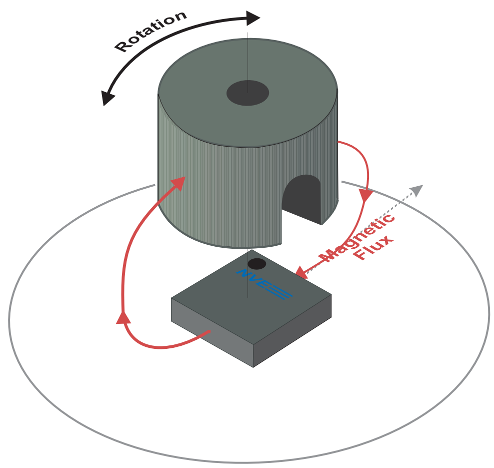
ASR001-11E Smart, Low-Power Angle Sensor



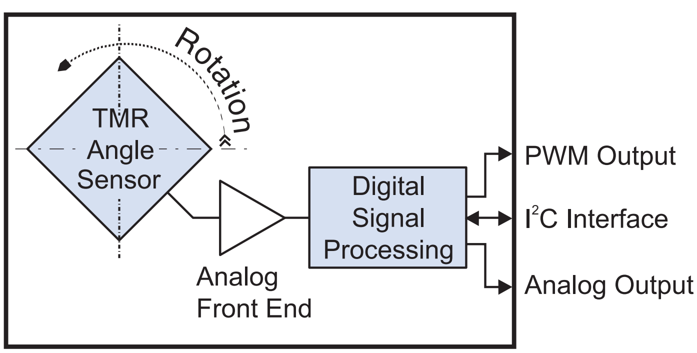
Features

- Robust airgap and misalignment tolerances
- I²C, PWM, and analog outputs
- 12 bit output resolution
- 17-point piecewise curve fitting and linearization
- Programmable offset, gain, and phase compensation
- Internal temperature compensation 5 volt supply
- 3.3 volt or 5 volt compatible I²C interface
- Overvoltage/reverse voltage protection
- Ultraminiature 3 x 3 x 0.8 mm TDFN8 package

Key Specifications

- ±0.5° accuracy
- Wide 30 − 200 Oe magnetic field operating range
- Up to 6000 RPM (100 Hz)
- 2.5 kSps sample rate
- 2.6 mA typical supply current
- −40°C to +125°C operating range

Block Diagram



Applications

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

Description

The ASR001 Smart Angle Sensor provides a precise digital indication of magnetic rotation.

The sensor combines a low-power Tunneling Magnetoresistance (TMR) sensor element with sophisticated digital signal processing. The digital signal processing improves accuracy and allows factory and application-specific calibration.

An I²C interface provides data as well as providing an external programming interface. Calibration coefficients are stored in an internal EEPROM.

Designed for harsh industrial or automotive environments, the ASR001 has overvoltage and reverse voltage protection, ESD protection, and full −40°C to +125°C operating temperature range.

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Absolute Maximum Ratings

Parameter	Min.	Max.	Units
Supply voltage	−12	24	Volts
Output voltage	−0.3	14	Volts
Input voltages (SCL, SDA, and CS)	−0.5	14	Volts
Storage temperature	−40	170	°C
ESD (Human Body Model)		2000	Volts
Applied magnetic field		Unlimited	Oe

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Operating Specifications

T_{min} to T_{max}; 4.5 V < V_{DD} < 5.5 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}	4.5		5.5	V	
Supply current	I_{DD}	1.5	2.6	3.0	mA	Max. at V_{DD} = 5.5V
Reference output	V_{REF}	3.30	3.3	3.38	V	
Start-up time	T_{STA}			5	ms	
Power-on Reset supply voltage	V_{POR}	1.95	2.00	2.20	V	
Brown-out power supply voltage	V_{BOR}	1.70	1.83	1.95	V	
Power-on Reset delay	t_{BOR}		8		µs	
Operating magnetic field strength	H				Oe	
ASR001		30		200		
ASR001A		30		70		
ASR001B		70		150		
ASR001C		150		200		
Angular accuracy, fixed bias[1]	θ_{min}			±0.5 ±2	Angular Degrees	25°C $T_{min} \le T \le T_{max}$
Angular accuracy, variable bias[2]	θ_{min}				Angular Degrees	$T_{min} \le T \le T_{max}$
ASR001				±5		
ASR001A				±3.5		
ASR001B				±3.5		
ASR001C				±3.5		
Angular precision	δ			12	bits	
Angular hysteresis	[illegible]				Angular Degrees	
ASR001				0.10		
ASR001A				0.05		
ASR001B				0.05		
ASR001C				0.05		
Internal Temperature Sensor						
Temperature update rate	T_{UPD}	20		2500	Hz	
Temperature hysteresis	T_{HYST}	0		12	°C	
Analog Output						
Frequency response	f_{MAX}	2.5			kHz	
Resolution				12	bits	
Low-level analog output voltage	V_{OL}	0		50	mV	$I_L = -50$ µA
High-level analog output voltage	V_{OH}	$V_{DD}-0.05$		V_{DD}	V	$I_L = 50$ µA
PWM Output						
Operating frequency	f_{PWM}	15.2		1953	Hz	
Logic low output voltage	V_{PWMOL}		0.150		V	10 KΩ pull-up
Logic low output current	I_{PWMOL}			4	mA	V_{PWMOL} = 0.4V
Logic high output voltage	V_{PWMOH}		4.90		V	10 KΩ pull-up
Rise time of PWM			10		ns	10 KΩ pull-up; 10 pF load
Fall time of PWM			10		ns	

