NVE CORPORATION

ASR002 Smart TMR Angle Sensor

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 TDFN6 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.

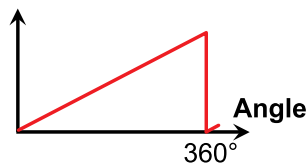The sensor is factory calibrated, with coefficients stored in internal memory.

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.

Block Diagram
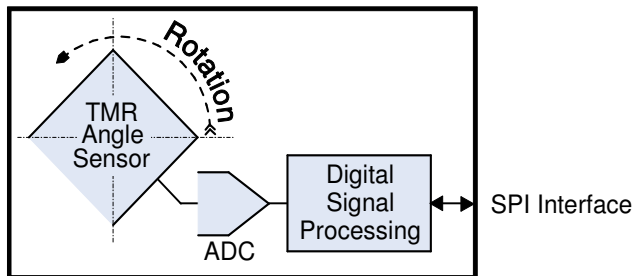
Transfer Function

Boundary Ratings

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

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

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Operating temperature	T_{min}; T_{max}	−40		125	°C	
Supply voltage	V_{DD}	2.2		3.6	V	
Supply current	I_{DD}		4	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 hysteresis	ʃ			0.1		
Repeatability			±0.2		Angular Degrees	Fixed temperature and bias[1]
Angular accuracy, fixed bias[1]	ε			±2 ±3		0 to 85°C −40 to 125°C
Angular accuracy, variable bias[2]				±6 ±6		25°C −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	Mbits/s	Full duplex
SCLK Rise time	t_R				ns	
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	See figure 7
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}			3	μs	See figure 4
Data read time	t_{READ}			10	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	θ_{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.

ASR002 Overview

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.
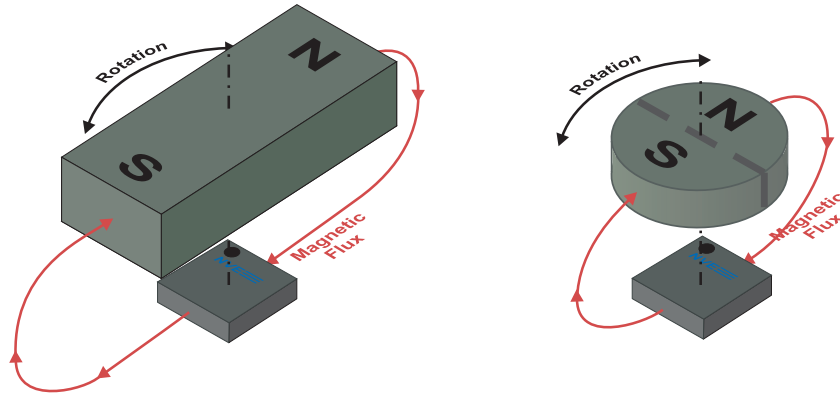
Figure 1. Sensor operation.

ASR002 Operation
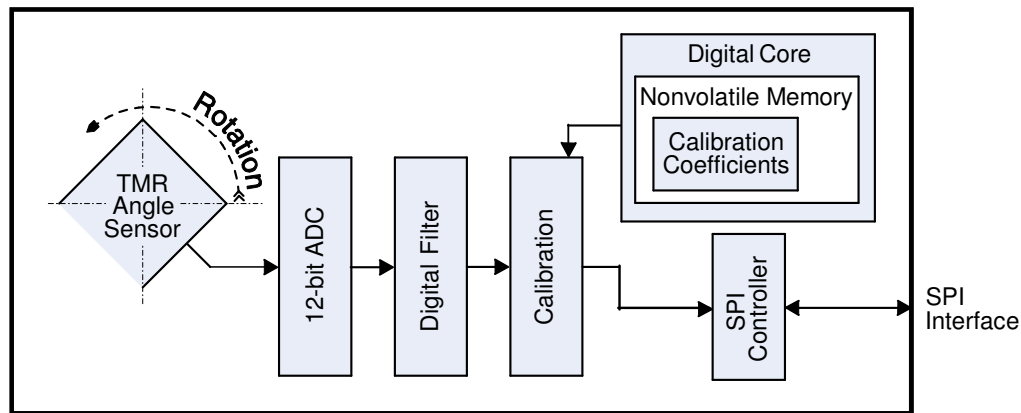
A detailed block diagram is shown below:

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 θ_{DIR} parameter.

