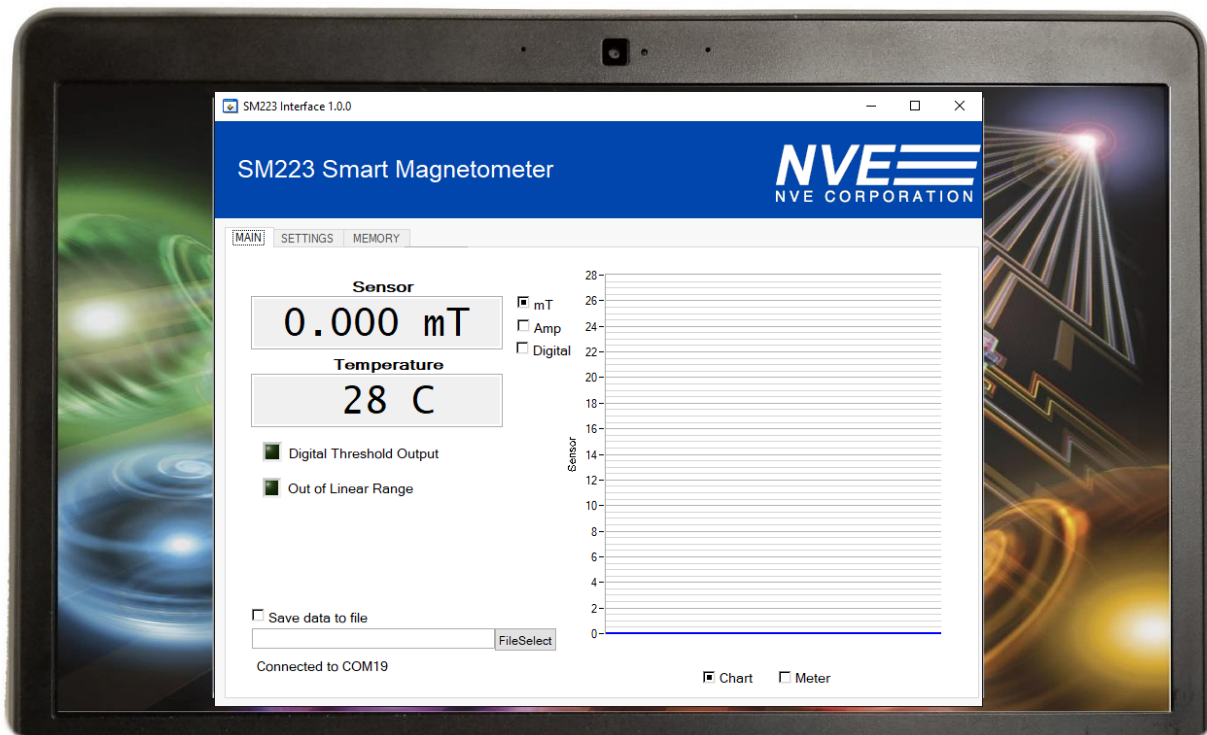


AG973: SM223 TMR Smart I²C Magnetometer Demonstration Board



Summary

The AG973 Demonstration Board provides a sophisticated user interface for the SM223-10E Smart Magnetometer. The demonstration kit includes:

- USB-powered Demonstration Board with:
 - an SM223-10E sensor
 - a microcontroller connected to the sensor via I²C
 - a regulated 3.3 volt supply to power the SM223-10E
 - direct access to sensor pins or jumpers for microcontroller connections
 - current-carrying trace under the sensor for current-sensing evaluation
- A small ceramic magnet for testing as a proximity sensor
- USB cable to connect the Demonstration Board to a computer
- A powerful, intuitive graphical user interface with one-click installation

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1. Overview

SM223-10E Features:

- Tunneling Magnetoresistance (TMR) for precision and low power
- I²C communication interface
- In-plane sensitivity—more usable than Hall effect sensors
- Factory calibrated
- Programmable offset and gain correction
- Internal temperature compensation
- 1.7 to 3.6V supply
- -40°C to 125°C operating range
- Ultraminiature 2.5 x 2.5 x 0.8 mm TDFN6 package

SM223-10E Key Specifications:

- Wide 0 to 1.5 mT linear range
- ±2% of full-scale accuracy from 0 to 125 °C
- ±4% of full-scale accuracy for -40 °C to 125 °C
- Fast 15000 samples per second update rate

2. Quick Start

- 2.1. Run the Setup file from the USB stick if provided, or download from <https://github.com/NveCorporation> to install the User Interface on a Windows PC.
- 2.2. Click on the desktop icon to launch the User Interface application.
- 2.3. The user interface will show the applied field, which can be changed by moving a magnet relative to the sensor:

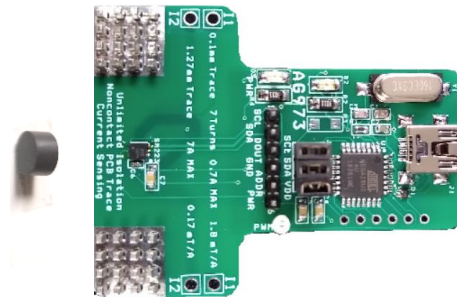


Figure 1. Measuring the field from a magnet with the SM223 Demonstration Board.

