance	θ_{JA}		320		°C/W	
Package power dissipation			500		mW	
I²C Interface						
Data transfer rate	DR			400	kBaud	I²C fast mode
Bus voltage	V_{BUS}	3		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
Capacitive load	C_B			400	pF	
I/O capacitance	$C_{I/O}$			10	pF	

SM324 Overview

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

The heart of the SM324 is a tunneling magnetoresistive (TMR) sensor. With the lowest active current consumption of 1.5 mA typical and an idle mode current of 50 nA typical and tiny 2.5 x 2.5 mm 6-pin TDFN package, the SM324 is the smallest, lowest-power magnetometer in its class.

Factory calibration for gain and offset is combined with a temperature correction and digital linearization to produce unprecedented accuracy and precision in extreme environments. The SM324 provides extraordinary 1.0% of full scale accuracy over temperature from −20 to 20 Oe.

SM324 Operation

A detailed block diagram is shown below:

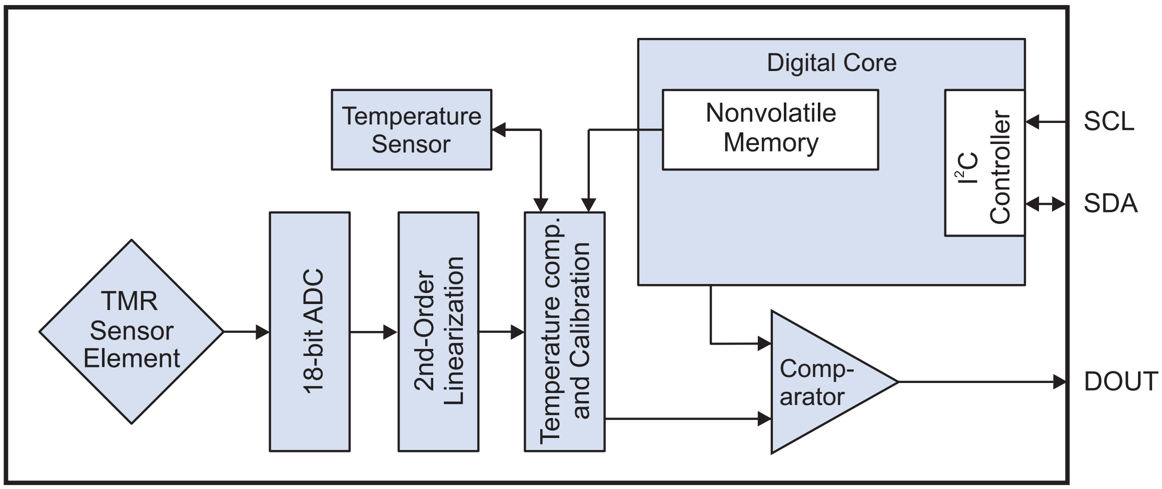

Figure 1. Detailed block diagram.

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 I^{2}C 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 I^{2}C interface.

User Defined Memory

Twenty-four 16-bit blocks of nonvolatile memory are available for general purpose use in the SM324. A factory serial number is programmed into the first two blocks. This number can be overwritten if needed. $ID_{0\text{-}1}$ of the nonvolatile memory are reserved for this. 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 3-byte parameter, OFFS, is available for user adjustments to environments with non-zero magnetic fields. OFFS is a signed integer value with the MSB the sign bit (1 = negative). This translates to ±50 full scale control for this parameter.

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 is also a signed integer with the MSB the sign bit (1 = negative) and ±50 full scale control.

Digital Output for Threshold Detection

The SM324 has a programmable digital output that can be configured for threshold detection. The output is programmable with 24-bit threshold parameters (TRSH1 and TRSH2). TRSH1 and THSH2 are unsigned integer values translating to a 0 to 100% full scale value.

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 actively 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 TRC parameter.

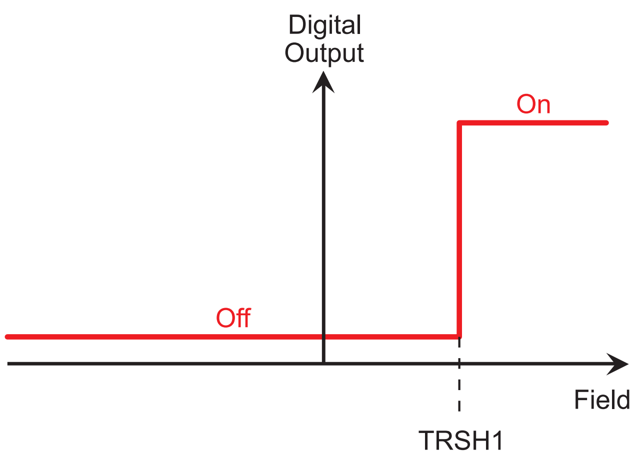

Fig. 2a. Normal mode (TRC = 01 bin).