Figure 3. Zero-angle reference (θ_0) and rotation direction (θ_{DIR}).The rotational center of the sensor is the package center.

Zero-Angle Reference Point

A programmable parameter θ_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 θ_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:

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

Where θ = is the measured angle; θ_n = the filtered angle; $\theta_{n\text{-}1}$ 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 four-wire, full-duplex 2 megabit per second connection with the sensor as the slave to an external master such as a microcontroller. SPI data (MOSI and MISO) and the Clock (SCLK) are 2.2 volt to five-volt compliant. The 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:
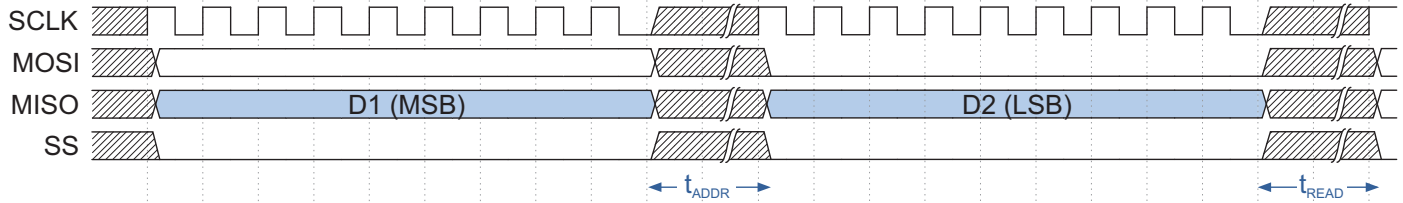
Figure 4a. Sending the address for a read.
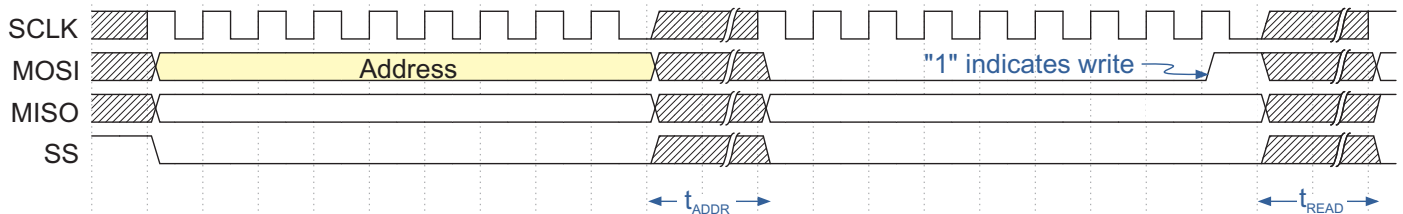

Figure 4b. Reading data.

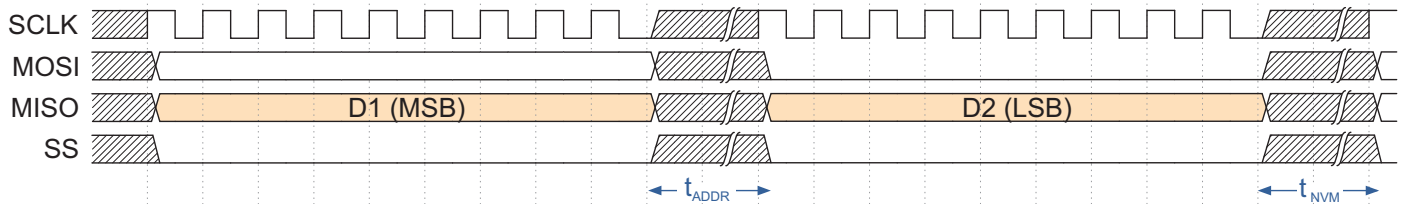**Figure 5a. Sending the address for a write.**

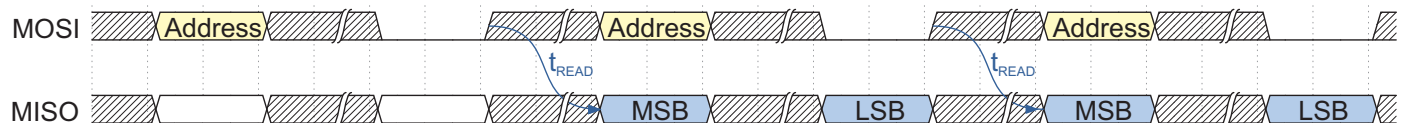**Figure 5b. Writing data.**

Figure 6. Continuous read.