3. The Demonstration Board

3.1 Board Layout

The demonstration board interfaces an SM223 Smart Magnetometer via I²C with a host computer via USB:

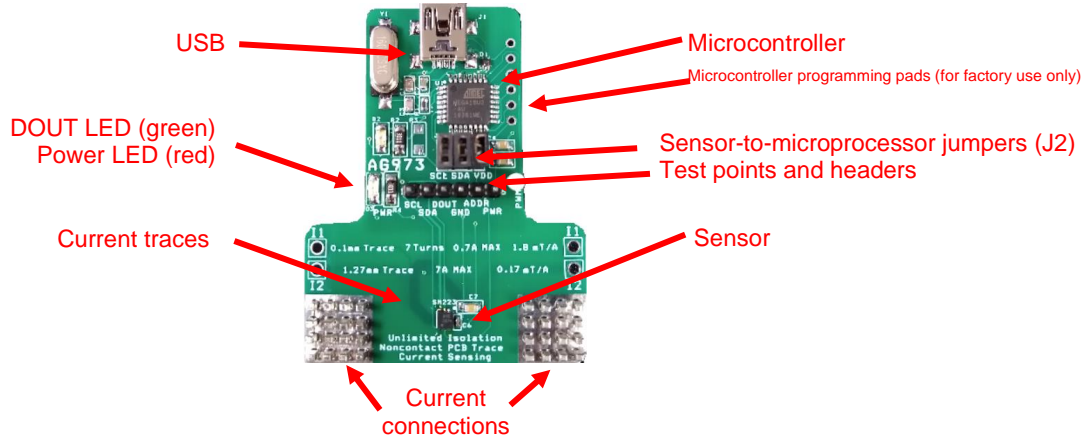


Figure 2. The Demonstration Board (actual size).

3.1.1 J2 Sensor-to-Microprocessor Jumpers

For normal operation, jumpers connect the SM223 Smart Magnetometer to the microcontroller. The jumpers can be removed, however, and the pins used to connect the microcontroller to an external SM223 sensor, or to connect the on-board SM223 to external circuitry:

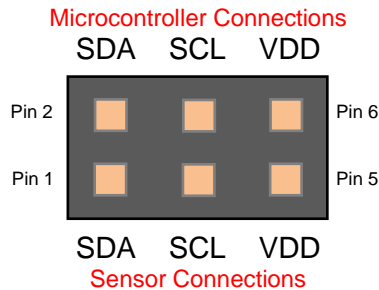


Figure 3. J2 Sensor-to-Microprocessor Jumpers.

3.2 Schematic

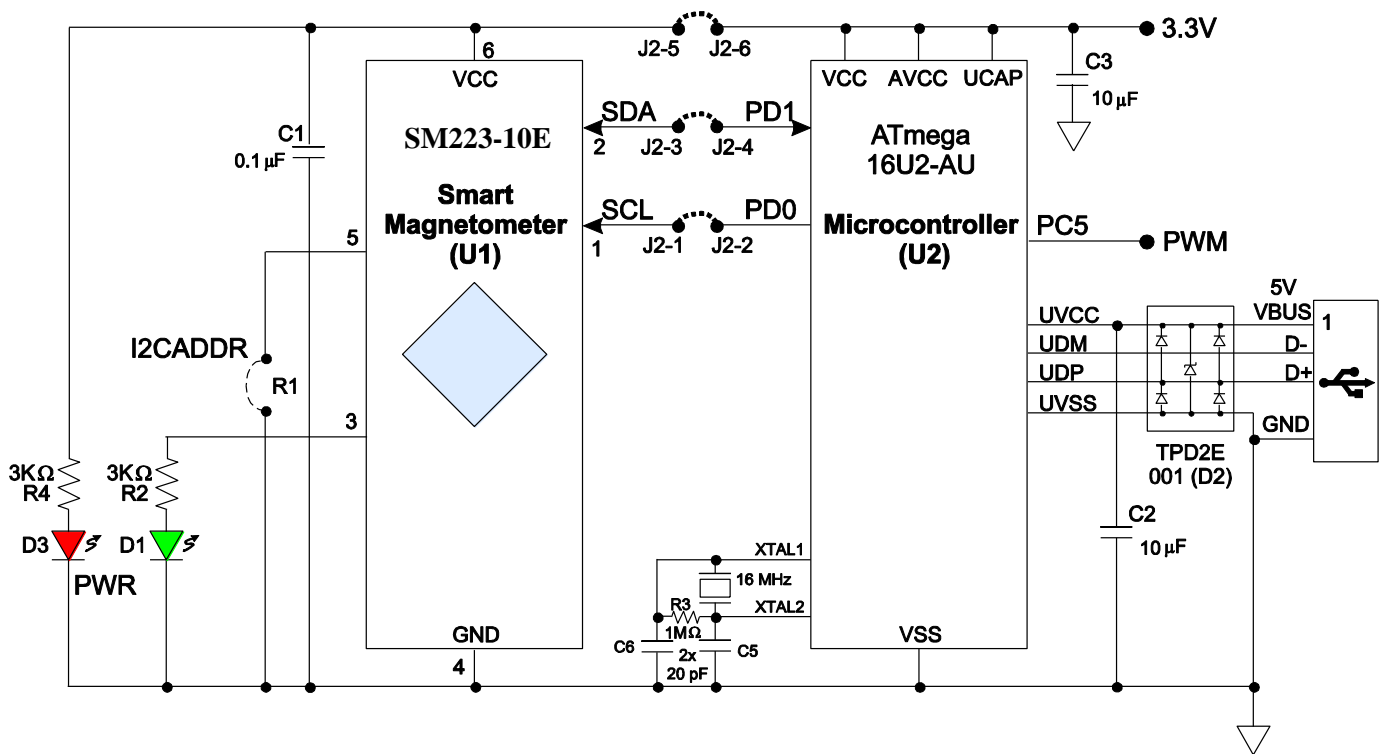


Figure 4. Demonstration Board Schematic.