I^2C Interface	**Symbol**	**Min.**	**Typ.**	**Max.**	**Units**	**Test Condition**
Data transfer rate	DR			400	kBaud	I^2C fast mode
Bus voltage	V_{BUS}	3		5.5	V	
Output response and transmission times				400	µs	400 kBaud
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
Hold Time (repeated) START Condition	$t_{HD;STA}$	4			µs	$f_{SCL} \leq 100kHz$
		0.6				$f_{SCL} > 100kHz$
SCL low time	t_{LOW}	4.7				$f_{SCL} \leq 100kHz$
		1.3				$f_{SCL} > 100kHz$
SCL high time	t_{HIGH}	4				$f_{SCL} \leq 100kHz$
		0.6				$f_{SCL} > 100kHz$
Set-up time for repeated START	$t_{SU;STA}$	4.7				$f_{SCL} \leq 100kHz$
		0.6				$f_{SCL} > 100kHz$
Data hold time	$t_{HD;DAT}$	0		3.45		$f_{SCL} \leq 100kHz$
		0		0.9		$f_{SCL} > 100kHz$
Data setup time	$t_{SU;DAT}$	250			ns	$f_{SCL} \leq 100kHz$
		100				$f_{SCL} > 100kHz$
Setup time for STOP condition	$t_{SU;STO}$	4			µs	$f_{SCL} \leq 100kHz$
		0.6				$f_{SCL} > 100kHz$
Bus free time between STOP and START	T_{BUFF}	4.7				$f_{SCL} \leq 100kHz$
		1.3				$f_{SCL} > 100kHz$
Capacitive load	C_B			400	pF	
Rise time of SDA and SCL	t_{OR}			300	ns	$C_B < 400$ pF
Fall time of SDA and SCL	t_{OF}			250	ns	
I/O capacitance	$C_{I/O}$			10	pF	
CS internal pull-down resistance	CS_R		100		kΩ	
Filter Characteristics						
Filter hysteresis	θ_{HYST}	0		10	Angular Degrees	
FIR filter taps		1		4		
Piecewise Linearization						
Number of segments	N_{SEG}	1		16		
Bin size	θ_{BIN}	360/4096		360	Angular Degrees	
Upper clipping range	$CLIP_U$	0		360		
Lower clipping range	$CLIP_L$	0		360		
EEPROM Characteristics						
Write time				16	msec	
Endurance			100,000		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 between the bias magnet and sensor so the magnitude of the magnetic field at the sensor is constant. 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 specification range.

ASR001 Overview

The ASR001 is a non-contact rotation sensor designed for applications where size and power are limited. With the lowest current consumption of 2.6 mA typical and tiny 3 x 3 mm 8-pin TDFN package, the ASR001 is the smallest, lowest-power sensor in its class.

The heart of the ASR001 is a tunneling magnetoresistive (TMR) sensor. In a typical configuration, an external magnet provides a saturating 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 analog signal conditioning for offset, phase and amplitude correction is combined with a temperature sensor and digital linearization to produce unprecedented accuracy and precision.

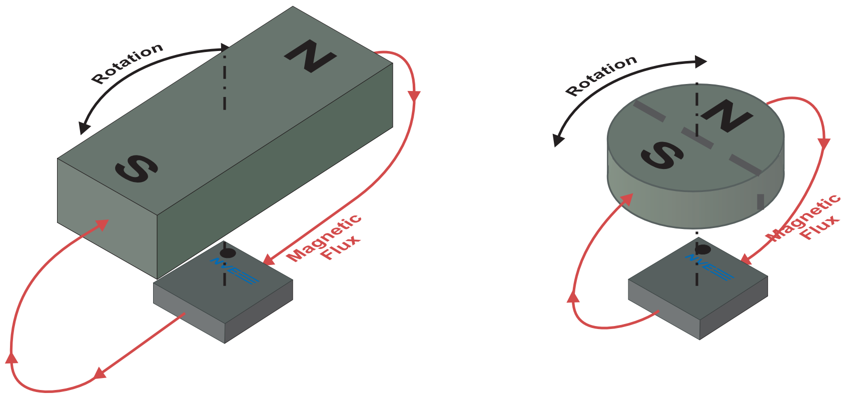

Figure 1. Sensor operation.

ASR001 Operation

A detailed block diagram is shown below:

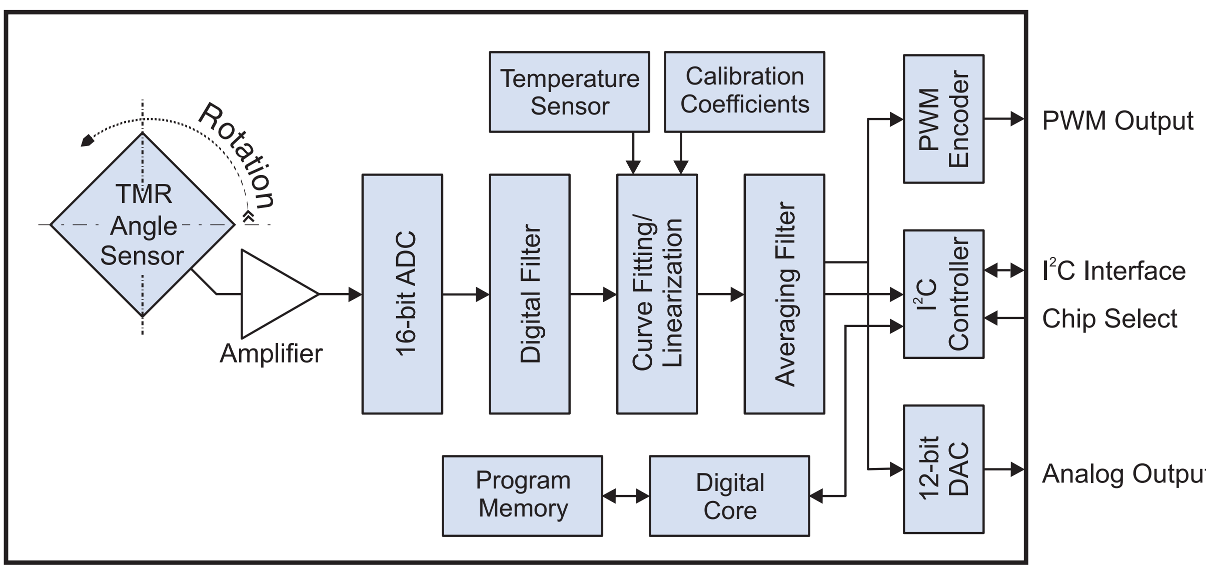

Figure 2. Detailed block diagram.

An integrated piecewise linear (PWL) fitting function allows mapping virtually any motion of an external magnet to an arbitrary output function. In this way, nonlinear magnet fields during motion can be linearized or fit to other waveforms. The ASR001 is also equipped with two programmable digital filters for mechanically noisy environments.

Three outputs are available for maximum flexibility: an industry-standard 3–5-volt compatible I^{2}C output for interfacing directly to microcontrollers and FPGAs; a pulse-width modulated (PWM) output, and a precise analog output that can be used with ADCs.

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The ASR001 has robust circuitry to protect against reversed supply and severe overvoltage, plus integrated ESD protection to provide 2000 volts of ESD immunity.

In addition to linearization, several other parameters can be programmed into the ASR001 through the I^2C interface.

Rotation Direction
The ASR001 can provide increasing output values for either clockwise or counterclockwise field rotations. Counterclockwise is defined as a rotating field vector through pins 1-4-5-8, and clockwise through pins 1-8-5-4. The rotation direction can be programmed using the θ_{DIR} parameter.

