

## ASR012 Smart I<sup>2</sup>C TMR Angle Sensor



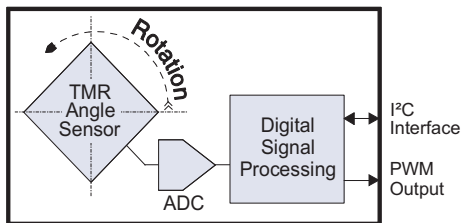
### Features

- Rotational speeds to 375,000 RPM
- 3.3 volt or 5 volt compatible I<sup>2</sup>C interface
- PWM output
- Robust airgap and misalignment tolerances
- Factory calibrated
- Ultraminiature 2.5 x 2.5 x 0.8 mm TDFN6 package

### Key Specifications

- 0.1° resolution
- ±0.2° repeatability
- Robust 6 to 20 mT 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

### Block Diagram



### Applications

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

### Description

ASR012 TMR Smart Angle Sensors provide a precise digital angle measurement over a wide range of speeds.

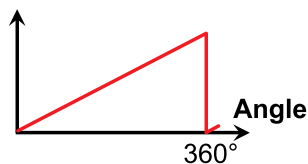
The sensor combines precise, low-power Tunneling Magnetoresistance (TMR) sensing elements with sophisticated digital signal processing.

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

An I<sup>2</sup>C interface provides angle data and allows setting device parameters. A PWM output also provides angle data.

The ASR012 is designed for harsh industrial or automotive environments with ESD protection, and full -40 °C to 125 °C operating temperature range.

### Transfer Function



## Boundary Ratings

Parameter	Min.	Max.	Units
Supply voltage	-12	4.2	Volts
Input and output voltages (SDA, SCL, PWM, and I2CADDR)	-0.5	$V_{cc}+2.5$ up to 5.8	Volts
Input current	-100	+100	mA
Storage temperature	-55	150	°C
ESD (Human Body Model)		2000	Volts
Applied magnetic field		Unlimited	Tesla

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

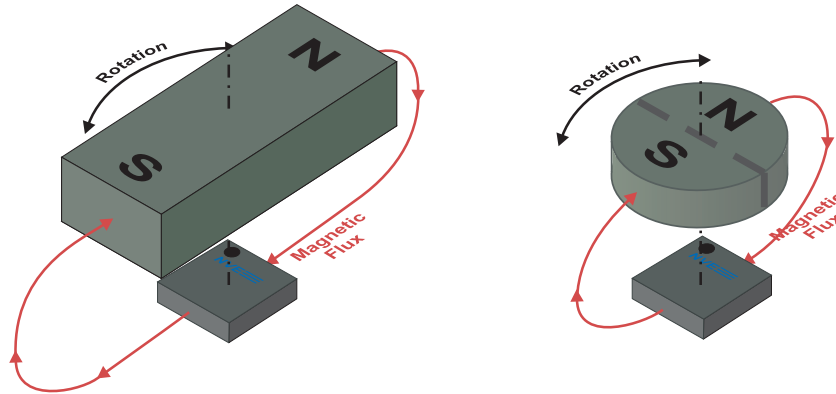
Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Operating temperature	T <sub>min</sub> ; T <sub>max</sub>	−40		125	°C	
Supply voltage	V <sub>DD</sub>	2.2		3.6	V	
Supply current	I <sub>DD</sub>		4	6	mA	Max. at V <sub>DD</sub> = 3.6V
Power-on Reset supply voltage	V <sub>POR</sub>		1.4		V	
Brown-out power supply voltage	V <sub>BOR</sub>	0.75	1	1.36	V	
Start-up time	T <sub>STA</sub>		15		ms	
Magnetics						
Applied magnetic field strength	H	6	12	20	mT	
Accuracy and Repeatability						
Angular resolution	δ		0.1		Angular Degrees	
Angular hysteresis	ℑ			0.1		
Repeatability			±0.2			Fixed temperature and bias <sup>1</sup>
Angular accuracy, fixed bias <sup>1</sup>	ε			±2 ±3		0 to 85°C −40 to 125°C
Angular accuracy, variable bias <sup>2</sup>				±6		−40 to 125°C
Speed						
Sample rate			12.5		kSps	
I <sup>2</sup> C Interface						
Data transfer rate	DR			400	kBaud	
Bus voltage	V <sub>BUS</sub>	2.2		5.5	V	
Output response and transmission times				20	μs	400 kBaud
Low level input threshold voltage	V <sub>IL</sub>	0.8			V	
High level input threshold voltage	V <sub>IH</sub>			2.2	V	
Low level output current	I <sub>OL</sub>	3			mA	V <sub>OL</sub> = 0.4V
I/O capacitance	C <sub>I/O</sub>			10	pF	
PWM Output						
PWM frequency			24		kHz	
RAM Timing						
Address setup time	t <sub>ADDR</sub>	3			μs	See figure 4
Data read time	t <sub>READ</sub>	10			μs	
Nonvolatile Memory Characteristics						
Address setup time	t <sub>ADDR</sub>	3			μs	See figure 5
Data read time	t <sub>READ</sub>	10			μs	
Data write time	t <sub>NVM</sub>	20			ms	
Endurance			10000		Cycles	
Package Thermal Characteristics						
Junction-to-ambient thermal resistance	θ <sub>JA</sub>		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 the 17.5 mT factory calibration field.
2. “Variable Bias” means the magnitude of the magnetic field at the sensor can vary across the entire specification range.