Manufacturer Part #	Manufacturer (optional)	Reference designators	Quantity per board	Part description/ specs (optional, but recommended)
SM223-10E	NVE	SM223	1	SMART TMR I2C MAGNETOMETER SENSOR, 1.5mT
ATMEGA16U2-AU	Microchip Technology	U1	1	IC MCU 8BIT 16KB FLASH 32TQFP
APT3216LSECK/J3-PRV	Kingbright	D3	1	LED RED CLEAR 1206 SMD
TPD2E001DRLR	Texas Instruments	D1	1	TVS DIODE 5.5V SOT5
APT3216LZGCK	Kingbright	D2	1	LED GREEN CLEAR 1206 SMD
RK73H2ATTD3001F	KOA Speer Electronics, Inc.	R2,R4	2	RES 3K OHM 1% 1/4W 0805
RC0603FR-071ML	Yageo	R1	1	RES 1M OHM 1% 1/10W 0603
		R3	1	
LMK212AB7106MG-T	Taiyo Yuden	C4,C5,C7	3	CAP CER 10UF 10V X7R 125C 0805
885012206046	Würth Elektronik	C2	1	CAP CER 0.1UF 16V X7R 0603
885012205037	Würth Elektronik	C6	1	CAP CER 0.1UF 16V X7R 0402
CL10C200JB8NNNC	Samsung Electro-Mechanics	C1,C3	2	CAP CER 20PF 50V COG/NPO 0603
ECS-160-20-5PX-TR	ECS Inc.	Y1	1	CRYSTAL 16.0000MHZ 20PF SMD
690-005-299-043	EDAC Inc.	J1	1	CONN MINI USB RCPT RATYPE B SMD
PR20203VBDN	METZ CONNECT USA Inc.	J2,J3	2	PIN HEADER, THR, DUAL ROW, .100"
5007	Keystone Electronics	SCL,SDA,DOUT,GND,ADDR,PWR,PWM	7	TEST POINT PC MINI .04"D

3.3 Circuit Description

The Sensor

The SM223 (U1) has six pads: power (VDD and GND), I²C (SCL and SDA), the DOUT digital threshold output, and the I2CADDR pin to set the part's slave address.

Microcontroller

The SM223 is compatible with almost any microcontroller. This board uses a popular ATMEGA16U2 8-bit microcontroller (U2), which has integrated I²C and USB interfaces. The microcontroller also has an internal 3.3-volt regulator that is used to power the board.

LEDs

Red LED D3 shows the sensor is powered, indicating the board is connected to a powered USB port, and that the microcontroller power supply is operating.

I²C

I²C links the sensor and microcontroller. The SM223 is an I²C Slave, and the microcontroller is configured as the Master. The sensor's I²C interface is compatible with 3.3 or five-volt microcontrollers. The evaluation board uses five volts (from the USB port) for the microcontroller and 3.3 volts for the sensor.

Setting the I²C Address

By default, the I2CADDR line is left unconnected (R1 unpopulated) and the default I²C address is then 72 dec (48 hex). Installing a jumper (R1) to ground changes the sensor's I²C to 16 dec (10 hex).

Test Points, Connectors, and Jumpers

Six *Test Points* are provided for each of the six I/O pads. A location for an optional header for each of the six connections is provided adjacent to the test points.

Connector J2 allows normal operation by jumpering the SM223 sensor (U1) to the microcontroller (U2), or without jumpers the Connector can be used to provide direct access to the Sensor (see Figure 3 for details).

PWM Analog Output

A PWM output from the microcontroller tracks the field magnitude measured by the sensor, and can be connected to a multimeter or data acquisition system. The output is scaled to 0.1 volts/oersted (1 V/mT), or 1.5 volts at the full 15 Oe (1.5 mT) linear range. The output is referenced to board ground and ratiometric with the 3.3 V regulated supply. PWM resolution is eight bits over 3.3 volts, or about one part in 100 over the sensor's linear range. The PWM output is generated by the microcontroller, not directly by the sensor. The PWM output cannot go negative.

USB

The microcontroller has an integrated USB UART. A Transient Voltage Suppressor (D2) protects the microcontroller.

Current-Sensing Traces

The board has current traces under the sensor IC (the I_{in} connections) for evaluating the magnetometer as a current sensor. The current traces are:

- 0.1 mm wide, 700mA maximum, 1.4 mT/A

- 1.3 mm wide, 7A maximum, 0.15 mT/A
- 13 mm wide, 50A maximum, 0.046 mT/A

The listed maximum currents are for continuous operation with a safe temperature rise. Higher currents can be used for transient overcurrent detection. The current traces are fully electrically isolated by the FR4 PCB material, since they are on inner or bottom layers. The traces are not rated for safety isolation.