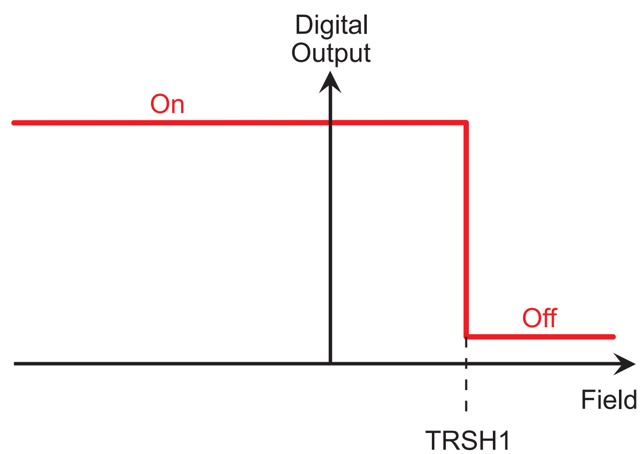

Fig. 2b. Inverted mode (TRC = 10 bin).

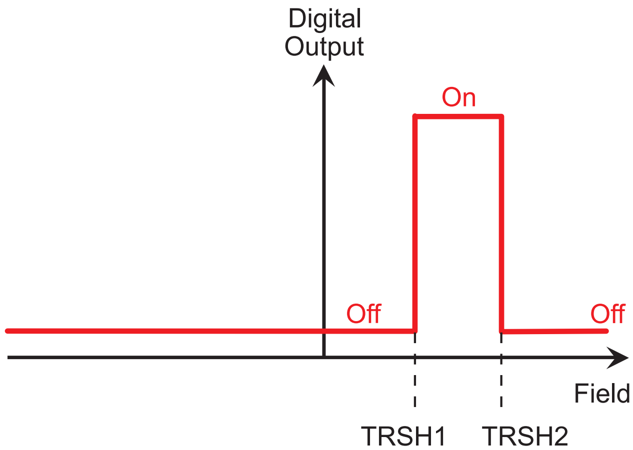

Fig. 2c. Window mode (TRC = 11 bin; TRSH2>TRSH1).

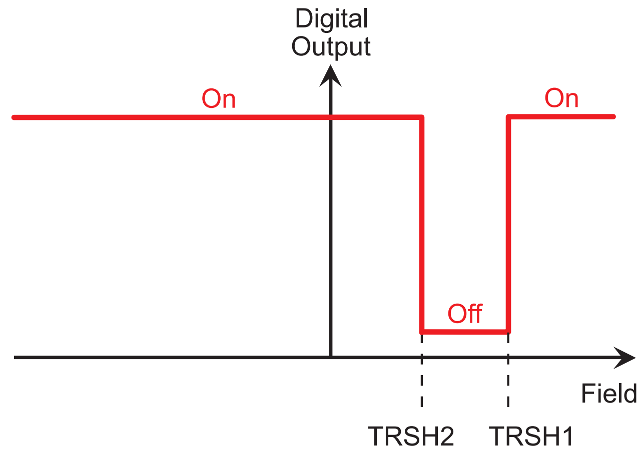

Fig. 2d. Inverted Window mode (TRC = 11; TRSH1>TRSH2).

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:

TRC (Bin)	**DOUT**
01	0: Measurement < TRSH1 1: Measurement > TRSH1
10	0: Measurement > TRSH1 1: Measurement < TRSH1
11	Output determined by threshold settings. If TRSH1 > TRSH2 1: Measurement > TRSH1 OR Measurement < TRSH2 0: TRSH1 > Measurement > TRSH2 If TRSH2 > TRSH1 1: TRSH1 < Measurement < TRSH2 0: Measurement > TRSH2 OR Measurement < TRSH1

Table 1. Digital Output (DOUT) Threshold Configuration

The Window mode (TRC = 11) can be used to provide a response independent of polarity. For example, the depfault settings of TRC = 11, TRSH1 = 75% (0xC00000), and TRSH2 = 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:

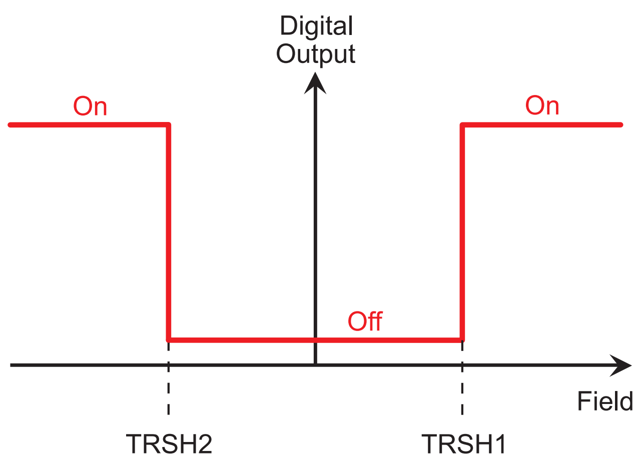

Fig. 2e. Default DOUT configuration (TRC = 11; TRSH1 = 75%; TRSH2 = 25%; for ominpolar DOUT).

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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:

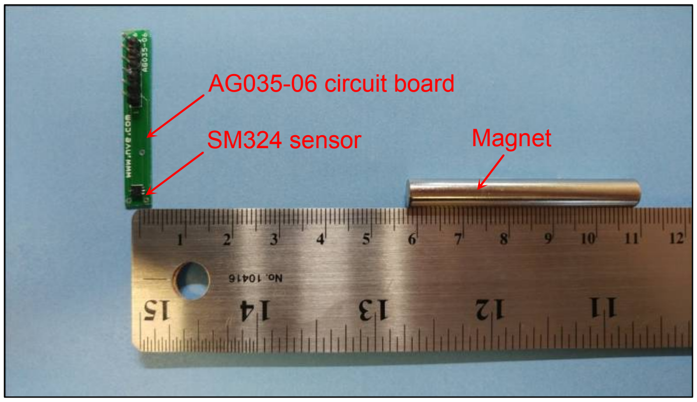

Figure 3. The SM324-10E sensor can be activated by a magnet more than 50 mm away. Maximum sensitivity is in plane with the sensor, with the magnet axis in the pin 2 to pin 5 sensor axis.

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

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

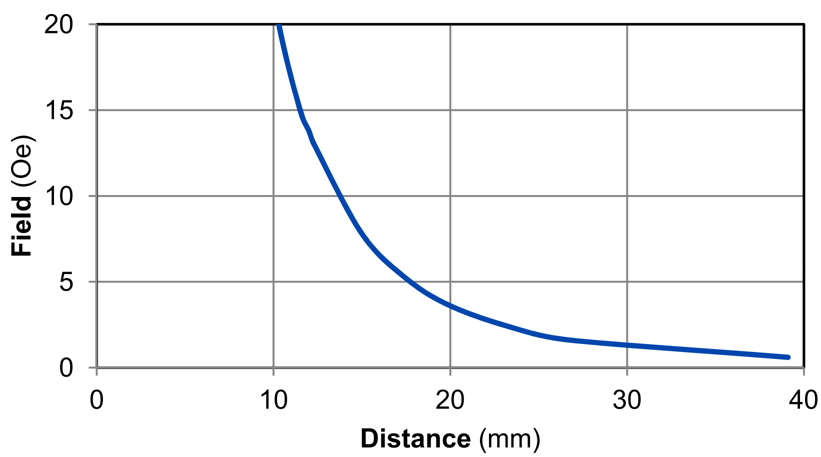

Figure 4. Field vs. distance from the center of the sensor (NVE part number 12216; ferrite magnet; d=6 mm; t=4 mm; C1/Y10T; M_s=B_r=2175 G).

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.

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:

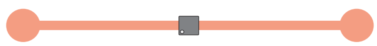

Figure 5a. 0.05" (1.3 mm) trace (0 – 5 A typ.).

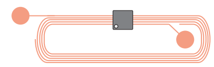

Figure 5b. Five turns of 0.0055" (0.14 mm) trace (0 – 1 A typ.).

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

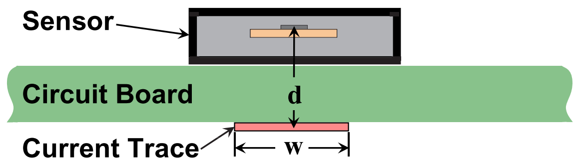

Figure 6. The geometry of current-sensing over a circuit board trace.

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

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Power-Saving Modes

Two operational modes are available with the SM324. A normal mode allows the user to retrieve a single sensor reading via I^2C and return the part to an ultra-low power idle state when communication is complete. A cyclic mode automatically updates the sensor read buffer at programmed interval. The SM324 returns to an idle state between readings. The mode of the sensor is set via an I^2C command (see Table 2 below), and the cyclic interval is programmed using the CINT parameter.