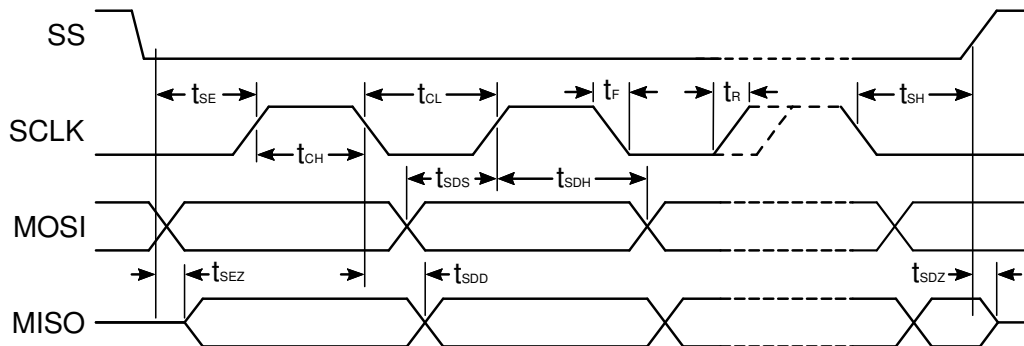SPI setup and hold timing constraints are shown in Figure 7:

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.

Straightforward Reading and Writing

The sensor is reset on a falling edge of SS. All reads and writes are initiated by the master pulling 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 four-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			0 – 3600	0x00	In tenths of a degree
Raw Sin Vector	$\text{Sin}\theta$			Approx. 1500 – 2500	0x01	Raw outputs centered at approx. 2048 with peak-peak amplitudes of approx. 1000.
Raw Cos Vector	$\text{Cos}\theta$	N/A	R		0x02	
Direction	Dir			0 – 1	0x03	0 = decreasing angle 1 = increasing angle
User-Programmable Parameters						
Rotation Direction	θ_{DIR}	0		0 – 1	0x40 [bit 0]	0 ➜ increasing CCW; 1 ➜ increasing CW (see Fig. 3)
Angular Offset	θ_0	0	R/W	0 – 3600	0x41 [bits 13:0]	Point at which angle is zero (see Fig. 3)
Digital Filter Constant	m	0		1 – 255	0x42	$f_{CUTOFF} = f_{SAMPLE}/(2\pi\,m)$; f_{SAMPLE} = approx. 12.5 kSps m = 1 disables filter
Direction Hysteresis	δ_{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 YY = year; WW = work week; XX = internal code.

Table 1. ASR002 Memory Locations.

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.

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.
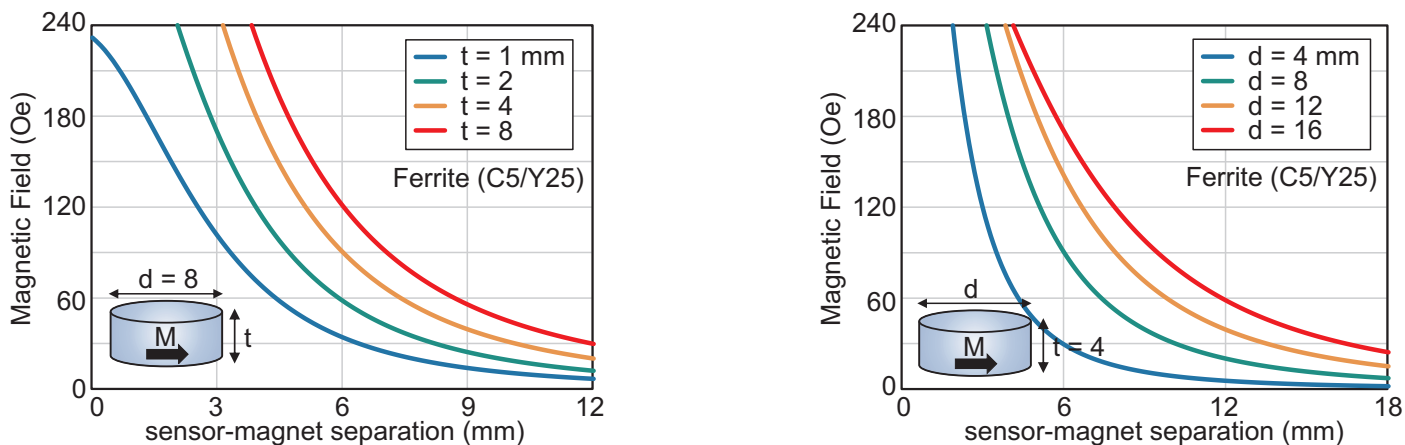

