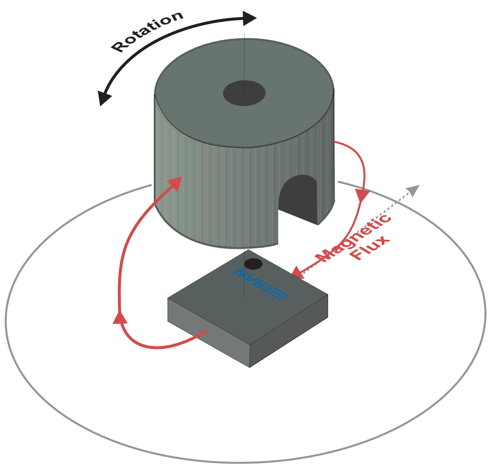
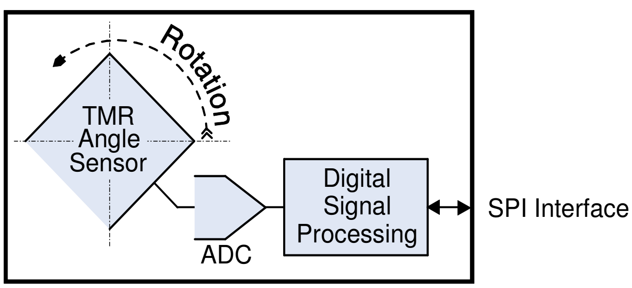
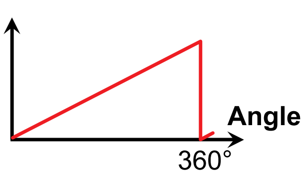
# ASR002 Smart TMR Angle Sensor




## Block Diagram




## Transfer Function




## Features

- Measures rotational speeds to 375,000 RPM
- 3.3 volt or 5 volt compatible four-wire SPI interface
- Robust airgap and misalignment tolerances
- Factory calibrated
- Ultraminiature 2.5 x 2.5x 0.8 mm TDFN package

## Key Specifications

- 0.1° resolution
- ±0.2° repeatability
- Robust 60 to 200 Oe magnetic field operating range
- Fast 12.5 kSps sample rate
- Flexible 2.2 to 3.6 V supply range
- Low 4 mA typical supply current
- Full −40°C to +125°C operating range

## Applications

- Rotary encoders
- Automotive applications
- Motor control
- Internet of Things (IoT) end nodes

## Description

ASR002 TMR Smart Angle Sensors provide a precise digital angle measurement over a wide range of speeds.

The sensor combines precise, low-power Tunneling Magnetoresistance (TMR) sensing elements with sophisticated digital signal processing.

The sensor is factory calibrated, with coefficients stored in internal memory.

A four-wire SPI interface provides angle data and allows setting device parameters.

The ASR002 is designed for harsh industrial or automotive environments with ESD protection, and full −40°C to +125°C operating temperature range.



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## 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 |



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## 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 | 6 | 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 | $T_{STA}$ | | 1 | | ms | |
| **Magnetics** | | | | | | |
| Applied magnetic field strength | H | 60 | | 200 | Oe | |
| **Accuracy and Repeatability** | | | | | | |
| Angular resolution | δ | | 0.1 | | Angular Degrees | |
| Angular hysteresis | ⎎ | | | 0.1 | | |
| Repeatability | | | ±0.2 | | | Fixed temperature and bias[1] |
| Angular accuracy, fixed bias[1] | ε | | | ±2<br>±3 | | 0 to 85°C<br>–40 to 125°C |
| Angular accuracy, variable bias[2] | | | | ±6<br>±6 | | 25°C<br>–40 to 125°C |
| **Speed** | | | | | | |
| Sample rate | | | 12.5 | | kSps | |
| **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 | Mbits/s | Full duplex |
| SCLK Rise time | $t_R$ | | | | ns | See figure 7 |
| 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 4 |
| Data read time | $t_{READ}$ | | | 20 | µs | |
| **Nonvolatile Memory Characteristics** | | | | | | |
| Address setup time | $t_{ADDR}$ | | | 3 | µs | See figure 5 |
| Data read time | $t_{READ}$ | | | 10 | µs | |
| Data write time | $t_{NVM}$ | | | 20 | ms | |
| Endurance | | | 10000 | | Cycles | |
| **Package Thermal Characteristics** | | | | | | |
| Junction-to-ambient thermal resistance | $\theta_{JA}$ | | 320 | | °C/W | |
| Package power dissipation | | | 500 | | mW | |

**Specification Notes:**

1. "Fixed Bias" means a fixed airgap within between the bias magnet and sensor so the magnitude of the magnetic field at the sensor is constant within the specified field range of the parts. The highest accuracy is obtained using fields closest to factory calibration.
2. "Variable Bias" means the magnitude of the magnetic field at the sensor can vary across the entire specification range.