Since the SM223 is bipolar it provides positive and negative outputs and can measure AC current.

Fields generated by clip leads can affect the sensor, so for precise measurements the lead positioning should be fixed, and ideally at right angles to the trace to minimize their effect on the sensor.

LED

Green LED D3 shows when the digital output (DOUT) is activated. A resistor (R2) sets the LED brightness.

Crystal

A crystal (Y1) provides the microcontroller time base as required for the USB interface. The sensor I²C interface operates over an extremely wide clock frequency, so crystal control is not required for the sensor itself.

Decoupling Capacitors

The board has a small (0201 / 0603 metric) 0.1 μ F ceramic capacitor (C1) close to the sensor and a 10 μ F capacitor (C4) a few millimeters away so it does not magnetically interfere with the sensor. The small capacitor is used because it contains very little ferromagnetic material.

There are also decoupling capacitors (C2 and C3) near the microcontroller as recommended by the microcontroller manufacturer.

Operating Temperature

The sensor is rated for the full -40 to 125 °C temperature range, but not all of the board components are rated for the full temperature range. Therefore the board is not recommended for environmental testing. Breakout boards are offered with the sensor and high-temperature bypass capacitors for such testing.

4. Magnets and Magnetic Operation

The Demonstration Kit includes a popular ferrite disk magnet. The magnetic field from the magnet at the center of the sensor is shown in this graph:

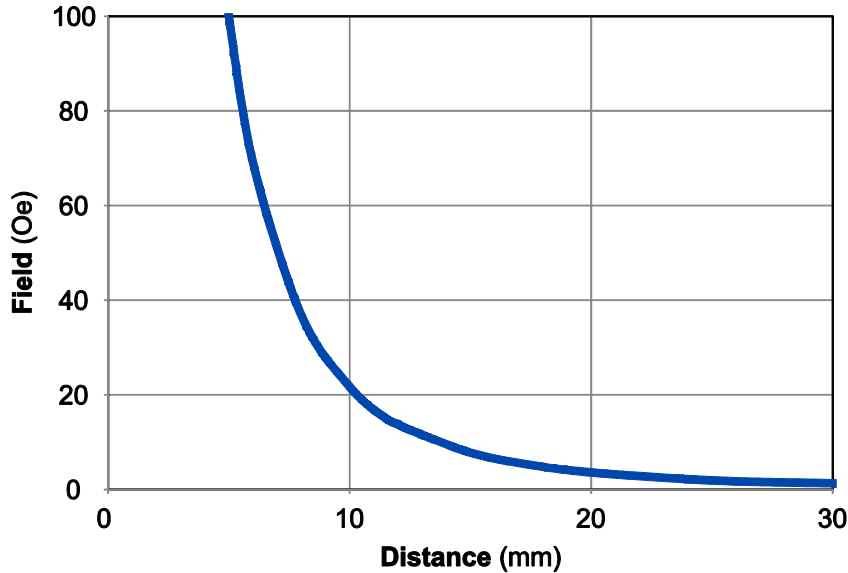


Figure 5. Magnetic field from the 6 mm dia. x 4 mm thick ferrite magnet
(referenced to the center of the sensor).

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.

4.1 Magnetic Thresholds

Typical thresholds for proximity sensing with the magnet included in the kit are shown in the following table:

Magnetic Threshold	Magnet Distance
1.5 mT	14.5 mm
1 mT*	17 mm
0.5 mT	22 mm
0.2 mT	30 mm

*Factory default

Table 1. Typical magnetic thresholds.

5. Current Sensing

SM223-10E sensors can measure the current through a circuit board trace by detecting the magnetic field generated by the current through the trace. In this application, the digital output can be used for current threshold detection or overcurrent protection. The demonstration board includes three current-sensing traces:

- Current 1: 0.1mm trace, seven turns, 700 mA max, first inner layer from top
- Current 2: 1.27mm trace, 7A max, second inner layer from top
- Current 3: 10.7mm trace, 50A max, bottom layer