Figure 8. Magnetic fields for various geometries of C5/Y25 ferrite magnets plotted for the distance between the magnet and sensor. Magnets with 8 mm diameter and various thicknesses are shown at left. Four millimeter magnets of various diameters are shown at right.

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:
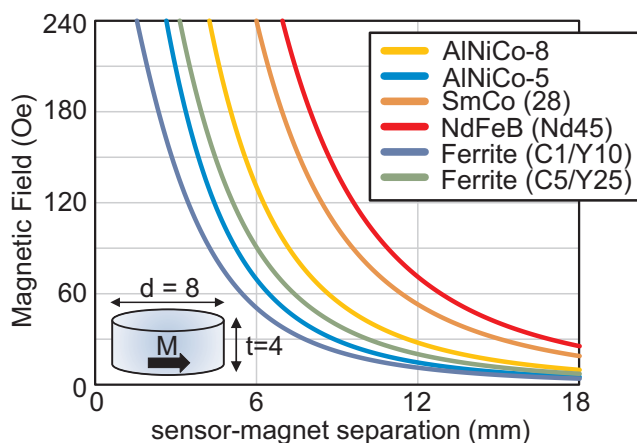

Figure 9. Magnetic fields from an 8 millimeter diameter, 4 millimeter thick magnet for increasing magnet-sensor separation. NdFeB materials produce the largest magnetic fields and separations. SmCo and AlNiCo materials offer the highest operating temperatures. Ferrite magnets are the most cost-effective.

Application Circuits

Typical Microcontrollers Interface
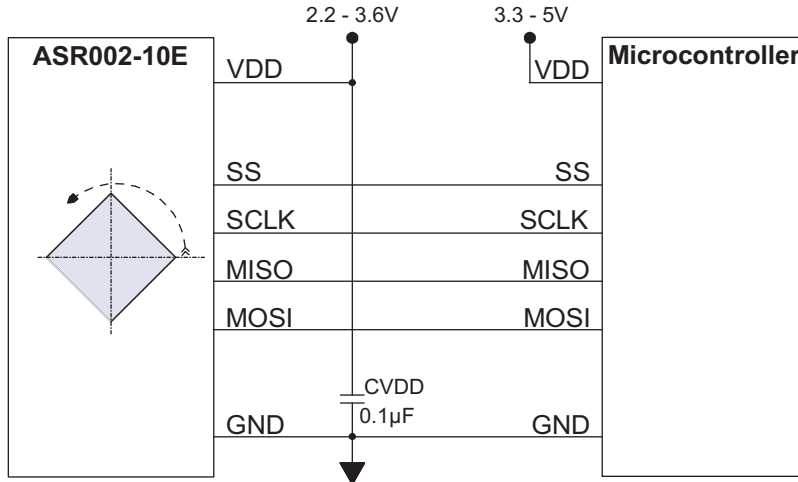A typical microcontroller interface is shown below:

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.

Typical Read and Write Communications Pseudocode

```
//SPI clock set elsewhere (2 MHz max.)
//SPSR = SPI Status Register; SPIF = SPI Status Register Interrupt flag
//SS set low (active) elsewhere
        {
        case COMM_GET_MEM:          //Routine to READ memory
SPDR=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;
        }
```