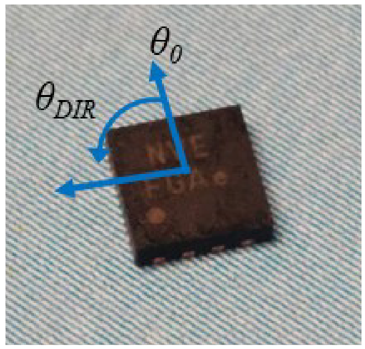

Figure 3. Zero-angle reference (θ_0) and rotation direction (θ_{DIR}). The rotational center of the sensor is the package center.

Zero-Angle Reference Point
A programmable parameter θ_0 sets the zero-degree reference. This is the angle of "discontinuity" where the angle output changes from 360° to 0°.

Overvoltage Protection
The ASR001 is equipped with robust overvoltage circuitry to prevent damage to the part in reverse and over-bias conditions.

User Defined Memory
Seven 16-bit blocks of nonvolatile memory are available for general purpose use in the ASR001. A factory serial number is programmed into the first six blocks. This number can be overwritten if needed. $ID_{1\text{-}7}$ of the EEPROM are reserved for this memory. Note that the EEPROM memory is subject to endurance limitations and should only be used for occasionally updated data.

User Lock
The user of the ASR001 can lock the sensor and prevent changes to the EEPROM registers. This feature can be used as a failsafe in factory assembly to prevent changes to device performance or operation. The EEPROM parameter for the user lock is LOCK.

Internal Temperature Sensor
An internal temperature sensor compensates for thermal variations of the TMR sensor elements in the ASR001. The temperature is updated at the same frequency as the magnetic sensor but can be updated less frequently using the T_{UPD} parameter to reduce chip power and noise. To minimize the impacts of electrical noise or thermal fluctuations, a hysteresis parameter T_{HYST} can be programmed into the sensor to reduce the temperature update rate. The hysteresis parameter approximately corresponds to degrees Celsius. User programmable update rates and corresponding approximate temperature hysteresis are listed in Tables 1 and 2 below.

Digital Code	Temperature Update Rate (Hz)
000	2500 (Default)
001	1250
010	625
011	310
100	160
101	80
110	40
111	20

Table 1. EEPROM codes for temperature update rate.

Digital Code	Update Hysteresis (°C)
00000	0
00001	2
00010	4
00011	6
00100	8
00101	10
00110-11111	12

Table 2. EEPROM codes for temperature update hysteresis.

Application-Specific Angle Remapping

The Curve Fitting/Linearization engine calculates the angle from the raw TMR sensor output. The Curve Fitting/Linearization engine can also be precisely tailored to customer applications using hysteresis or averaging filters and a piecewise linear (PWL) algorithm to remap the sensor output to virtually any waveform or contour. For example, non-linear magnet rotations or magnetic field actuations can be linearized. Furthermore, digital outputs can be generated using programmed thresholds. The signal path for the filters and PWL processing is shown in the diagram below.

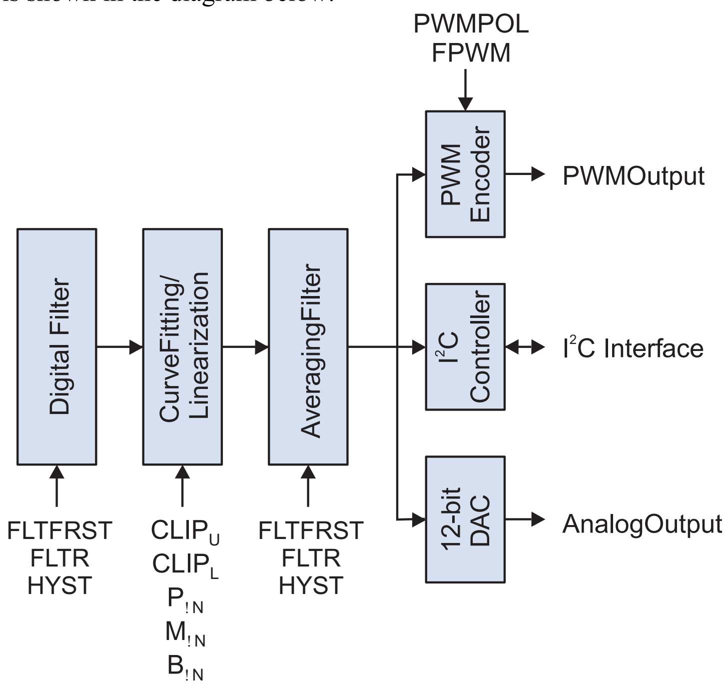

Figure 4. Signal path and key parameters through the filters and linearization engines.

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The first programmable filter prevents the output from updating unless the change in angle exceeds a programmable hysteresis parameter. The hysteresis parameter can be as low as the noise floor of the system. The hysteresis can be used to reduce sensor output, reduce system magnetic noise, or smooth otherwise abrupt transitions that may be generated by the application. The second filter is an averaging filter to dampen any rapid output changes.

Both filters can be used for aggressive signal reconditioning in noisy environments. A filter order parameter (FLTR) is used to set the combined effects of both the hysteresis and averaging, or FIR, filter. A summary of the combined filter settings is provided in the table below.

Filter Name	Nice	Mean	Aggressive	Hostile
Filter Order Parameter (FLTR)	0	1	2	3
FLTR Digital Value	00	01	10	11
FIR Filter Taps	0	0	1	3
Filter Type	Hysteresis Only		FIR and Hysteresis	

Table 3. Programmable filter configurations.

The programmable filters can be implemented before or after the PWL engine for added flexibility. This is controlled by the $FILT_{ORD}$ parameter.

The PWL engine can be used to remap the sensor output over a series of user defined continuous or discontinuous angular segments as shown in Figure 5. Each angular segment is defined by a series of user provided segmentation angles, $P_{\theta N}$ (0° to 360°) starting at the zero-angle reference. Each of up to 16 segments is defined by a linear intercept $B_{\theta N}$ (0 to100% full-scale) at the starting point of the segment and a slope through the segment, $M_{\theta N}$ (% / degree). For example, the third segment in Fig. 5 is defined by the expression $M_{\theta 2}\cdot(\theta - P_{\theta 2}) + B_{\theta 2}$.