## ASR002Overview

The ASR002 is a non-contact angle sensor designed for high speed applications where size is limited. The heart of the ASR002 is a tunneling magnetoresistive (TMR) sensor. In a typical configuration, an external magnet provides a magnetic field of 30 to 200 Oe in the plane of the sensor, as illustrated below for a bar magnet and a radially-magnetized disk magnet. Factory-programmed signal conditioning is combined with a temperature sensor and digital linearization to produce high speed, accuracy, and precision in a tiny 2.5 x 2.5 mm TDFN package.

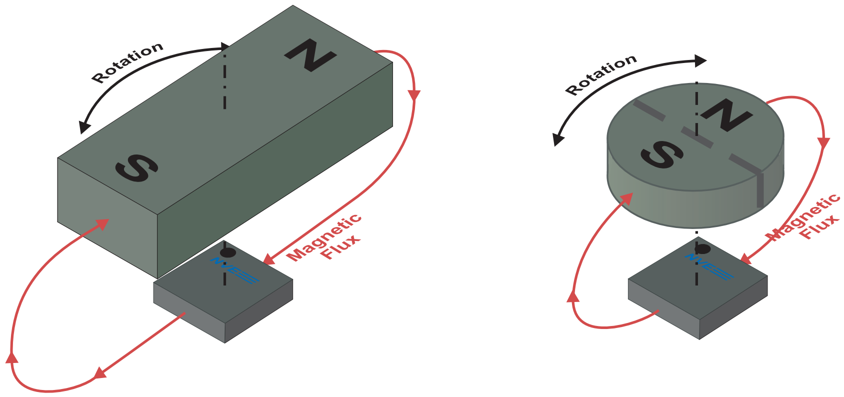


**Figure 1. Sensor operation.**

## ASR002Operation

A detailed block diagram is shown below:

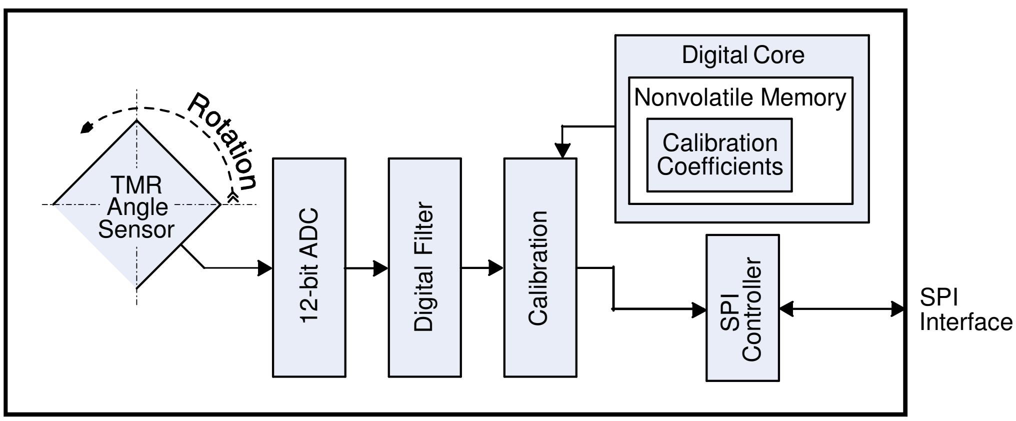


**Figure 2. Detailed block diagram.**

### *TMR Angle Sensor Element*

ASR002 sensors use unique TMR sensor elements that are inherently high speed and low noise. The digital core calculates the angle from sensor element Sine and Cosine vectors, and the raw sensor data are available from separate memory locations.

### *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 factory default is the filter turned off.

***Rotation Direction***
The ASR002 can provide increasing angle values for either clockwise or counterclockwise field rotations. Counterclockwise is defined as a rotating field vector through pins 1-3-4-6, and clockwise through pins 1-6-4-3. The rotation direction can be programmed using the $\theta_{DIR}$ parameter.