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 Mbits/s; MSB first; Mode 0
SPI.beginTransaction(SPISettings(2000000, MSBFIRST, SPI_MODE0));
digitalWrite(CS, HIGH); //Disable to reset the sensor
digitalWrite(10, LOW); //Re-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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Illustrative Arduino Code to Zero the Sensor

```
/******************************************************************************
Zeros an ASR002 at its current location to establish a "home position."
Arduino Uno connections: pin 11=MOSI; pin 12=MISO; pin 13=SCLK; pins 9 & 10=SS
Includes a simple procedure to read the angle.
******************************************************************************/
#include <SPI.h>
int angle;

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

//Set clock rate to 2 Mbits/s; MSB first; Mode 0
SPI.beginTransaction(SPISettings(2000000, MSBFIRST, SPI_MODE0));
digitalWrite(10, HIGH); //Disable to reset the sensor
digitalWrite(10, LOW); //Re-enable sensor

//Read starting angle
SPI.transfer (0); //Send 0 for address angle to read starting angle
delayMicroseconds (3); //Allow 3 us between address bytes
angle = (SPI.transfer (0x41))<<8; Read starting angle MSB and point to offset address
delayMicroseconds (3); //Allow 3 us between address bytes
angle |= SPI.transfer (1); //Read angle LSB; 2nd address byte = 1 for write
delayMicroseconds (10); //Allow 10 us for next data

//Reset offset
SPI.transfer (0); //Write offset MSB
delayMicroseconds (3); //Allow time between bytes
SPI.transfer (0); //Write offset LSB
delay (20); //20 ms NVM delay

//Write measured angle to offset parameter to zero the sensor
angle=getAngle(); //Read angle now that offset has been set to zero
SPI.transfer (0x41); //Point to offset address
delayMicroseconds (3); //Allow time between address bytes
SPI.transfer (1); //2nd address byte = 1 for write
delayMicroseconds (10);
SPI.transfer (0x41); //Write to offset parameter to zero the sensor
delayMicroseconds (3);
SPI.transfer (angle & 0xFF); //Write LSB
delay (20); //20 ms NVM delay
}

void loop() {}

//Procedure to read the angle
int getAngle(){
int angle;
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
return angle;
}
```

In Case of Difficulty

Random data, or measured angles outside the allowable 0 to 3600 range.
- The SPI clock may be too fast (the ASR002 maximum clock rate is specified as 2 Mbits/s).
- Ensure the Master is operating in the correct mode (Mode 0).

Random data, or measured angles outside the allowable 0 to 3600 range on the first readings after the sensor is selected.
- The sensor is reset on a falling edge of SS. Toggling SS HIGH, then LOW will ensure the sensor is reset.

MSB/LSB bytes are reversed.
- The MSB should be read first. SPI devices use different byte orders, but the ASR002 follows the most common convention of MSB first.

Angle data is shifted by one or more bits.
- This is usually because the sensor has not completed internal shifting of bits into the correct positions. Ensure there is enough settling time between writing the address and reading the data (10 µs minimum).

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

Parameters do not appear to be written correctly.
- Ensure that the Write bit is set in the second (LSB), i.e., the second address byte is a "1."

- Ensure there is adequate settling time before reading or using a written parameter (10 milliseconds minimum). Parameters are stored in nonvolatile memory, not RAM, and writing to nonvolatile memory is much slower.

Evaluation Support

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.
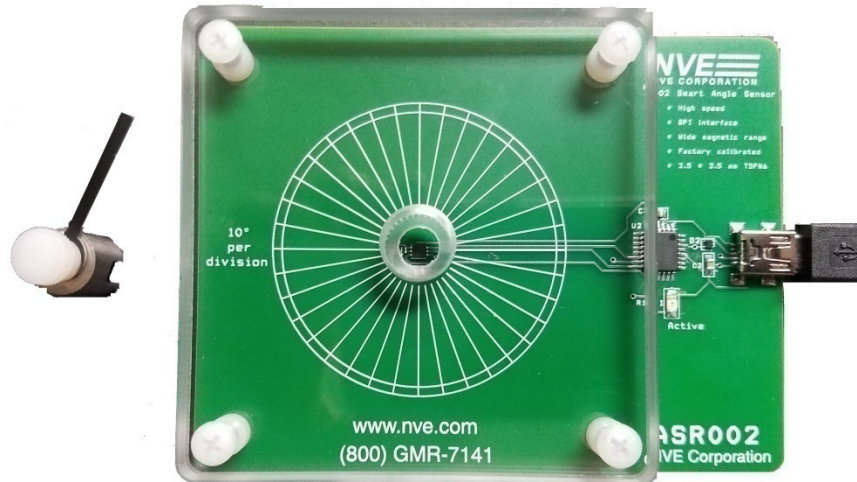

Figure 11. AG956-07E: Smart Angle Sensor Evaluation Kit.