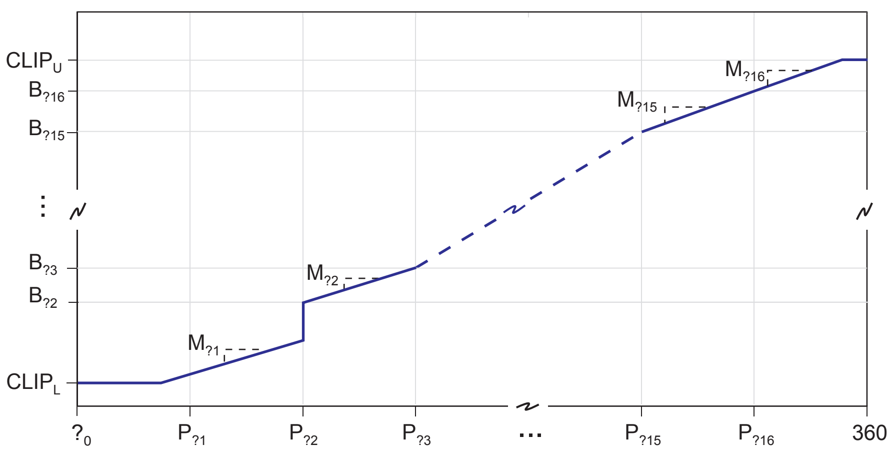

Figure 5. Illustrative piecewise linear remapping of ASR001 outputs.

All ASR001 output values are limited to maximum and minimum values defined by the upper and lower clamping limits respectively. The limits are set by $CLIP_U$ and $CLIP_L$. $CLIP_U$ and $CLIP_L$ are 14-bit values (0x3FFF = 100%, 0x1000 = 50%, etc.).

The EEPROM registers that contain mapping for the PWL parameters are defined as follows (n designates segment index from 1 to 16):
PWL_Bn: 14-bit unsigned value (bits 13:0, 0 to 16383) representing the intercept as percent of full-scale output (0 to 100).
PWL_Mn: 16-bit signed two's-complement value (bits 15:0, −32768 to 32767) representing the slope.
PWL_Pn: 10-bit unsigned value (bits 13:4, 0 to 1024) containing the start angle (0° to 360°) and a 4-bit slope shift code (bits 3:0).
PWL_COUNT: 4-bit value ranging from 0 to 15 containing the total number of segments (a value of zero corresponds to one segment).

The slope shift code in the lower four bits of register PWL_Pn represents a bit shift left (multiply by two) or bit shift right (divide by two). This allows the slope to be scaled from extremely shallow to very steep. The table below translates the slope shift code contained in the P register to the slope shift value (Sn).

PWL_Pn (bits 3:0)	Slope Shift (Sn)	Slope Scale Factor
0	16	65536
1	17	131072
2	18	262144
3	15	32768
4	14	16384
5	13	8192
6	12	4096
7	11	2048
8	10	1024
9	9	512
10	8	256
11	7	128
12	6	64
13	5	32
14	4	16
15	3	8

Table 4. PWL slope adjustments through bit shifts.

The original 12-bit output (θ_{in}) will remap to the PWL output (θ_{out}) using the function:

$$\theta_{out} = (PWL\_Bn >> 2) + (\theta_{in} - 4 * (PWL\_Pn >> 4)) * (PWL\_Mn >> S)$$

where ">>" represents a bit shift right (divide), "<<" represents a bit shift left (multiply), and both θ_{in} and θ_{out} are 12-bit values (0 to 4096) representing an angle from 0° to 360°.

The procedure for calculating register contents based on desired mapping per segment is described below:

1. Set starting values as follows:
   a. PWL_Bn = $B_{\theta N}$ / 100 ∗ 16383
   b. PWL_Pn = $P_{\theta N}$ / 360 ∗ 1024 (placed in bits 15:4)
   c. PWL_Mn = ($M_{\theta N}$) * 65536 * 360 / 100
   d. PWL_COUNT = Number of segments minus one
   e. S = 0
2. If PWL_Mn >= 32768 or PWL_Mn < -32768 then divide PWL_Mn by 2 and subtract 1 from Sn until PWL_Mn is between -32769 and 32768 or until Sn = -13
3. If PWL_Mn < 16384 or PWL_Mn >= -16384 then multiply PWL_Mn by 2 and add 1 to S until PWL_Mn is as close to 32767 (or -32768) as possible without going past it, or until Sn = 2.
4. Use the final value of Sn and the table above to find the corresponding shift code and place it into bits 3:0 of PWL_Pn.
5. Repeat steps 1through 4 until all desired segments are calculated.
6. Write final values of PWL_Pn, PWL_Bn, PWL_Mn, and PWL_COUNT registers to EEPROM.

Pseudocode for calculating registers contents based on desired mapping per segment is listed below:

```
// b = Segment intercept in units of % of full-scale (0-100)
// p = Segment start angle (0-360)
// m = Segment slope (%/deg)
// segments = Segment count

pwl_b = b / 100 * 16383;
pwl_p = (p / 360 * 1024) << 4;  // Leave lower four bits for shift code
```

```
pwl_m = m * 65536 * 360 / 100;
pwl_count = segments - 1;
s = 0;

// Maximize pwl_m value in twos-complement 16-bit space
// while keeping it within limits of shift capability.

while((pwl_m >= 32768 || pwl_m < -32768) && s > -13){
      pwl_m /= 2;
      s--;
};

while((pwl_m * 2 < 32768 || pwl_m * 2 >= -32768) && s < 2){
      pwl_m *= 2;
      s++;
};

// Calculate shift code and place in lower four bits of pwl_p

if(s<0)
 s = 2 - s;

pwl_p |= s;

// Write pwl_b, pwl_p, pwl_m, and pwl_count to EEPROM
```

Remapping Example

The default mapping of a 1:1 input to output PWL programming with one segment ($M_{\theta 1}$ = 100% / 360°, $B_{\theta 1}$ = 0, $P_{\theta 1}$ = 0) is listed below.

1. Set starting values as follows:
   a. PWL_B1 = 0/100 * 16383 = 0
   b. PWL_P1 = 0/360 * 1024 = 0
   c. PWL_M1 = (100/360) * 65536 * 360 / 100 = 65536
   d. PWL_COUNT = 0
   e. S1 = 0
2. Shift
   a. PWL_M1 = PWL_M1 / 2 = 32768, S1= S1 – 1 = -1
   b. PWL_M1 = PWL_M1 / 2 = 16384, S1 = S1 – 1 = -2
3. Skip
4. From table, an S value of -2 equals a bit code bits 3:0 of P_{regN} = 4
5. Write final values to PWL_P1, PWL_B1, PWL_M1, PWL_COUNT registers of EEPROM.

Notes:

• Segmentation angles must be in increasing order ($P_{\theta 1} < P_{\theta 2} < P_{\theta 3} \ldots P_{\theta 15} < P_{\theta 16}$).