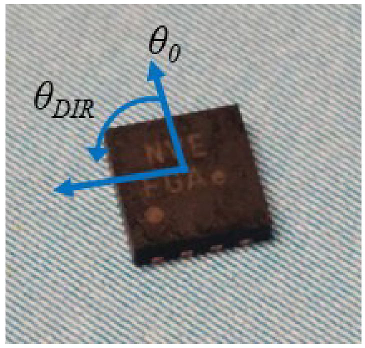


**Figure 3. Zero-angle reference ($\theta_0$) and rotation direction ($\theta_{DIR}$).The rotational center of the sensor is the package center.**

***Zero-Angle Reference Point***
A programmable parameter $\theta_0$ sets the zero-degree reference or angular offset. This is the angle of "discontinuity," that is, where the angle output changes from 360° to 0°. The default $\theta_0$ value is zero for magnetic fields pointing from pin 1 to pin 6.

***Direction and Hysteresis***
The Direction output indicates direction of rotation. A hysteresis setting can be changed to prevent small changes from causing the Direction output to "chatter," especially at low speed.

***Digital Filter***
The digital filter is an Infinite impulse response (IIR) weighted running average filter, which can reduce mechanical and electrical noise depending on the required speed.

The filtered output is calculated as follows:

$$\theta_n = \theta/m + [(m-1)/m]\theta_{n-1}$$

Where $\theta$ = is the measured angle; $\theta_n$ = the filtered angle; $\theta_{n-1}$ is the previous value of the filtered angle; and *m* is a constant that determines the cutoff frequency as follows:

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

Where $f_{CUTOFF}$ is the filter cutoff frequency and $f_{SAMPLE}$ is the sensor ADC sampling rate (approximately 12500/s). So for example, if $m = 10$, the cutoff frequency is approximately 200 Hz.

$m = 1$ disables filter so the output is simply updated with each sample.

## A Simple SPI Interface

The SPI interface is an industry standard full-duplex 2.5 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 digital angle is the default two byte response.

The ASR002 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:


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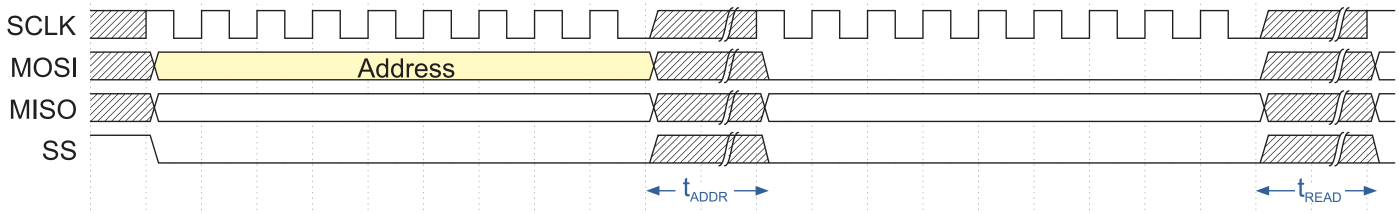


Figure 4a. Sending the address for a read.

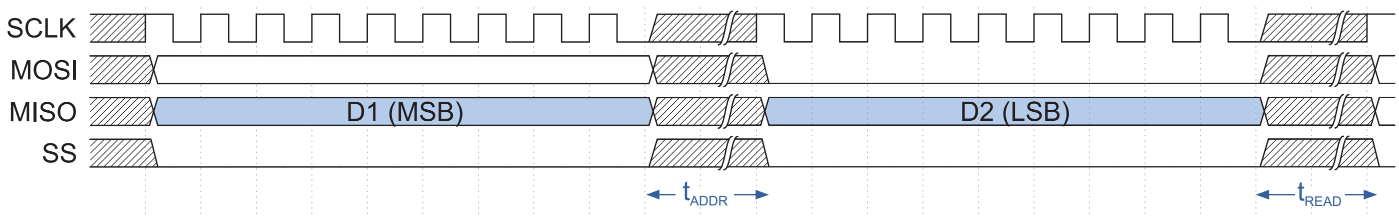


Figure 4b. Reading data.

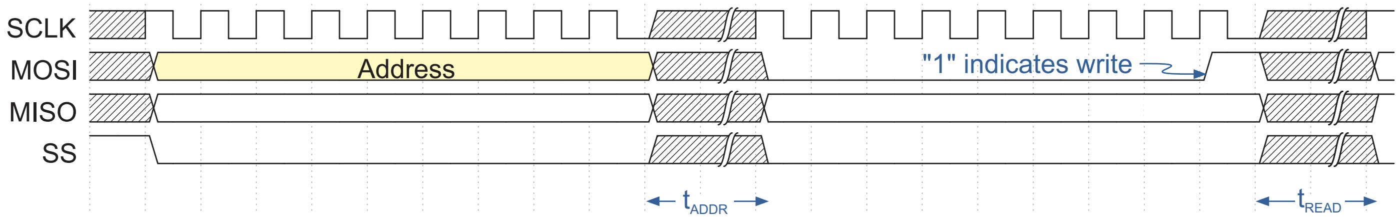


Figure 5a. Sending the address for a write.