### ASR012 Overview

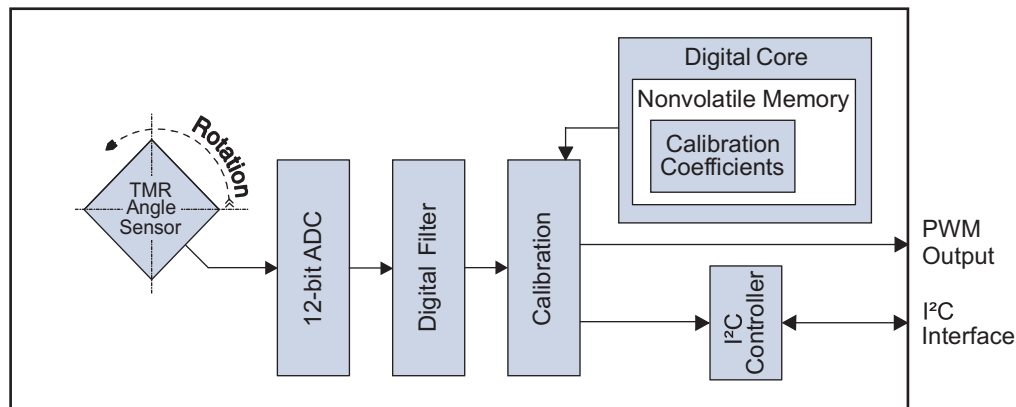
The ASR012 is a non-contact angle sensor designed for high speed applications where size is limited. The heart of the ASR012 is a tunneling magnetoresistive (TMR) sensor. In a typical configuration, an external magnet provides a magnetic field of 6 to 20 mT (60 to 200 Oe) in the plane of the sensor, as illustrated below for a bar magnet and a diametrically-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.**

### ASR012 Operation

A detailed block diagram is shown below:



**Figure 2. Detailed block diagram.**

### TMR Angle Sensor Element

ASR0x2 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

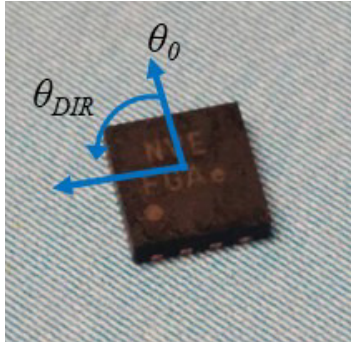
The sensor output is digitized with a 12-bit ADC. The extra bits ensure precision and computational accuracy.

### 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 ASR012 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.

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## **I<sup>2</sup>C Interface**

### ***Changing the I<sup>2</sup>C Address in Nonvolatile Memory***

The default I<sup>2</sup>C address is stored in nonvolatile memory, and can be changed like any other parameter. The I<sup>2</sup>C standard reserves certain addresses, so recommended I<sup>2</sup>C addresses are 16 to 238 (0x10 to 0xEE hex).

Note that if there are multiple ASR012's on the same I<sup>2</sup>C bus there will be a collision before addresses can be changed. Therefore changing the address in this way may require a single-sensor programming setup.

### ***Overriding the I<sup>2</sup>C Address with an External Jumper***

Grounding the I<sup>2</sup>C address override pin ("I2CADDR") changes the I<sup>2</sup>C address to 16 dec regardless of the programmed address. Leaving the pin open or tied HIGH invokes the I<sup>2</sup>C address in nonvolatile memory, which is 72 dec by default but can be reprogrammed by the user in memory location 0x44. The pin is checked only on power-up.

### ***Eight-Bit I<sup>2</sup>C Address***

In accordance with industry standards, ASR012 sensors have eight-bit I<sup>2</sup>C addresses (seven bits plus an R/W bit). Some I<sup>2</sup>C Master devices (such as Arduinos) send seven-bit addresses. In this case, the sensor address should be divided by two, so for example a default I<sup>2</sup>C address of 36 rather than 72 would be used.