Analog Output

The ASR001 can generate a V_{DD} proportioned analog output with a voltage value that indicates the angle. This output is generated though a delta-sigma digital-to-analog converter (DAC) with three poles of low-pass filtering. Two poles of the filter are active and on-chip. A third pole is passive and formed by a one kiloohm on-chip resistor and an external capacitor (C_{FLT}). Because of its output impedance, the analog output should be used with high input-impedance circuitry.

The maximum analog output swing is to within 50 millivolts of the supply rail and 15 millivolts of ground, so if the analog output is used, the output should be appropriately scaled.

The analog output is enabled with the OUT_A parameter.

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PWM Output

The ASR001 has a programmable pulse-width modulated (PWM) output where the duty cycle indicates the angle. The PWM frequency can be set between 15.2 Hz and 1.953 kHz with the f_{PWM} parameter, and the corresponding digital codes are shown in the table below. The OUT_{PWM} parameter enables the PWM output, and the polarity of the output waveform is programmable with the PWM_{POL} parameter.

Digital Code	PWM Frequency (f_{PWM}; KHz)
000	1.953
001	0.976
010	0.488
011	0.244
100	0.122
101	0.0610
110	0.0305
111	0.0152

Table 5. EEPROM codes for PWM frequency.

The PWM output is open drain, so an external pull-up resistor is required. The PWM output rise time depends on the pull-up resistor. A smaller pull-up resistor provides faster rise times and therefore better accuracy; larger values reduce power consumption.

I²C Interface

The I²C interface is an industry standard full-duplex 400 kHz connection with the sensor as the slave to an external master such as a microcontroller. I²C Data (SDA) and Clock (SCL) are 3.3-volt and five-volt compliant. The digital angle is read from I²C address (0x00).

Consistent with industry practice, SDA and SCL are open-drain, and pull up resistors to V_{DD} are normally needed. The SDA and SCL pins should not be left floating for proper power-up/operation, and should be tied to V_{DD} if not used.

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

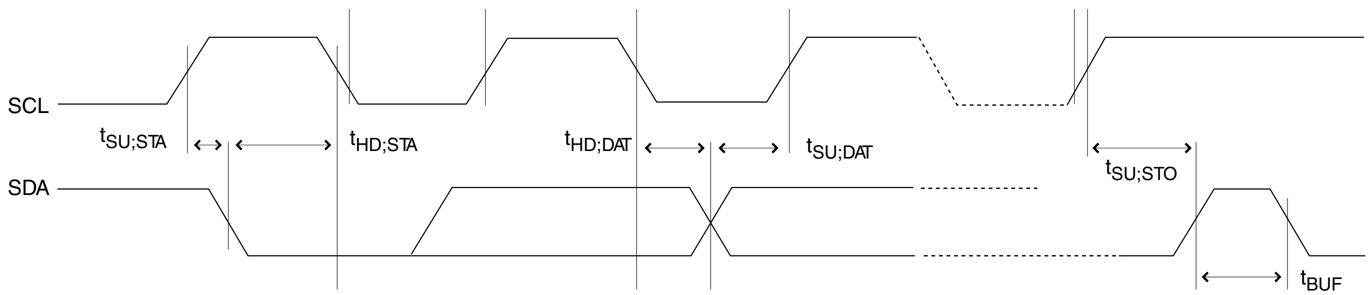

Figure 6. I²C timing diagram.

I²C Address

The ASR001 has a seven-bit address, which can be defined in the EEPROM with the I^2C_{ADD} parameter. The I²C standard reserves addresses 0 to 7, so allowable I²C addresses are 8 to 127. The factory default I²C Slave Address is 16 (0x10 hex).

I²C Deselect

A logic "LOW" on the CS pin deactivates the sensor from the I²C bus. This allows hardware selection of sensors, or programing of new Slave Addresses by temporarily disabling conflicting ASR sensors on the same bus. The pin can be disabled with the CS_{EN} parameter to avoid accidentally deselecting a sensor. The pin has an internal pull-down resistor, so it must be tied HIGH for normal operation.

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I²C Format

The I²C interface allows access to data and parameters. Address 0 is the angle, which is stored in RAM; addresses 0x01 to 0x3F are EEPROM parameters.

Reading the angle is a simple three-byte sequence. The master writes the sensor's seven-bit I²C address with read bit set; then reads the two-byte angle. This sequence can be repeated to continuously read the angle.

EEPROM is accessed with a four-byte sequence. The first byte is the sensor's I²C address, the second byte is the EEPROM address, and the third and fourth bytes are the data to be read or written.
Detailed read/write sequences are as follows:

Reading the Angle

1. The master requests two bytes of data using the sensor's seven-bit I²C device address with the read bit set.
2. The sensor will acknowledge the request after completing its most recent angle calculation (this requires up to 400 µs).
3. The Master can then read the two-byte (12-bit) angle data with the 8-bit lower data byte followed by the 4-bit upper byte.
4. This read sequence can be repeated to continuously read the angle.

Reading EEPROM Parameters

1. The Master should write two bytes--first the I²C device address, then the EEPROM memory address. The sensor will acknowledge the I²C after completing its most recent angle calculation (this requires up to 400 µs).
2. The read buffer will be loaded (this takes up to 15 µs).
3. The Master can perform a Read by providing the seven-bit I²C address with the least-significant bit high (the least-significant bit high indicates a Read per the I²C specification).
4. The device will acknowledge when there is data in the read buffer.
5. The Master reads the lower data byte, then the upper byte.
6. To read a different EEPROM address, repeat the four-byte sequence with the new EEPROM address.
7. To read the same EEPROM address again, the target memory address should first be set back to 0, and then to the desired EEPROM address. This sequence is necessary because of ambiguities caused by simply sending the same EEPROM address on consecutive sequences.
8. To return to the normal operating mode where the Master reads the angle, the address should be set back to 0 with the chip address followed by a "0."

Writing EEPROM Parameters

1. The Master should write four bytes: the chip address, the EEPROM memory address, the lower data byte, and then the upper byte.
2. The sensor will acknowledge the I²C after the current angle calculation is completed and the requested EEPROM parameters are available (this requires up to 400 µs).
3. Allow 18 ms for data to be written to the EEPROM.
4. For the piecewise linear parameters to be read from the I²C interface, the internal address needs to be changed back to the "0" default address. This is done with a two-byte I²C transfer to the device (the device I²C address byte followed by a 0).

Notes:

1. The read bit (least-significant bit) does not need to be set in Masters that do not support eight-bit addressing.
2. Angle sensing is suspended during I²C EEPROM reads and writes.
3. The ASR001 is incompatible with multi-word data transfers and only single-word transfers are supported.