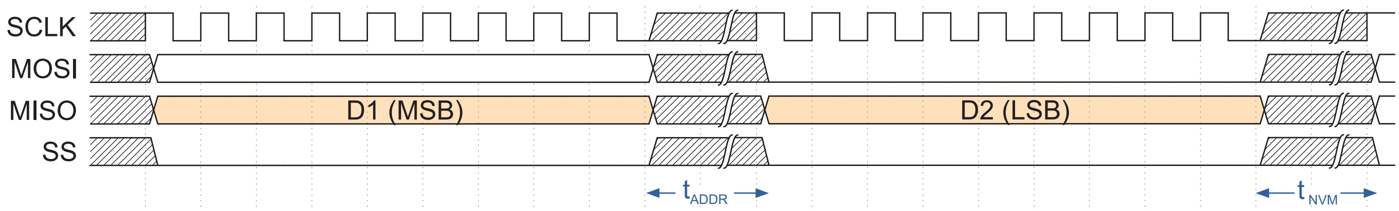


Figure 5b. Writing data.

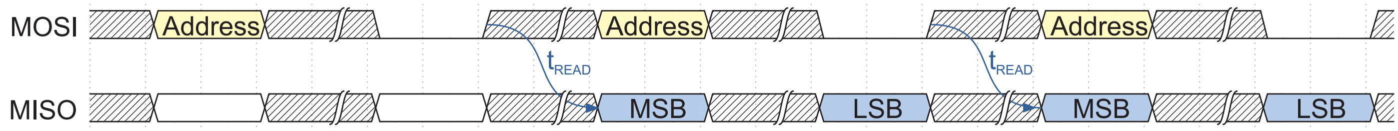


Figure 6. Continuous read.



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

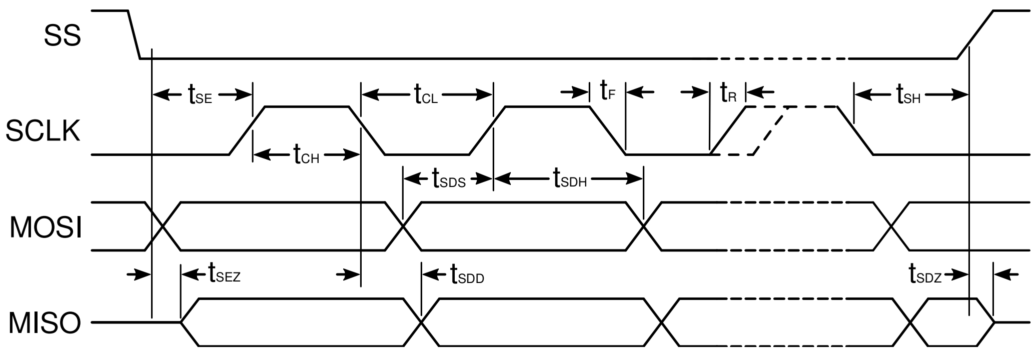


**Figure 7. SPI setup and hold timing.**

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

## Unique Architecture

The ASR002 uses a unique "Von Neumann" architecture where all data and parameters are written and read from memory. This eliminates the need for explicit commands. In addition, all data and coefficients are two byte, which dramatically simplifies firmware, streamlines system development, and allows high-speed communication over a simple two-wire I²C interface.

## Straightforward Reading and Writing

All reads and writes are initiated by the master pulling the SS "LOW" and sending an eight-bit address to the ASR002 plus a second byte. The least significant bit of the second address byte indicates whether the address request is for a read or a write ("0" is a read; "1" is a write). The slave responds with two bytes of data.

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

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

## Memory Map

The ASR002 memory provides access to angle data and user-programmable parameters. The memory is accessed via SPI as described in the SPI interface section.