### ***Reading and Writing the Sensor Memory***

Data is read by first writing an address byte to the sensor (with the I<sup>2</sup>C Read/Write bit set to "Write"). Subsequent I<sup>2</sup>C read commands will return the data or parameter in the active address.

The default memory address is 0, which is the calibrated sensor output, so "out of the box" the sensor output can simply be retrieved with I<sup>2</sup>C read commands.

### ***Reading the Angle***

To read the angle, the master simply writes zero for the "0" angle address, then reads the two-byte angle, which is expressed in tenths of degrees. The active address will remain the same until changes, so the angle can be read repeatedly without writing the address each time.

### ***Reading and Writing Parameters***

Reading and writing parameters are simple three-byte sequences. The master writes a byte for the parameter address, then reads or writes two bytes for the parameter value.

The number of bits in different parameters varies. Unused bits are sent as zeros by the sensor. Similarly, unused bits should be written as zeros to the sensor to avoid an out-of-range parameter that could be ignored.

Because of the slower speed of the sensor's nonvolatile memory, allow 15 ms for parameter writes.

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## **PWM Analog Output**

The PWM output tracks the measured angle and can be externally filtered as an analog output. The output is ratiometric with the power supply, i.e., equal to  $V_{DD}$  at 360°, so the output is 9.2 mV per degree with a 3.3 V supply.

## Memory Map

The ASR012 memory provides access to angle data and user-programmable parameters. The memory is accessed via I<sup>2</sup>C.

Parameter	Symbol	Default	Read/Write	Range	Address	Description
Data						
Angle	$\theta$	N/A	R	0 – 3600	0x00	In tenths of a degree
Raw Sin Vector	Sin $\theta$			Approx. 1500 – 2500	0x01	Raw outputs centered at approx. 2048 with peak-peak amplitudes of approx. 1000.
Raw Cos Vector	Cos $\theta$				0x02	
Direction	Dir			0 – 1	0x03	0 = decreasing angle 1 = increasing angle
User-Programmable Parameters						
Rotation Direction	$\theta_{\text{DIR}}$	0	R/W	0 – 1	0x40 [bit 0]	0 → increasing CCW; 1 → increasing CW (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	1		1 – 255	0x42	$f_{\text{CUTOFF}} = f_{\text{SAMPLE}} / (2\pi m)$ ; $f_{\text{SAMPLE}}$ = approx. 12.5 kSps m = 1 disables filter
Direction Hysteresis	$\delta_{\text{DIR}}$	25		0 – 255 (0 – 25.5°)	0x43	Hysteresis of the “Dir” output; in tenths of a degree
I <sup>2</sup> C address	I2CADDR		R/W	16 to 238 (0x10 to 0xEE)	0x44	I2CADDR with pin 1 floating or HIGH
Read-Only Memory						
Lot code	YY	N/A	R	N/A (ASCII)	0x80	ASCII date code in the form YYWWXX, where: YY = year; WW = work week; XX = internal code.
	WW				0x81	
	XX				0x82	

**Table 1. ASR012 Memory Locations.**

### **Power-Up and Initialization**

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#### ***Absolute position***

Unlike some encoder types, ASR0x2 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 I<sup>2</sup>C), and remain for the life of the product if desired.

### **Minimizing Noise**

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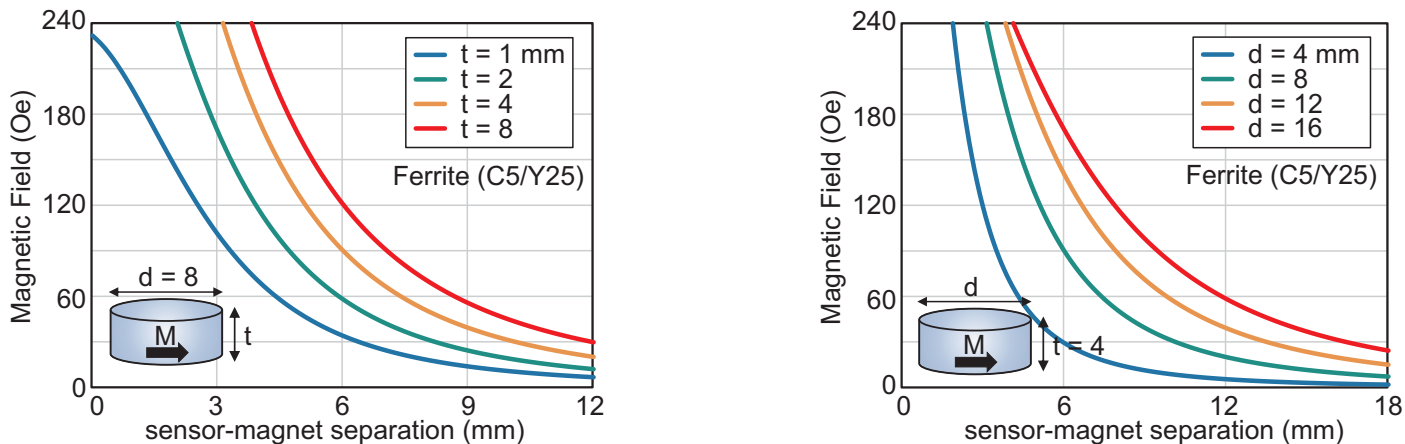
Several steps minimize noise:

- A 10  $\mu$ F bypass capacitor is recommended as close as possible to the  $V_{DD}$  and GND pins. A 0.080 x 0.050 inch or smaller capacitor is recommended to minimize magnetic interference with the sensor.
- Use a circuit board ground plane.
- Grounding the sensor's center pad allows the leadframe to act as a shield.



### Magnet Selection

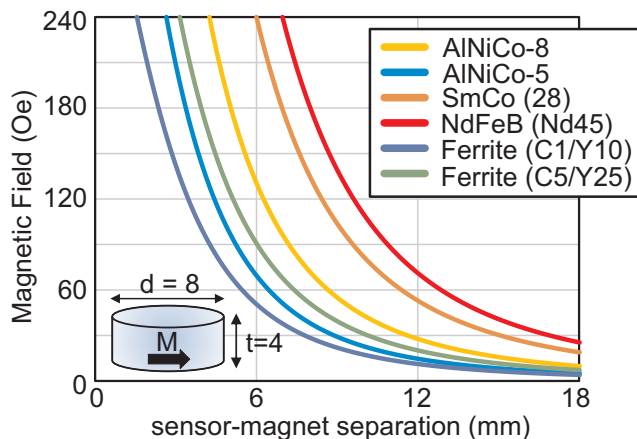
The sensor's wide operating field range of 6 to 20 mT (60 to 200 Oe) allows inexpensive magnets and operation over a wide range of magnet spacing. The figures below show the magnetic field for various magnet geometries and distances for inexpensive C5/Y25 grade ferrite magnets:



**Figure 8. Magnetic fields for various geometries of C5/Y25 ferrite magnets plotted for the distance between the magnet and sensor. Eight-millimeter diameter magnets of various thicknesses are shown at left, and four-millimeter thick magnets of various diameters are shown at right.**

Field varies less with distance for larger magnets, so maximizing magnet size within the mechanical constraints of the system maximizes accuracy.

Higher-grade magnets can be used for high-temperature applications or large magnet-sensor separations. The graph below shows field strengths with various 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.**

Our free Web app can be used to determine optimum separations for various magnet sizes and materials:

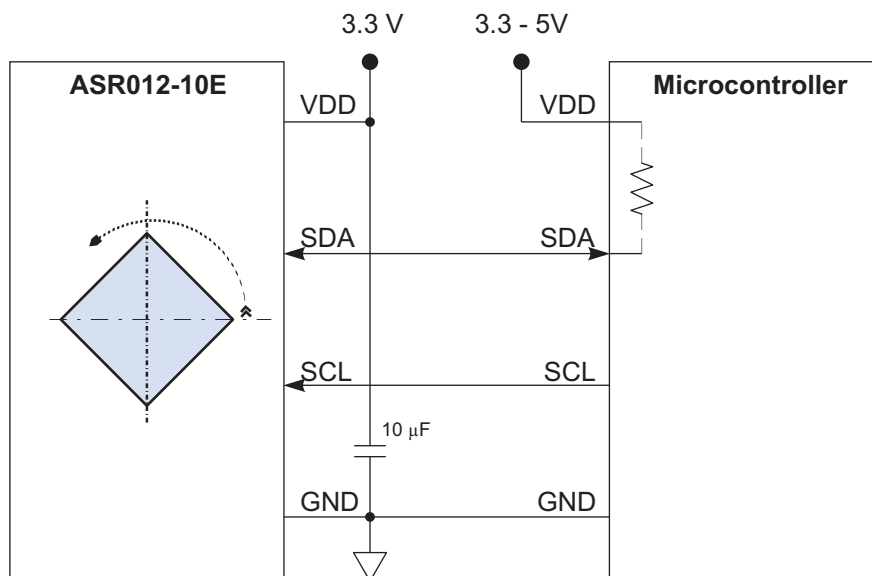
<https://www.nve.com/spec/calculators.php>.

[NVE's Online Store](#) stocks popular magnets.