Socket Board
The AG954-07E provides a TDFN6 socket for easy interface to sensors such as the ASR002-10E without soldering:
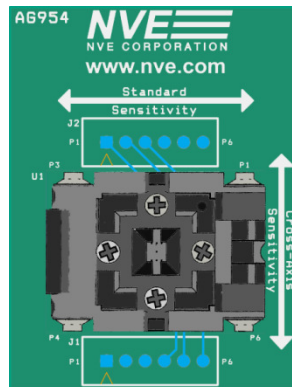

Figure 14. AG954-07E: TDFN socket board
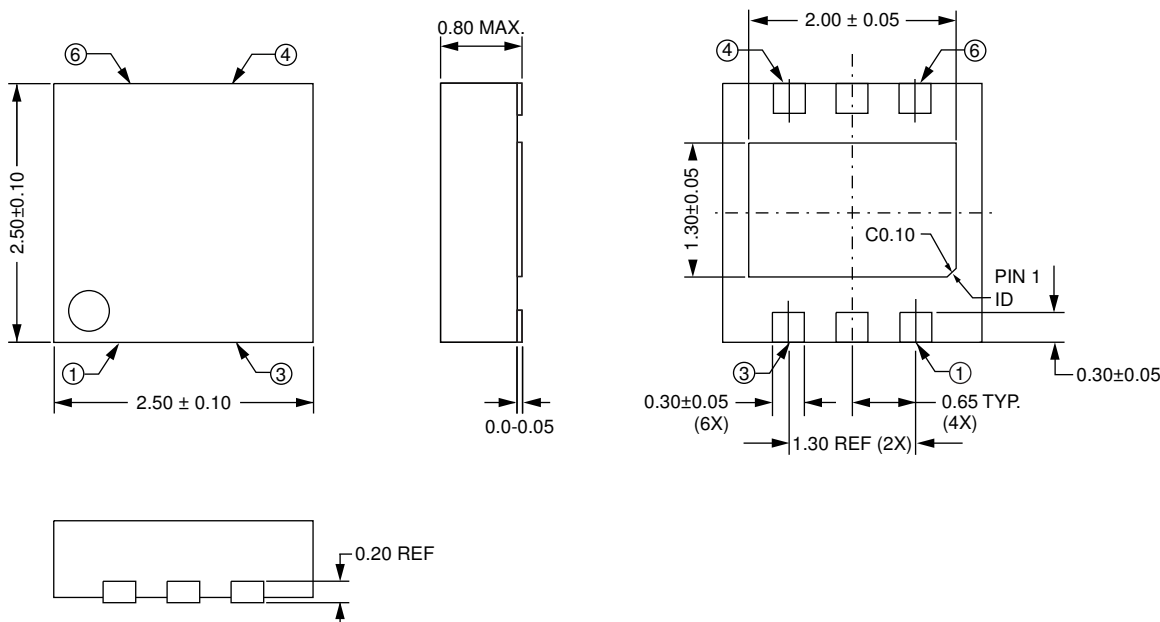1.5" x 2" (38 mm x 50 mm)(actual size)

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

Figure 12. AG035-06 TDFN6 bare circuit board
1.57" x 0.25" (40mm x 6 mm) (actual size).

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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)

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

RoHS
COMPLIANT

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

Revision History

SB-00-081-C
Jan. 2019

Change
- Faster RAM timing.
- Reduced data transfer rate from 2.5 to 2 Mbits/s for more design margin.
- Corrected number of bits in angular offset.
- Added Arduino code to zero the Sensor.
- Added "In Case of Difficulty" section
- Dropped daisy-chained SPI application diagram (not supported).
- Added AG954-07E socket board.
- Typographic and cosmetic changes.

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.

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The information and data provided in datasheets shall define the specification of the product as agreed between NVE and its customer, unless NVE and customer have explicitly agreed otherwise in writing. All specifications are based on NVE test protocols. In no event however, shall an agreement be valid in which the NVE product is deemed to offer functions and qualities beyond those described in the datasheet.

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