| Parameter | Symbol | Default | Read/ Write | Range | Address | Description |
|---|---|---|---|---|---|---|
| **Data** | | | | | | |
| Angle | θ | N/A | R | 0 – 3600 | 0x00 | In tenths of a degree |
| Raw Sin Vector | Sinθ | | | Approx. 1500 – 2500 | 0x01 | Raw outputs centered at approx. 2048 with peak-peak amplitudes of approx. 1000. |
| Raw Cos Vector | Cosθ | | | | 0x02 | |
| Direction | Dir | | | 0 – 1 | 0x03 | 0 = decreasing angle<br>1 = increasing angle |
| **User-Programmable Parameters** | | | | | | |
| Rotation Direction | $\theta_{DIR}$ | 0 | R/W | 0 – 1 | 0x40 [bit 0] | 0 ➔ increasing CCW;<br>1 ➔ increasing CW<br>(see Fig. 3) |
| Angular Offset | $\theta_0$ | 0 | | 0 – 3600 | 0x41 [bits 13:0] | Point at which angle is zero (see Fig. 3) |
| Digital Filter Constant | m | 0 | | 1 – 255 | 0x42 | $f_{CUTOFF} = f_{SAMPLE}/(2\pi\ m)$;<br>$f_{SAMPLE}$ = approx. 12.5 kSps<br>m = 1 disables filter |
| Direction Hysteresis | $\delta_{DIR}$ | 25 | | 0 – 255 (0 – 25.5°) | 0x43 | Hysteresis of the "Dir" output; in tenths of a degree |
| **Read-Only Memory** | | | | | | |
| Lot code | | | R | | 0x80 – 0x85 | Date code in ASCII; right-most character in address 80; left-most in address 85; format YYWWXX, where<br>YY = year;<br>WW = work week;<br>XX =internal code. |

**Table 1. ASR002 Memory Locations.**



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## Power-Up and Initialization

***Absolute position***
Unlike some encoder types, ASR002 sensors detect absolute position and maintain position information when the power is removed. The sensor powers up indicating the correct position.

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

## Supply Decoupling

$V_{DD}$ should be bypassed with a 0.1μF capacitor (preferably nonmagnetic), placed as close as possible to the sensor pads. Inadequate bypassing can cause noise or anomalous device behavior.



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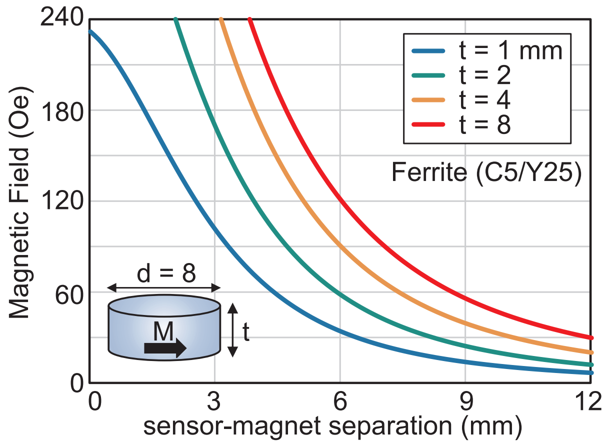
## Magnet Selection

The sensor operates with as little as a 30 Oe magnetic field, and is accurate up to 200 Oe. This wide magnetic field range allows inexpensive magnets and operation over a wide range of magnet spacing. Larger or stronger magnets require more distance to avoid oversaturating the sensor; smaller or weaker magnets may require closer spacing. Low-cost, diametrically-magnetized ferrite disk magnets can be used with these sensors. Bar magnets can also be used in some configurations. This allows greater flexibility with mechanical construction and miniaturization of the system. The figures below show the magnetic field for various magnet geometries and different distances between the sensor and an inexpensive C5/Y25 grade ferrite magnet.



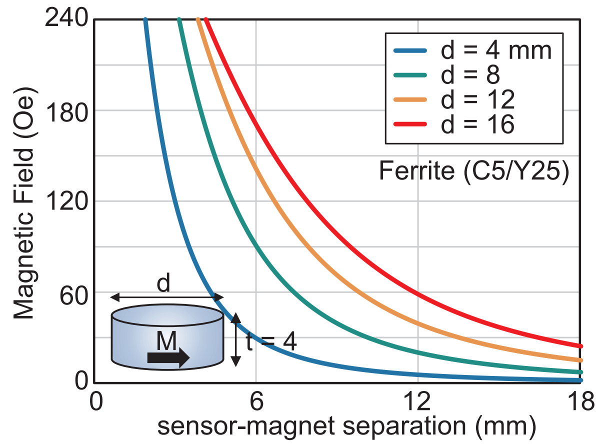




**Figure 8. Magnetic fields for various geometries of C5/Y25 ferrite magnets plotted for the distance between the magnet and sensor. Magnets with 8 mm diameter and various thicknesses are shown at left. Four millimeter magnets of various diameters are shown at right.**

Smaller magnets produce larger field gradients as shown in Fig. 8. Variations in magnetic field over the operating position of the sensor can reduce accuracy. Maximizing the magnet size within the mechanical constraints of the system is recommended for highest accuracy.