## Application Circuits

### Typical Microcontrollers Interface

A typical microcontroller interface is shown below:



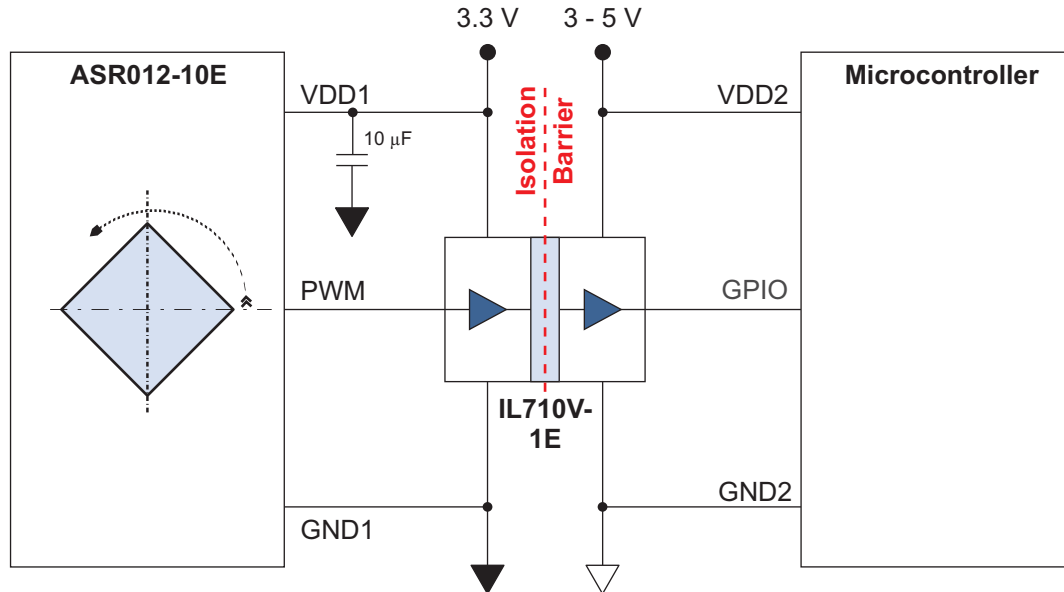
**Figure 10. Typical microcontroller interface.**

The ASR012 is configured as a Slave and the microcontroller should be configured as the Master. The ASR012 I<sup>2</sup>C interface is compatible with 3.3 or 5 volt microcontrollers.

The ASR012 SDA line is 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 generally the sensor supply.

### Double Isolation Circuit

Double isolation from human interface to line-voltage driven electrical circuitry is required in some safety intensive applications such as medical instruments. The mechanical gap between the magnet and the sensor can provide one level of isolation from a knob or other human interface. Galvanic isolation from the sensor to the microcontroller provides a second isolation barrier:



**Figure 11. Double-isolated microcontroller interface.**

Since it is single-channel and unidirectional, the PWM output can be easily isolated with just a single-channel digital isolator. The I<sup>2</sup>C interface is more complex and expensive to isolate since there are two bidirectional, open-drain lines.

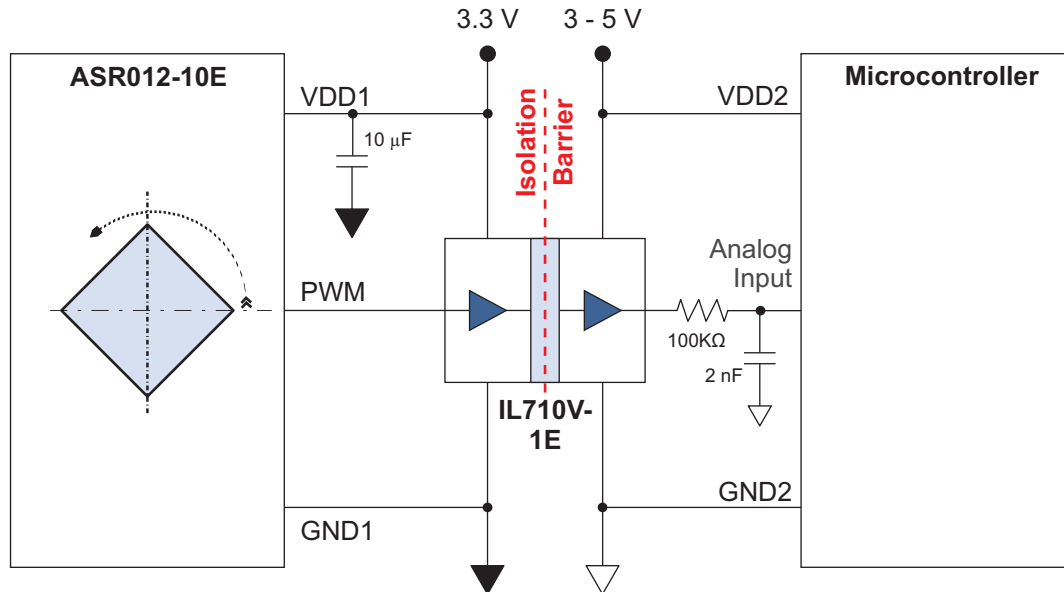
The IsoLoop IL710V-1E isolator in the circuit above is a UL/VDE-compliant, ultra-miniature MSOP galvanic isolator with a 2.5 kV isolation rating. The isolator can also level-shift between the 3.3-volt sensor and a five-volt microcontroller.