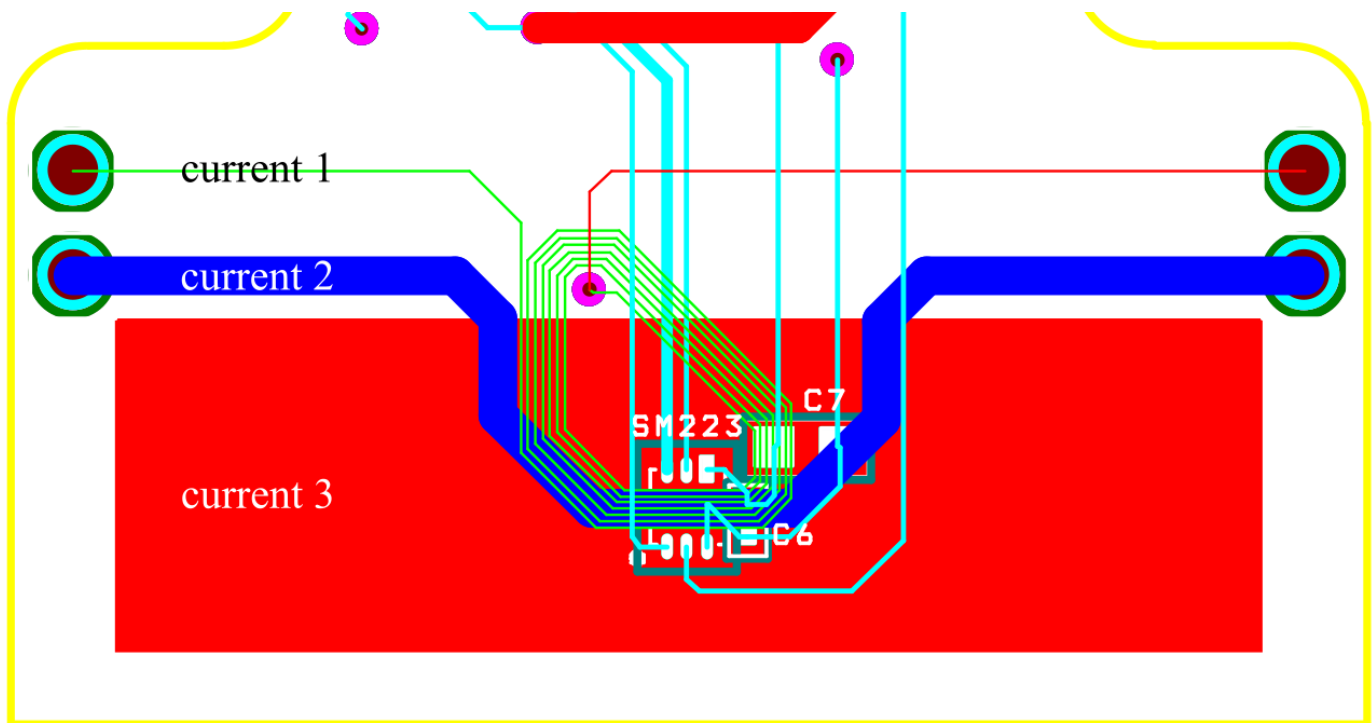


Figure 6. Current traces (top view).

The magnetic field generated can be approximated by Ampere’s law:

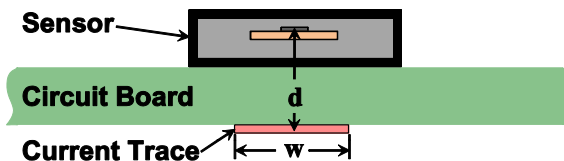


Figure 7. Current-sensing over a circuit board trace (side view)

$$H = \frac{0.4 \cdot I \cdot \arctan \left[\frac{w}{2d} \right]}{w}$$

[“H” in mT, “I” in amps, and “d” in millimeters]

The distance “d” can be determined from the circuit board stackup and the position of the sensor elements in the SM223 package. In practice, circuit board thickness tolerances up to $\pm 10\%$ force this approximate calculation to be checked experimentally and calibrated. The AG973 circuit board is nominally 0.8 mm thick, and the sensor elements are nominally 0.55mm from the sensor package bottom.

For example, the trace on the bottom of the circuit board, “d” is the distance from the bottom of the sensor package to the sensor element, which is $0.8 + 0.55$ millimeters, and “w” is 10.7 millimeters. The field is therefore approximately 0.05 mT/A. Magnetic material placed near the current trace or sensor (including permanent circuit board components) and variations in circuit board thickness will influence this parameter, so end-of-line calibration is typically required for high accuracy.

6. User Interface Software Installation

6.1 System Requirements

The software system requirements are:

- 64-bit Windows 7 or later
- A USB 2.0 port

6.2 Software Installation

6.2.1. Run the Setup file on the USB stick if provided to begin the installation, or download the file from <https://github.com/NveCorporation>.