Trial ferrite magnets are available with NVE's demonstration kits. Other materials and geometries are available to suit high-temperature applications or even larger magnet-sensor separations. Contact NVE customer support for recommendations on magnet material. NVE's Online Store also stocks compatible magnets.

The graph below shows how magnet size can be reduced by using alternative magnet materials:

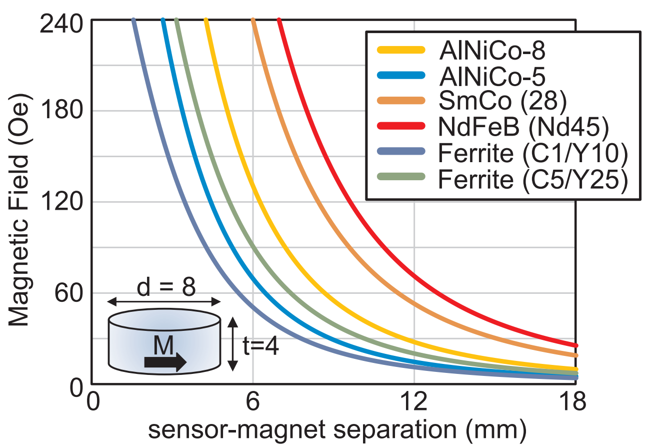



**Figure 9. Magnetic fields from an 8 millimeter diameter, 4 millimeter thick magnet for increasing magnet-sensor separation. NdFeB materials produce the largest magnetic fields and separations. SmCo and AlNiCo materials offer the highest operating temperatures. Ferrite magnets are the most cost-effective.**



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## Application Circuits

***Typical Microcontrollers Interface***

A typical microcontroller interface is shown below:

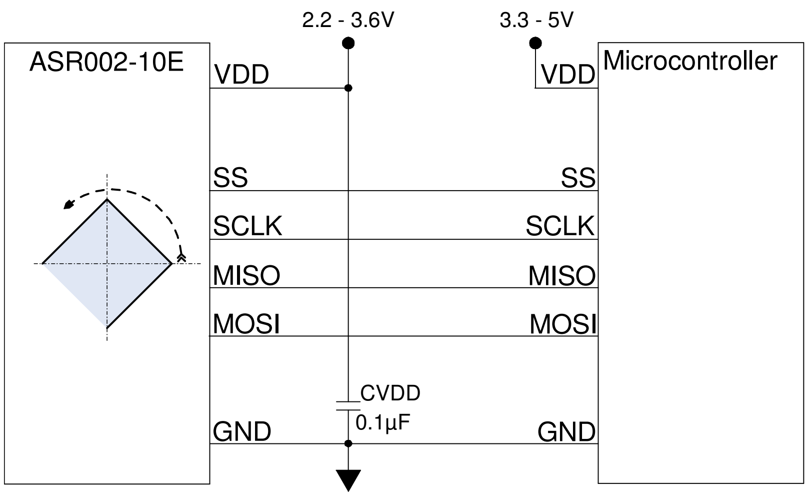


**Figure 10. Typical microcontroller interface.**

The ASR002 is configured as a Slave and the microcontroller should be configured as the Master. The ASR002 SPI interface is compatible with 3.3 or five-volt microcontrollers.

***Daisy Chaining Multiple Sensors with Isolated Microcontroller***
Multiple ASR002's can be configured on the same data and select bus. The configuration below shows three sensors connector to a microcontroller master through a single IL717E isolated data coupler. This mode of selection works with factory-default sensors without having to reset addresses for different sensors and provides isolation with a minimal number of components.