The PWM signal can be decoded by the microcontroller using commonly-available routines.

There may be inaccuracies at angles close to zero if the PWM pulses are too narrow to be detected by the microcontroller.

**Filtered PWM Read by an Analog Input**

If speed is not critical, the isolated PWM signal can be filtered with a resistor and capacitor and connected to a microcontroller analog input. This provides accurate readings at all angles, including angles close to zero.



**Figure 12. Filtered PWM read by a microcontroller analog input.**

The 100 kΩ resistor avoids loading the isolator output while providing a low enough impedance for most microcontroller analog inputs. The 2 nF filter capacitor yields a 200 μs time constant, which is adequate to filter the sensor's 24 kHz PWM output. The resultant cutoff frequency is approximately 31 kHz.

### Illustrative Arduino Code for Continuously Reading Angles

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```
//Reads ASR012 angle via I2C via an Arduino Uno. SDA-->A4; A5-->SCL
#include <SPI.h>
int angle; //Sensor output (tenths of a degree)

void setup() {
  Wire.begin(); //Join I2C bus as Master
}
void loop() {
  Wire.requestFrom(36,2); //Request two bytes from sensor (I2C address 72/2=36)
  angle = Wire.read()<<8; //Read angle MSB
  angle |= Wire.read(); //Read angle LSB
  delay(200); //5 samples per second
}
```

### Pseudo Code for I<sup>2</sup>C Reading and Writing

```
uint16_t read_from_sensor(uint8_t ASR012_i2c_address, uint8_t read_location_address)
{
    while (!i2c_start(ASR012_i2c_address)) i2c_stop(); //spins till bus is available to
    start
    i2c_write(read_location_address);
    i2c_stop();
    while (!i2c_rep_start((ASR012_i2c_address) | 0x01)); // write the address of the sensor
    with the read bit set
    uint8_t MSB = i2c_read(0); //MSB read from bus, no nack
    uint8_t LSB = i2c_read(1); //LSB read from bus, nack to notify sensor that transfer is
    done
    i2c_stop(); //read is complete

    return (MSB << 8) | LSB;
}

void write_to_sensor(uint8_t ASR012_i2c_address, uint8_t write_location_address,
uint8_t MSB, uint8_t LSB){

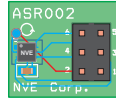
    while (!i2c_start(ASR012_i2c_address)) i2c_stop(); //spins till bus is available
    to start