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EEPROM Register

The ASR001 uses an internal EEPROM to enable user programmable parameters such as I^2C address, rotation direction, piecewise linear values, etc. The EEPROM is written using the scheme described in the I^2C interface section. Programmable parameters are listed in Table 5 with default values. The memory address and number of bits for each parameter are also provided.

Parameter	Symbol	Default	Value	EEPROM Address (hex)	Bits	Description
Device Identifiers						
Device ID	ID_{1-7}	ID_{1-7} = SN		08-0E	[15:0]	
I^2C Address	I^2C_{ADD}	16	0x10	06	[7:0]	
CS Pin Enable	CS_{EN}	Enabled	1	01	[4]	If "1," the ASR can by deselected by driving CS LOW. Set to "0" prevent accidental deselection.
Magnetic Field Parameters						
Rotation Direction	θ_{DIR}	CCW	0	01	[0]	CW = 1, CCW = 0 See Fig. 3
Zero Point	θ_0	0	0	05	[13:0]	Point at which angle is zero; see Fig. 3
Misc.						
User Lock	LOCK	Unlocked	0	07	[3:0]	Lock: 0005
Temperature Parameters						
Update Rate	T_{UPD}	2500 Hz	000	02	[6:4]	See Table 1
Update Hysteresis	T_{HYST}	0°	00000	02	[11:7]	See Table 2
Filter Parameters						
Filter	FILT	0	0	01	[3:2]	See Table 3
Filter Hysteresis	θ_{HYST}	0°	0	01	[15:8]	
Filter-PWL Sequential Order	$FILT_{ORD}$	1	1	01	[1]	Filter before PWL
Piecewise Linear Parameters						
Number of Segments	PWL_COUNT	1		0F	[13:0]	Defaults to 1:1 mapping
Segment Start Angles	$PWL\_P_{\theta N}$	0		10-1F	[15:0]	
Segment Slopes	$PWL\_M_{\theta N}$	0		20-2F	[15:0]	
Segment Intercepts	$PWL\_B_{\theta N}$	0		30-3F	[15:0]	
Lower Clipping Limit	$CLIP_L$	10°	0x01C7	03	[13:0]	
Upper Clipping Limit	$CLIP_U$	350°	0x3E38	04	[13:0]	
Analog Output Parameters						
Analog Output Enable	OUT_A	Enabled	1	1	[6]	
PWM Parameters						
Operating Frequency	f_{PWM}	500 kHz	100	2	[2:0]	See Table 5
PWM Polarity	PWM_{POL}	0	0	2	[3]	Duty cycle ~ θ
PWM Output Enable	OUT_{PWM}	Enabled	1	1	[5]	

Table 5. ASR001 Programmable Parameters.

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Control Registers	Address (hex)	Factory Default (hex)	Notes
Register 1	01	0042	
Register 2	02	0000	
Lower Clamp Limit	03	01C7	14-bit value
Upper Clamp Limit	04	3E38	14-bit value
Zero-Angle Reference	05	0000	14-bit value
I^2C Address	06	0008	6-bit value
Customer Lock	07	0000	4-bit value
Device ID	08-0E	Factory ID	
PWL Segment Count	0F	0000	4-bit value
PWL Segment Angles	10	0004	Bits [14:4] start angle Bits [3:0] shift code
	11-1F	0000	
PWL Segment Slopes	20	4000	16-bit signed value
	21-2F	0000	
PWL Segment Intercept	30-3F	0000	14-bit unsigned value

Table 6. Default EEPROM Register Settings

Supply and Reference Decoupling

V_{DD} and V_{REF} should be bypassed with 0.1µF capacitors placed as close as possible to the pins.

Analog Output Capacitor

If the analog output is used, an external 0.01 µF capacitor is recommended between A_{out} and GND to form the last stage of a reconstruction filter.

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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.

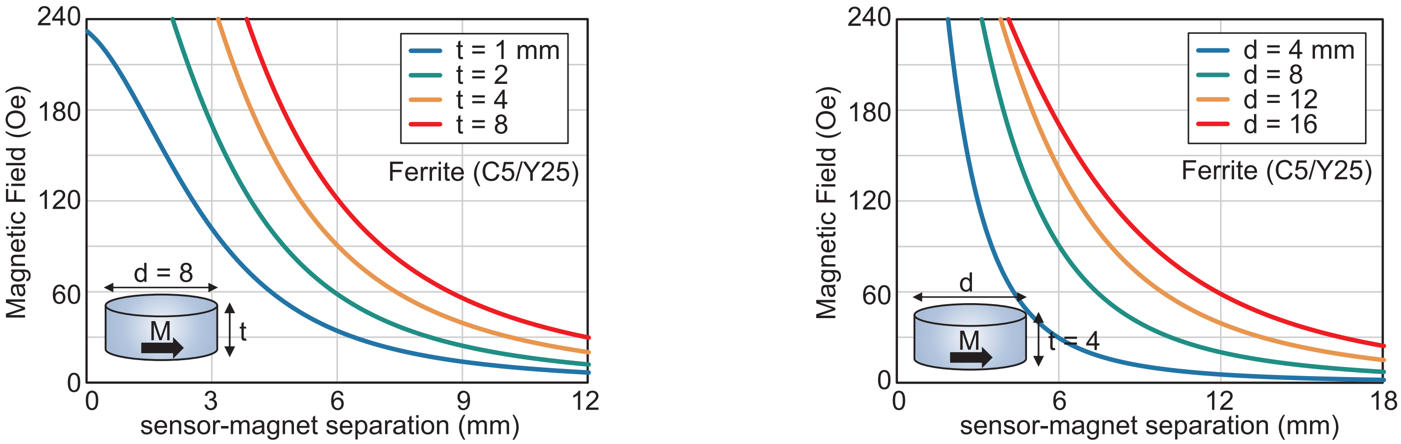

Figure 7. Magnetic fields for various geometries of C5/Y25 ferrite magnets plotted for the distance between the magnet and sensor. Magnets with 8 mm diameter and various thicknesses are shown at left. Four millimeter thick magnets of various diameters are shown at right.

Smaller magnets produce larger field gradients as shown in Fig. 7. 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 evaluation 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 or use NVE's web apps to determine the optimum operating separations for other magnet sizes and materials at https://www.nve.com/spec/calculators.php. NVE's Online Store also lists compatible magnets.