6.2.2. Run the Setup file to install the User Interface and USB driver.

6.2.3. Click on the desktop shortcut to run the software.

6.2.3. Connect the demo board to a USB port.

7. User Interface Operation

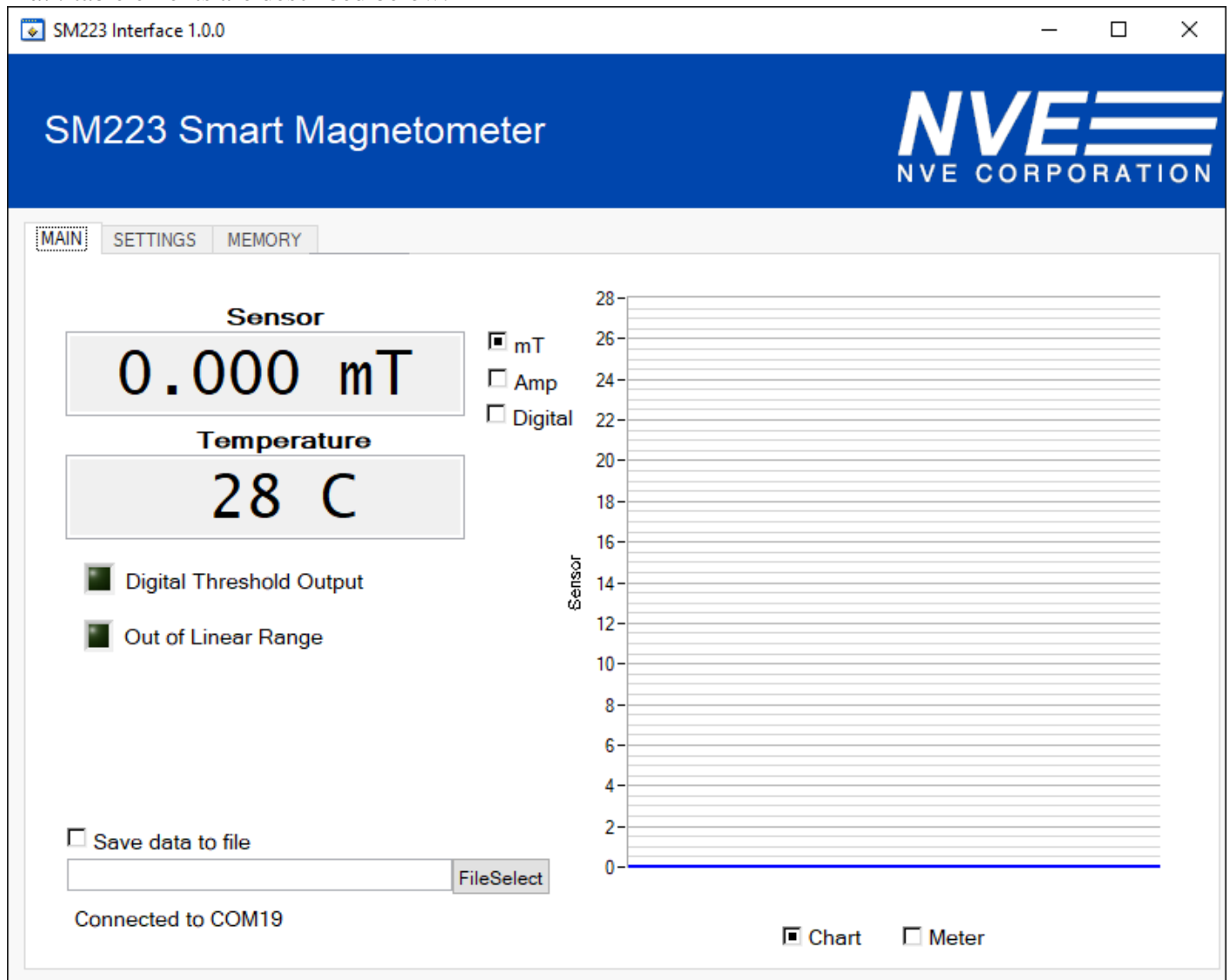
The User Interface allows reading sensor data, setting the digital output threshold parameters, and reading and writing the nonvolatile sensor parameters and calibration constants.

After starting the application, a single window with three tabbed panels is displayed. The three tabs are:

1. Main – Displays measurement results in digital and graphical formats.
2. Settings – Sets the digital output threshold, hysteresis, offset, and digital filter constant. Parameters are changed by entering a number and hitting “Enter.” This tab also allows changing between omnipolar, unipolar, and bipolar digital outputs by selecting either the desired image or the corresponding radio button.
3. Memory – A table shows the sensor’s data, parameters, and calibration constants. Data and parameters are displayed in real time, and can be changed by entering the desired value in the write address.

7.1. Main Tab

Main tab elements are described below:



Sensor – Displays the output of the device in mT, amps, or the sensor’s integer digital output as selected by the radio buttons. Double right-clicking the display changes oersted or amps precision.

Temperature – Displays the calibrated temperature from the sensor in degrees Celsius. The sensor’s maximum operating temperature is 125°C.

Digital Threshold Output – Shows the state of the sensor’s DOUT output. The DOUT threshold, hysteresis, and configuration can be set in the Settings Tab.

Out of Linear Range – Warns that the sensor field exceeds its linear range, so the reading may be inaccurate.

Chart – Displays a “strip chart” on right side of the tab with the measurement on the y-axis. The chart is updated approximately 10 times per second.