    i2c_write(write_location_address); //sensor write location is written to the bus
    i2c_write(MSB); //MSB first
    i2c_write(LSB); //LSB second
    i2c_stop(); //write is complete
    delay(15); 15 ms delay after write to nonvolatile memory
}
```

## Evaluation Support

### Breakout Board

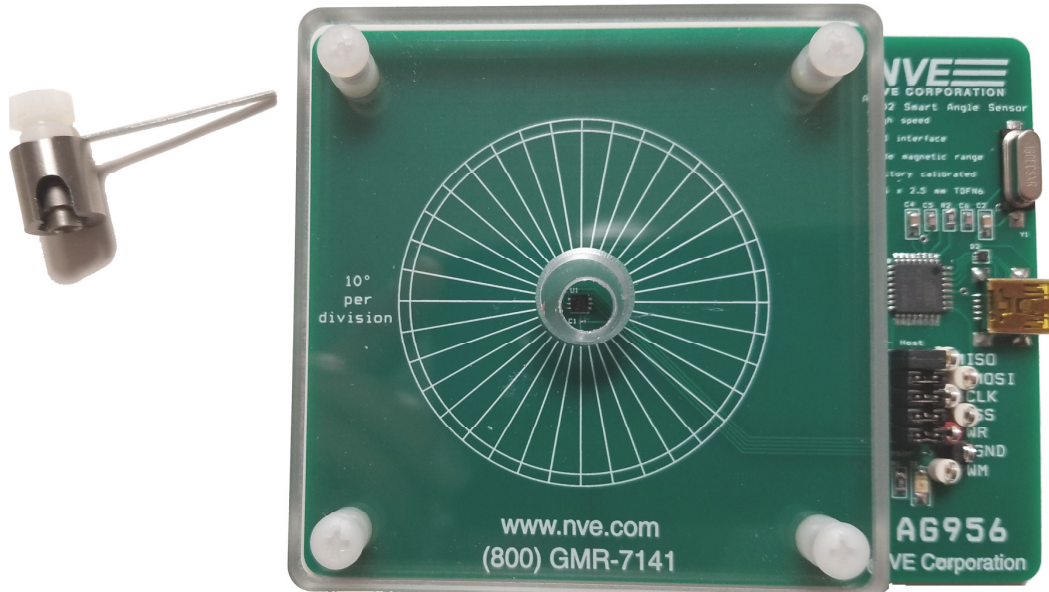
The AG957-07E breakout board provides easy connections to an ASR012-10E angle sensor with a six pin connector. It also has a recommended 10  $\mu$ F bypass capacitor:



**Figure 13. ASR012 breakout board (actual size)**  
0.5" x 0.6" (12 mm x 15 mm)

### Smart Angle Sensor Evaluation Kit

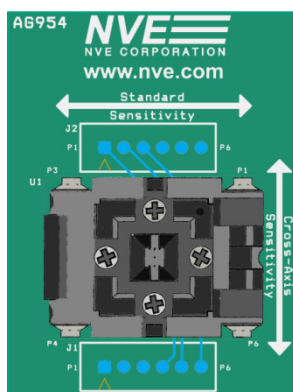
This simple board includes an ASR012-10E Smart Angle Sensor, a microcontroller that interfaces to the Sensor via I<sup>2</sup>C, and to a PC via USB. The kit includes a diametrically-magnetized cylindrical horseshoe magnet and fixturing. A PC-based user interface provides two-way communication with the sensor to display the sensor outputs and change the sensor's parameters.



**Figure 14. ASR012 Smart Angle Sensor Evaluation Kit.**

### Socket Board

The AG954-07E provides a TDFN6 socket for easy interface to sensors such as the ASR012-10E without soldering:



**Figure 15. AG954-07E: TDFN socket board**  
1.5" x 2" (38 mm x 50 mm)(actual size)



### Magnets

NVE stocks five popular magnets for use with its angle sensors:

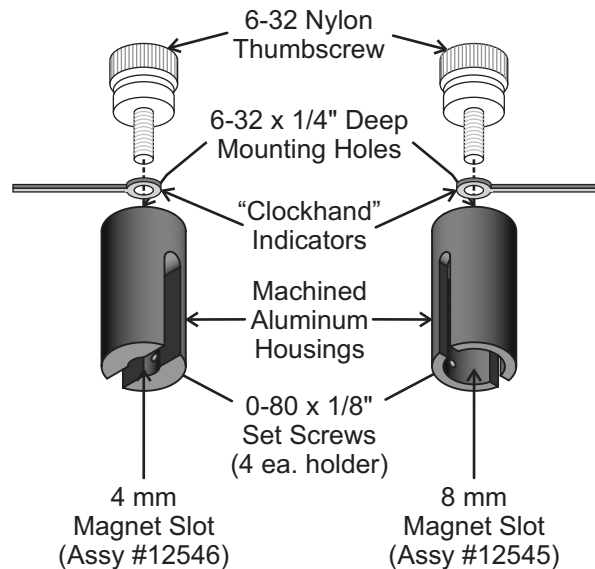
NVE Part Number	Compatible Magnet Holder	Diameter (mm)	Length (mm)	Typ. sensor distance (mm; 12 mT nom. field)	Material and Configuration
12526	4 mm	4	4	3	C5/Y25 ferrite disk magnets
12249	N/A	12.5	3.5	4	
12527	8 mm	8	4	5	
12528	8 mm	8	8	6	
12426*	N/A	11	11	8	Alnico-5 round horseshoe magnet with mounting hole

\*Included in the Smart Angle Sensor Evaluation Kits.

**Table 2. Popular magnets for angle sensing.**

### Magnet Holders

NVE offers two magnet holders for evaluation and prototyping. The holders are machined aluminum. Set screws secure the magnets in the holders and allow magnet position adjustments. There are threaded mounting holes for a thumbscrew to turn the magnet, or the hole can be used to attach the holder to a rotating shaft. A “clock hand” indicator helps track magnet rotation:



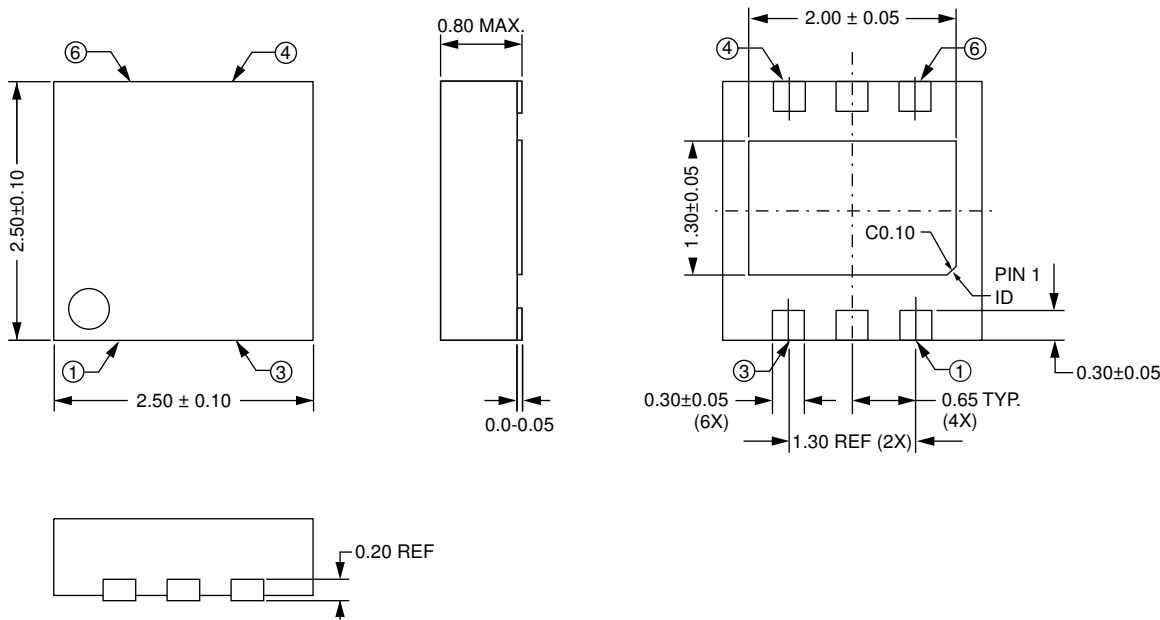