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

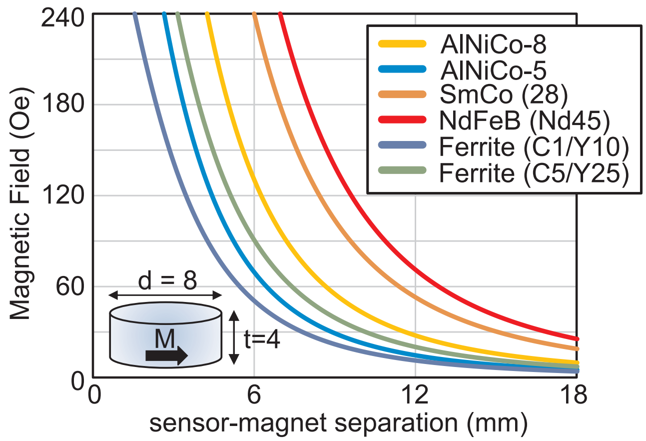

Figure 8. Magnetic fields from an 8 millimeter diameter, 4 millimeter thick magnet for increasing magnet-sensor separation. NdFeB materials produce the largest magnetic fields and separations. SmCo and AlNiCo materials offer the highest operating temperatures. Ferrite magnets are the most cost-effective.

Absolute position

Unlike some encoder types, ASR001 sensors detect absolute position and maintain position information when the power is removed. The sensor immediately powers up indicating the correct position.

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I/O Equivalent Circuits

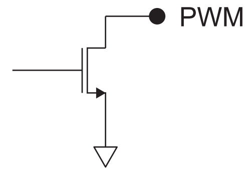

Figure 9. PWM digital output equivalent circuit.

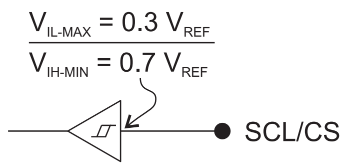

Figure 10. Digital input (SCL and CS) equivalent circuit.

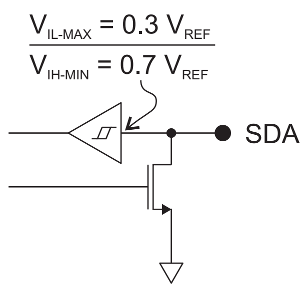

Figure 11. Bidirectional I^2C pin (SDA) equivalent circuit.

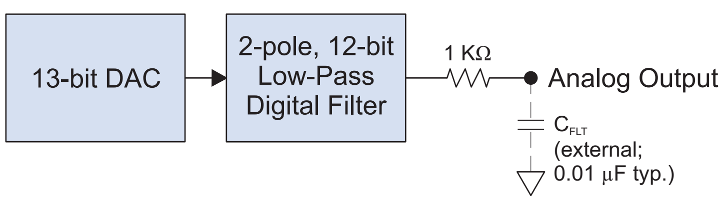

Figure 12. Analog output equivalent circuit.

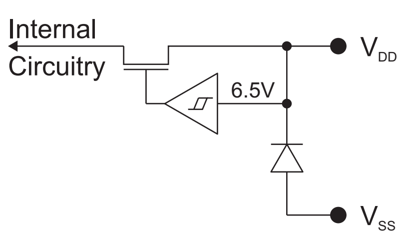

Figure 13. Overvoltage/reverse voltage protection equivalent circuit.

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Typical Performance Graphs

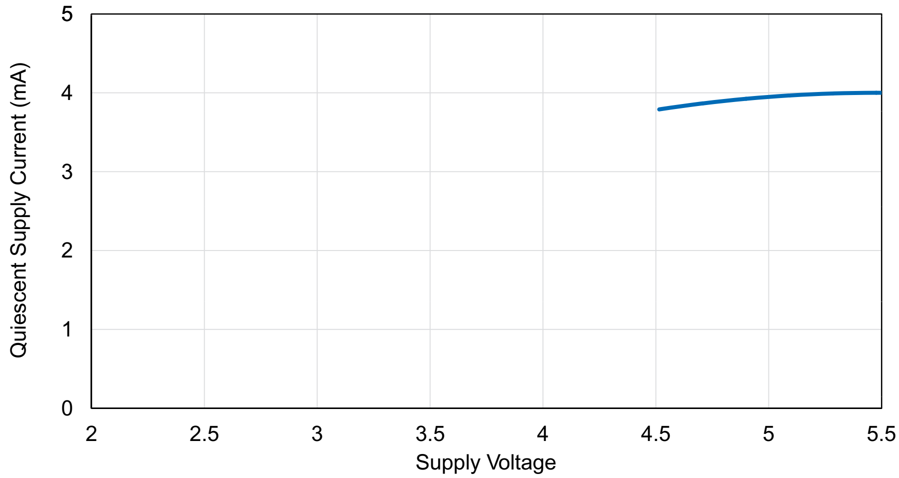

Figure 14. Typical Quiescent Supply Current (25°C).

Illustrative Microcontroller Code

```
/*********************************************************************************
Reads an out-of the-box ASR001 angle sensor with an Arduino Uno and outputs the angle
via the serial port. I2C SDA on A4; SCL on A5.
*********************************************************************************/

#include <Wire.h> //I2C library
int angle; //Measured angle

void setup() {
  Serial.begin(9600); //Initialize serial communication at 9.6 kbps
  Wire.begin(); //Join I2C bus as master
}

void loop() {
  Wire.requestFrom(8,2); //Request two bytes from address 8 (ASR001)
  while(Wire.available()) { //Wait for data
    angle = Wire.read() & 0xFF; //Receive lower byte
    angle |= Wire.read() << 8; //Receive upper byte (four bits) and shift into position

  Serial.println(float(angle)/4096.0*360.0); //Scale and print angle
  }
delay(500); //Two samples per second
}
```


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```
/************************************************************************************
Calculates instantaneous rotational speed and direction using an ASR001 angle sensor
with an Arduino Uno. I2C SDA on A4; SCL on A5. PWM outputs for demonstration purposes.
************************************************************************************/
#include <Wire.h> //I2C Library
int angle; //Measured angle
int angleOld; //Previous angle measurement
int spd; //Instantaneous rotational speed
bool ref; //The angular reference output; TRUE if 0 < angle <  refWidth
const int refWidth = 12; //Width of the reference pulse in angular degrees

const int spdPWMpin = 9; //Analog speed output pin
const int cwLEDpin = 2; //LED pins (w/150 Ohm resistors for 20 mA LEDs; 1.5K for 2 mA)
const int ccwLEDpin = 5;
const int refLEDpin = 3; //Zero-angle reference indicator pin

void setup() {
  pinMode(cwLEDpin, OUTPUT);
  pinMode(ccwLEDpin, OUTPUT);
  pinMode(refLEDpin, OUTPUT);
  Serial.begin(9600);
  Wire.begin(); //Join I2C bus as master
}
void loop() {
  Wire.requestFrom(8,2); //Request two bytes from sensor (address 8)
  while (Wire.available()) { //Wait for data
    angle = Wire.read() & 0xFF; //Receive lower byte
    angle |= Wire.read() << 8; //Receive upper byte (4 bits)

  spd = (angle-angleOld);
  ref = long(angle)*360L/4096L < refWidth; //Update the reference output