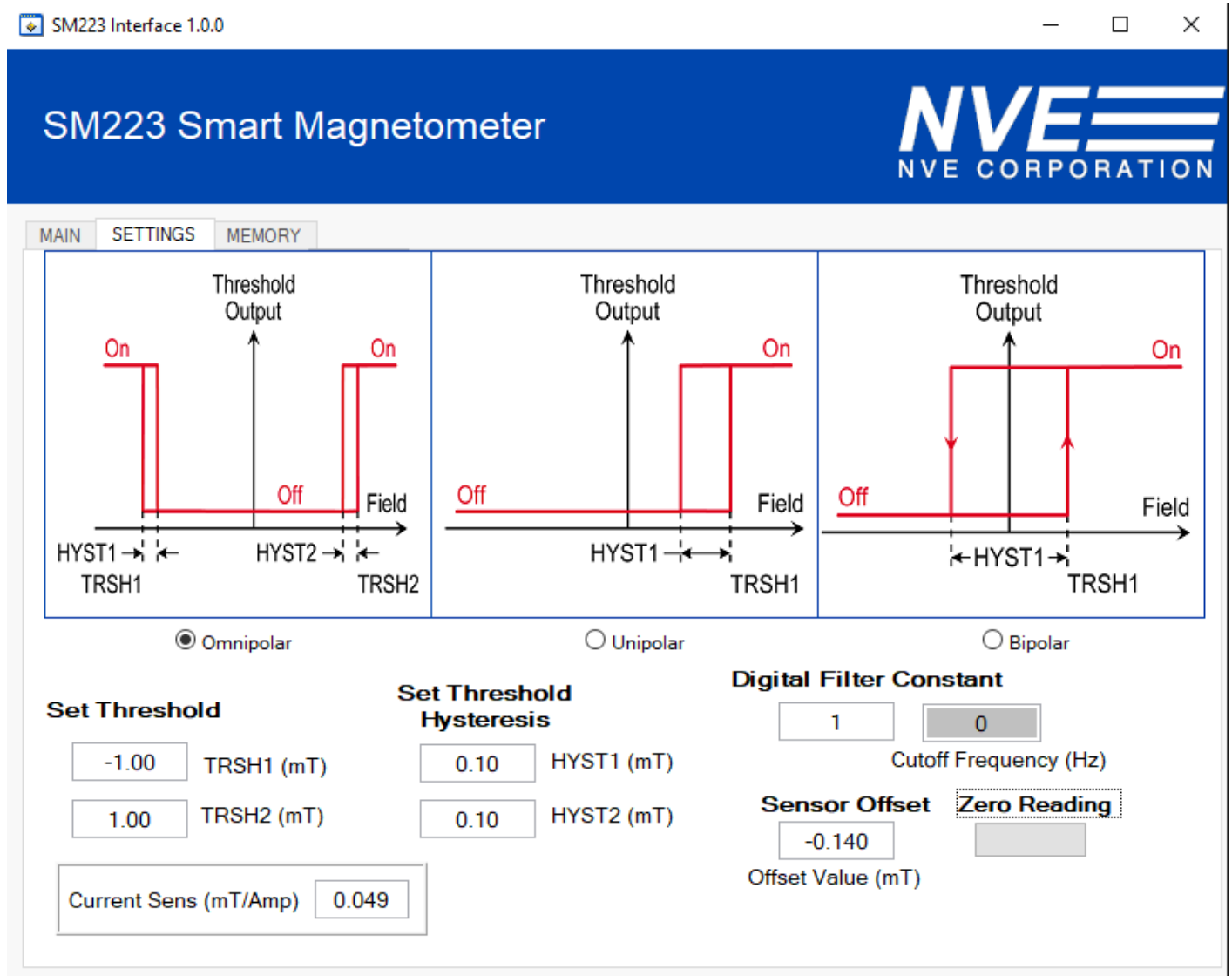
Meter – Displays a virtual meter on the right side of the tab.

Save Data to File – Checking this box saves data points (date, time stamp, elapsed time, temperature, and sensor field or current output) to a file chosen under the *File Select* button. The box can be checked and unchecked while the demo is running. Data are updated every 100 milliseconds when the box is checked.

File Select – Opens a pop-up window to select a csv format data file. Data are continuously added to the file whenever the “Save data to file” box is checked.

7.2. Settings Tab

The Settings Tab allows setting parameters for the Digital Threshold Output, the Current Sensing Sensitivity, and the Digital Filter Constant. Parameters can be entered into the appropriate boxes.



Omnipolar (the default configuration) – The output turns on when the magnitude of a field of either polarity exceeds the threshold. The field can be. Uses both THRS and both HYST parameters.

Unipolar –The output turns on when one pole is applied, and turns off when the field is reduced or reversed. Only requires THRS1 and HYST1; $HYST1 < |THRS1|$.

Bipolar – The output will turn on when the field exceeds the threshold and off with the opposite field. Only requires THRS1 and HYST1; $HYST1 > |THRS1|$.

Sensor Offset –Sets the sensor offset, which can be used to zero background magnetic fields.

Set Threshold – Sets the sensor’s digital output (DOUT) turn-on threshold.