**Figure 16. Four millimeter magnet holder (part #12546; left) and 8 mm magnet holder (part #12545; right).**  
0.44" dia. x 0.88" tall (11 mm x 22 mm) outside dimensions; actual size).

The holders are compatible with several popular diametrically-magnetized disk magnets and can be used in Smart Angle Sensor Evaluation Kits:

Holder Part Number	Outside Dimensions	Compatible Magnets (NVE part #s)	Magnet Diameter (mm)	Max. Magnet Length (mm)
12546	11 mm dia. x 22 mm tall	12526	4	4
12545		12527; 12528	8	8

**Table 3. Magnet holders.**

**2.5 x 2.5 mm TDFN6 Package**



Pad	Symbol	Description
1	GND	Ground/ $V_{SS}$
2	SDA	I <sup>2</sup> C Data (bidirectional; open drain)
3	SCL	I <sup>2</sup> C Clock (input)
4	VDD	Power Supply (bypass with a 10 $\mu$ F capacitor)
5	PWM	PWM Output
6	I2CADDR	I <sup>2</sup> C address override (LOW-true input; read on power-up). Grounding this pin changes the I <sup>2</sup> C address to 16 dec regardless of the programmed address. Open or HIGH invokes the I <sup>2</sup> C address in nonvolatile memory.
Center pad		Internal leadframe connection; connect to GND to minimize noise.

**Notes:**

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



### Ordering Information

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# ASR012 - 10E TR13

#### Product Family

ASR = Smart Angle Sensors

#### I/O

00 = SPI

01 = I<sup>2</sup>C

#### Sensor Element

2 = High speed, medium accuracy

#### Field Range Identifier

Blank = General Purpose (6 to 20 mT / 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

### Available Product Variants

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Part Number	Evaluation Kit	Repeatability	Speed	Outputs
ASR002-10E	AG956-07	0.2°	12500 Sps	SPI
ASR012-10E	AG963-07			I <sup>2</sup> C; PWM

### Revision History

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**SB-00-081-RevA**

January 2020

**Changes**

- Added application diagrams.
- Added illustrative Arduino code and I<sup>2</sup>C pseudocode.
- Moved I2CADDR parameter memory address.
- Initial release.

**SB-00-081-PRELIM**

December 2019

**Change**

- Preliminary release.

### Datasheet Limitations

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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SB-00-081\_AS012-10\_RevA

*January 2020*