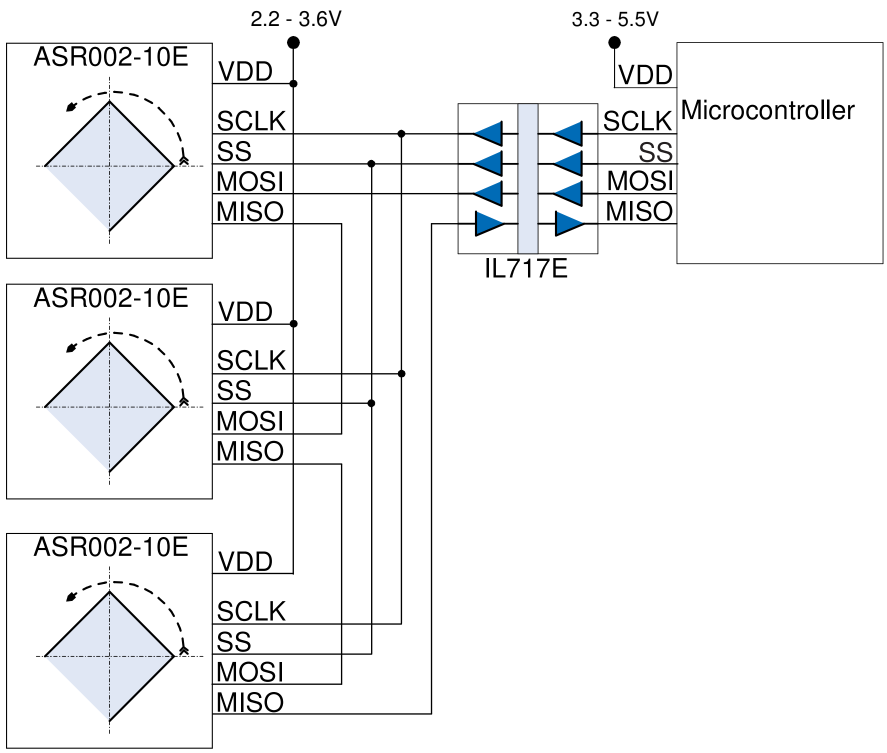


**Figure 11. Daisy-chaining multiple sensors with an isolated microcontroller.**


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**Typical Read and Write Communications Pseudocode**

```
//SPI clock set elsewhere (2.5 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=buffer[1];                   //Sends the address to read from
while(! (SPSR & (1<<SPIF)));      //Waits for transmission
_delay_us(3);                     //Allow 3 microseconds between address bytes

SPDR=0x00;                        //'0' for second address byte (indicates read)
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=buffer[1];                   //Puts the address to read from in the buffer
while(! (SPSR & (1<<SPIF)));      //Wait for transmission to be complete
_delay_us(3);                     //Allow address byte to be sent

SPDR=0x01;                        //'1' for second address byte (write bit)
while(! (SPSR & (1<<SPIF)));      //Wait for transmission to complete
_delay_us(10);                    //Allows time for data 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;
      }
```