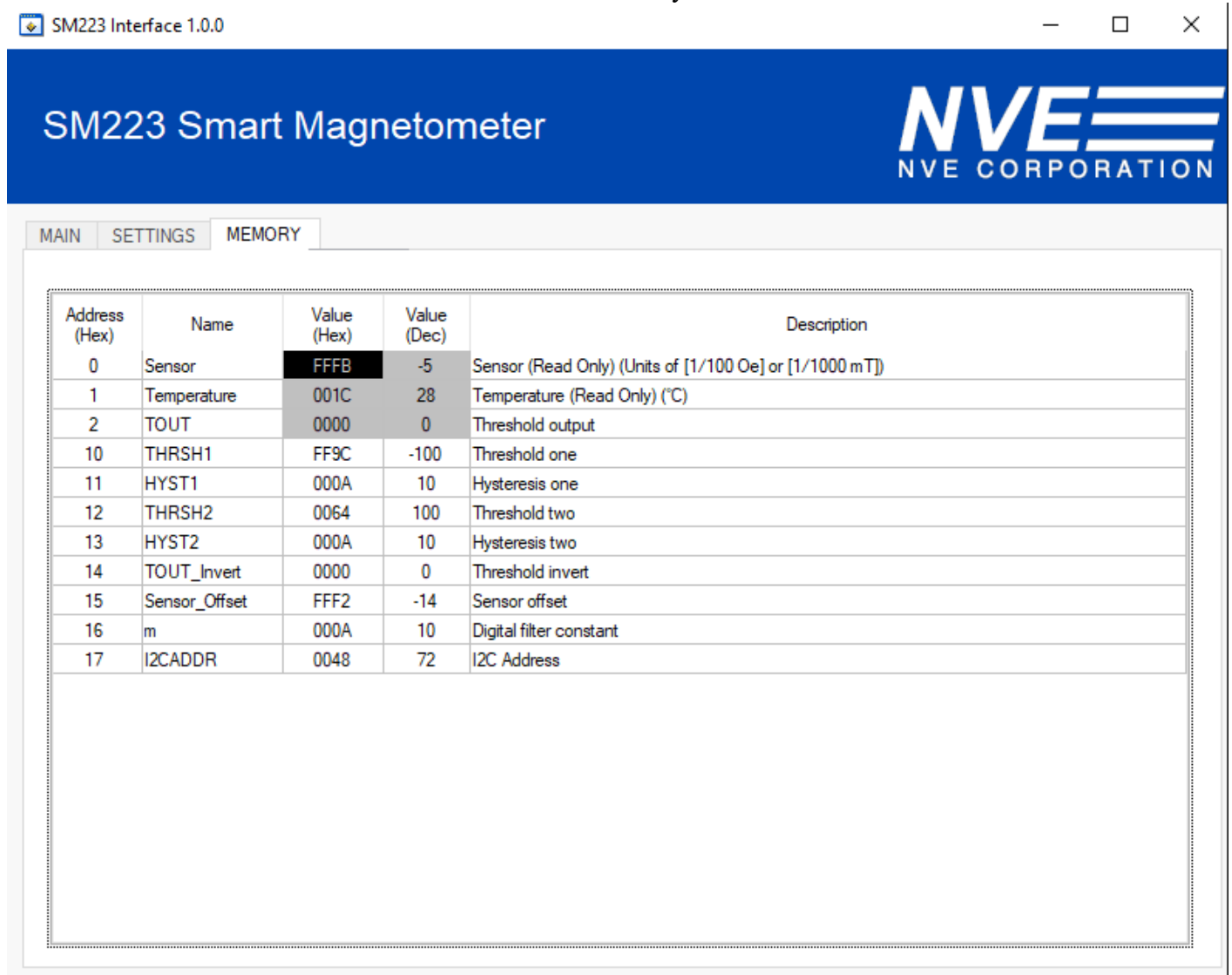
Set Threshold Hysteresis – Used to change the magnetic threshold differential in the sensor’s nonvolatile memory. The digital output will turn off at *Threshold – Hysteresis*.

Digital Filter Constant – Sets the filter constant which will change the cutoff frequency of the internal filter. The cutoff frequency will be updated and displayed to the right. The range is 1 to 127 (dec). The factory-default sensor constant is “1,” which disables the filter.

Factory Reset – Sets the calibration constants back to the factory defaults.

7.3. Memory Tab

This tab allows direct access to the sensor's internal memory:



Address (Hex)	Name	Value (Hex)	Value (Dec)	Description
0	Sensor	FFFB	-5	Sensor (Read Only) (Units of [1/100 Oe] or [1/1000 mT])
1	Temperature	001C	28	Temperature (Read Only) (°C)
2	TOUT	0000	0	Threshold output
10	THRSH1	FF9C	-100	Threshold one
11	HYST1	000A	10	Hysteresis one
12	THRSH2	0064	100	Threshold two
13	HYST2	000A	10	Hysteresis two
14	TOUT_Invert	0000	0	Threshold invert
15	Sensor_Offset	FFF2	-14	Sensor offset
16	m	000A	10	Digital filter constant
17	I2CADDR	0048	72	I2C Address

Data are written to and read from different addresses. Addresses 0 to 16 hex are read addresses, while addresses 30 to 36 hex are write addresses. For example the Sensor Offset is written to address 35 hex and read from address 15 hex.

Data in the Read Addresses are updated continuously as the software is running, and reflect changes made in the write address table or the Settings Tab. Write address table values may not always reflect the actual values in the sensor, however, since they are not written until a value is entered and committed with the enter key.

Data and parameters are all two-byte signed integers, although the allowable range of values is different for different parameters. Note that calibration constants are set at the factory and vary from part to part.

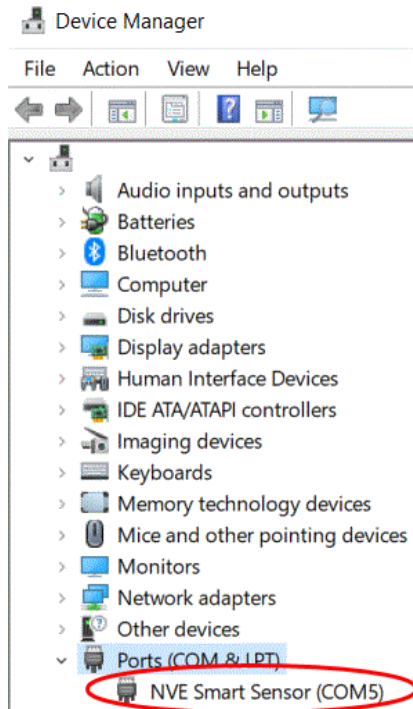
8. Troubleshooting

No communication with the Sensor

1. Ensure there are jumpers on each J2 pin pair.

No communications with the computer

1. Check the USB cable.
2. Verify the USB port under Windows Device Manager:



3. Reinstall the software.

9. Revision History

SB-00-151-A

April 2022

Change

- Initial Release

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