A read can be performed at any time in cyclic mode, and the latest full 24-bit sensor and temperature measurement will be returned. In fact, a read from any memory address in cyclic mode will return the sensor/temp measurement. Reading or writing to memory requires a 0xBF to stop cyclic mode.

The sensor's digital threshold output is updated by single and oversample measure commands in normal mode or on the timed cadence of the cyclic measurements in cyclic mode.

Parameter Value (Binary)	Cyclic Mode 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 2. CINT Parameter values.

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 parameter.
Single Measure	0xAA	24-bit sensor plus 24-bit temperature measurement
Cyclic Measure	0xAB	Cyclic 24-bit sensor plus 24-bit temperature measurement
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 3. SM324 Command Options

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. I²C Data (SDA) and Clock (SCL) are 3.3-volt and five-volt compliant.

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 and should be tied to V_{DD} if not used.

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.

I²C Format

Each command follows the sequence shown below. All I²C read responses start with a status byte followed by the data word. The data word 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	Data [23:16]	A	Data [15:8]	A	Data [7:0]	A	Data [23:16]	A	Data [15:8]	A	Data [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 is 0 if integrity test passed and 1 if the test failed. This bit indicates whether the checksum-based integrity test passed or 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, digital output threshold and configuration parameter, cyclic mode interval, etc. Each register is 16 bits and is written using the scheme described in the I²C interface section. Programmable parameters are listed in Table 4 with default values. The memory address and number of bits for each parameter are also provided.

Parameter	Symbol	Default	Value	Nonvolatile Memory Address (hex)	Bits	Notes
Device Identifiers						
Device ID	$ID_{0\text{-}1}$	$ID_{0\text{-}1}$ = SN		(R) 00-01, (W) 40-41	[15:0]	
User Memory				(R) 20-38, (W) 60-78	[15:0]	
I²C Address	I^2C_{ADD}	0x10	16	0x02	[6:0]	Address changes require power cycle.
Temperature Parameters						
Temperature Offset (LSB)	TEMP	0x0000	0	0x18	[15:0]	Signed. MSB is sign (1=negative), bits 22:0 are magnitude (±50% FS).
Temperature Offset (MSB)		0x00	0	0x19	[15:8]	
Sensor Parameters						
Sensor Offset (LSB)	OFFS	0x00	0	0x17	[15:0]	Signed. MSB is sign (1=negative), bits 22:0 are magnitude (±50% FS).
Sensor Offset (LSB)		0x0000	0	0x19	[7:0]	
Mode Parameters						
Cyclic Interval	CINT	000_{BIN}	0	0x02	[14:12]	
Digital Output Configuration						
Threshold 1 (LSB)	TRSH1	0x0000	10 Oe	0x13	[15:0]	Unsigned (0–100 %FS)
Threshold 1 (MSB)		0xC0		0x15	[7:0]	
Threshold 2 (LSB)	TRSH2	0x0000	−10 Oe	0x14	[15:0]	
Threshold 2 (MSB)		0x40		0x15	[15:8]	
Threshold Configuration	TRC	11_{BIN}	3	0x02	[8:7]	

Table 4. SM324 Programmable Parameters.

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Memory Registers	Memory Address	Factory Default (hex)	Notes
ID0	0x01[15:0]	-	
ID1	0x02 [15:0]	-	
I^2C Address	0x02 [6:0]	0x10	
Threshold Configuration	0x02 [8:7]	11_{BIN}	
Factory	0x02 [11:9]	000_{BIN}	Do not change
Cyclic Interval	0x02 [14:12]	000_{BIN}	
Factory	0x02 [15]	1	Do not change
Factory	0x03-0x12 [15:0]	-	Do not change
Threshold 1 (LSB)	0x13 [15:0]	0x0000	
Threshold 2 (LSB)	0x14 [15:0]	0x0000	
Threshold 1,2 (MSB)	0x15 [15:0]	0x40C0	±10 Oe
Factory	0x16 [15:0]	-	Do not change
Sensor Offset (LSB)	0x17 [15:0]	0x0000	
Thermometer Offset (LSB)	0x18 [15:0]	0x0000	
Sensor, Thermometer Offset (MSB)	0x19 [15:0]	0x0000	

Table 5. Default Memory Register Settings

Supply and Reference Decoupling

V_{DD} should be bypassed with a 1 nF 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:

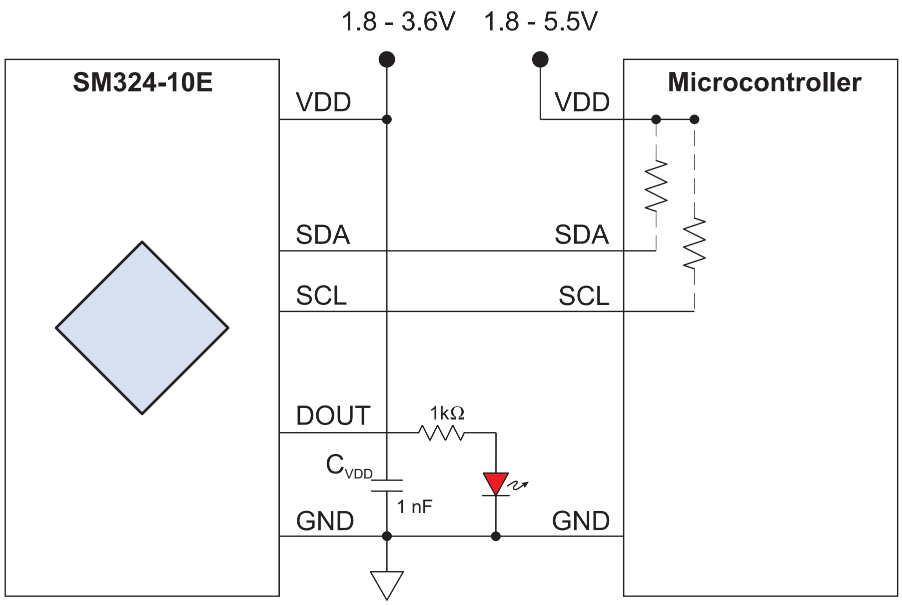

Figure 9. Typical microcontroller interface.

The SM324 is configured as a Slave and the microcontroller should be configured as the Master. The SM324 I^2C 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 supply.

V_{DD} should be bypassed with a 1 nF 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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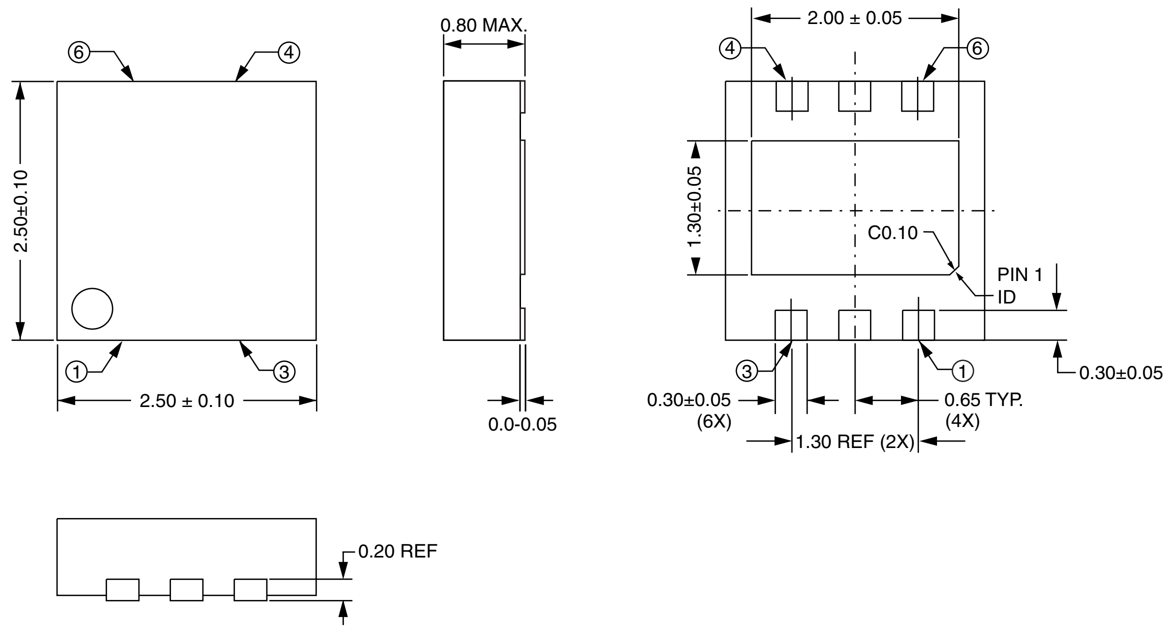
2.5 x 2.5 mm TDFN6 Package (approx. 15x actual size)



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.

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-PRELIM	Change
July 2018	• Initial Release

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