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## Illustrative Arduino Code for Continuous Read

```
/*****************************************************************************
Continuously read the angle from an NVE ASR002 Smart Angle Sensor
Arduino Uno connections: pin 10=SS; pin 11=MOSI; pin 12=MISO; pin 13=SCLK
*****************************************************************************/

#include <SPI.h>
int angle;

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

//Set clock rate at 2.5 MHz; MSB first, and Mode 0
SPI.beginTransaction(SPISettings(2500000, MSBFIRST, SPI_MODE0));
digitalWrite(10, LOW); //Enable sensor
}

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



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## Evaluation Kit

**Smart Angle Sensor Evaluation Kit**

This simple board includes anASR002-10E Smart Angle Sensor, a microcontroller that interfaces to the Sensor via SPI, and to a PC via USB. The kit includes a diametrical magnet and fixturing. A PC-based user interface provides two-way communication with the sensor to display the sensor outputs and change the sensor’s parameters.

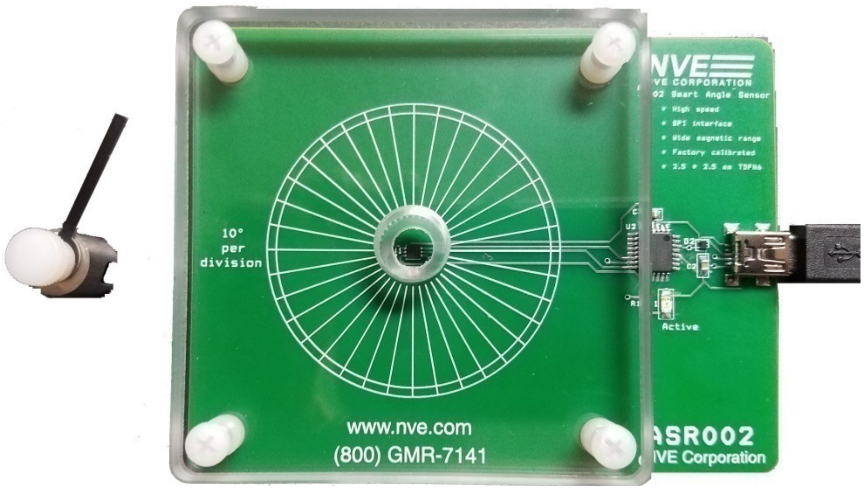


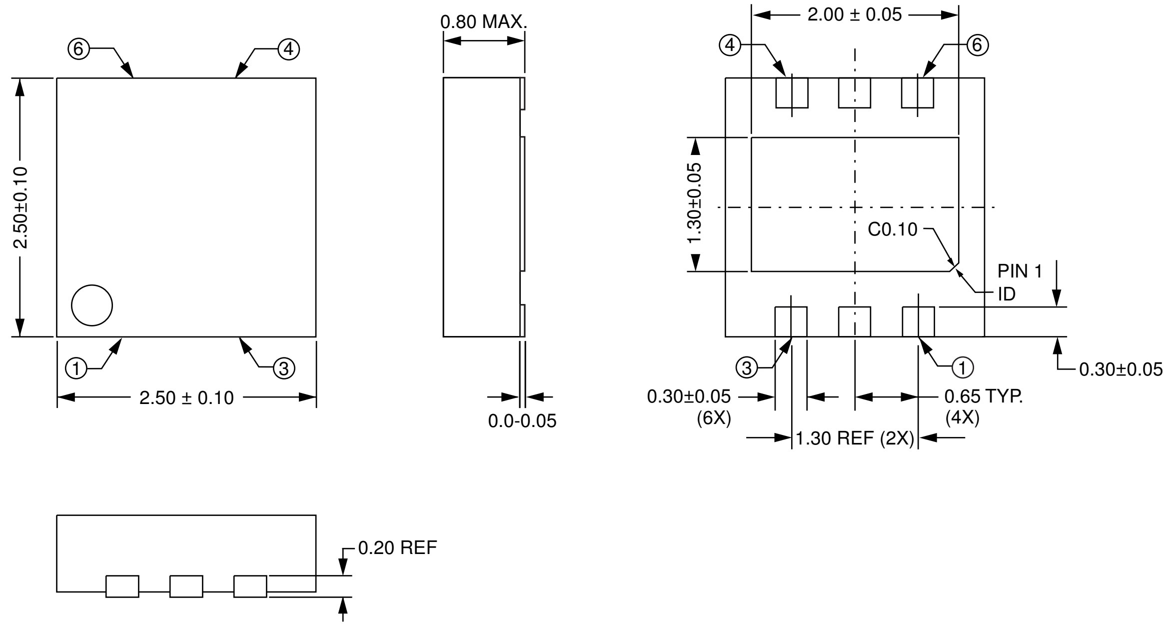

**Figure 12. AG954-07E: Smart Angle Sensor Evaluation Kit.**

**Bare Circuit Board**

The AG035-06 bare circuit board provides easy connections to TDFN6 devices such as the ASR002-10E:


**Figure 13. AG035-06 bare circuit board**
1.57" x 0.25" (40mm x 6 mm) TDFN6
(actual size).

## 2.5 x 2.5 mm TDFN6 Package




| Pad | Symbol | Description |
|---|---|---|
| 1 | GND | Ground/$V_{SS}$ |
| 2 | SCLK | SPI Clock Input |
| 3 | MISO | Sensor SPI Data Output |
| 4 | VDD | Power Supply (bypass with a 0.1µF capacitor) |
| 5 | MOSI | Sensor SPI Data Input |
| 6 | SS | Sensor Select Input (low to select) |

RoHS COMPLIANT

**Notes:**
- Dimensions in inches (millimeters).
- Soldering profile per JEDEC J-STD-020C, MSL 1.

## Ordering Information

# ASR002 - 10E TR13

**Product Family**
ASR = Smart Angle Sensors

**Base Part Number**
002 = High speed, medium accuracy

**Field Range Identifier**
Blank = General Purpose (60 to 200 Oe)

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

**Bulk Packaging**
TR13 = 13" Tape and Reel Package



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## Revision History

**SB-00-081-B**
Jan. 2019

**Change**
- Added typical communications pseudocode.
- Typographic and cosmetic changes.

**SB-00-081-A**
Jan. 2019

**Change**
- Expanded and updated SPI timing specifications.
- Added detailed SPI timing diagrams.
- Tightened typ. supply current specification to 4 mA.
- Revised minimum operating field to 60 Oe.
- Added sensor direction output and hysteresis parameter.
- Added raw Sin and Cos vector outputs.
- Added illustrative microcontroller code.
- Finalized pinout.
- Added evaluation kit and board.
- Dropped customer calibration capability (unnecessary).
- Various typographic corrections.
- “Rev. A” release.

**SB-00-081-PRELIM**
Oct. 2018

**Change**
- Preliminary release.



NVE Corporation 11409 Valley View Road, Eden Prairie, MN 55344-3617 Phone: (952) 829-9217 Fax: (952) 829-9189 www.nve.com 

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An ISO 9001 Certified Company

NVE Corporation
11409 Valley View Road
Eden Prairie, MN 55344-3617 USA
Telephone: (952) 829-9217
www.nve.com
e-mail: sensor-info@nve.com



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