//Output direction, reference, and speed
    digitalWrite(ccwLEDpin, spd>0);
    digitalWrite(cwLEDpin, spd<0);
    digitalWrite(refLEDpin, ref);
    analogWrite(spdPWMpin, abs(spd));
  angleOld = angle;
delay(10); //100 samples/second
  }
  }
```

Application Circuits

Typical Microcontrollers Interface

A typical microcontroller interface is shown below:

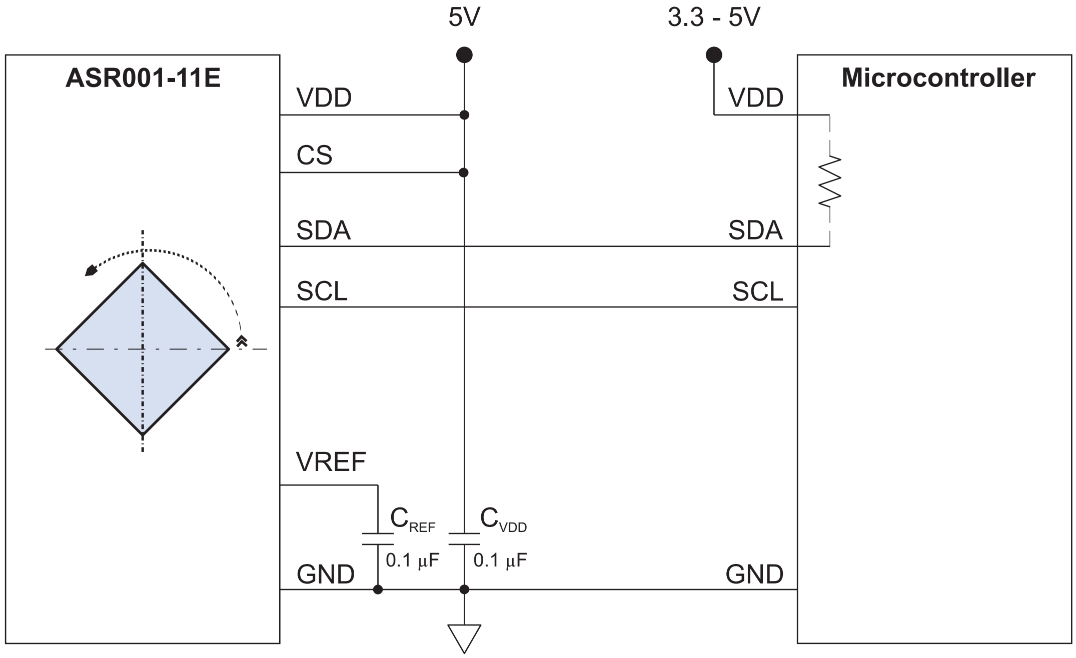

Figure 15. Typical microcontroller interface.

The ASR001 is configured as a Slave and the microcontroller should be configured as the Master. The ASR001 I^2C interface is compatible with 3.3 or 5 volt microcontrollers.

The ASR001 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 microcontroller supply.

Sensor analog and PWM outputs provide versatility but are not normally needed with I^2C microcontrollers.

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:

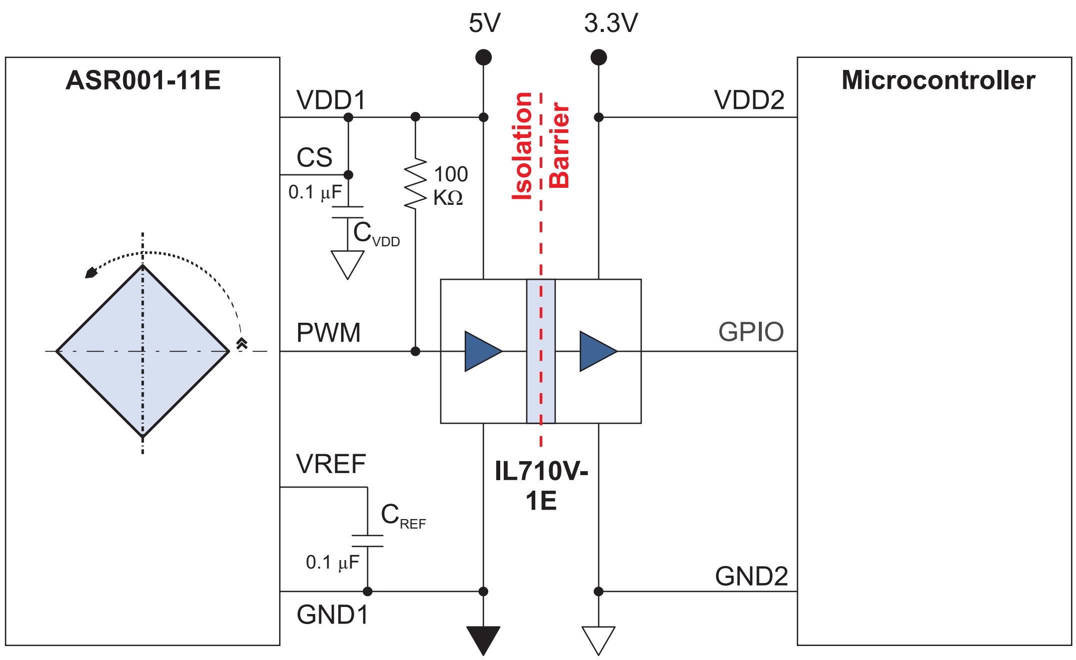

Figure 16. Double-isolated microcontroller interface.

Since it is single-channel and unidirectional, the PWM output can be easily isolated with just a single-channel digital isolator. The I^2C 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 five-volt sensor and a 3.3-volt microcontroller.

The PWM signal can be decoded by the microcontroller using commonly-available routines. If speed is not critical, the isolated PWM signal can be filtered with a resistor and capacitor and connected to a microcontroller analog input.

The ASR001 SDA and SCL pins should be tied to V_{DD} if not used.

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Hardware Selection of Multiple Sensors

The ASR001's CS can be used for hardware selection of multiple ASR001 sensors with the same Slave addresses. This mode of selection works with factory-default sensors without having to reset addresses for different sensors. The CS should be driven HIGH for the sensor to be activated, with the other CS pins LOW:

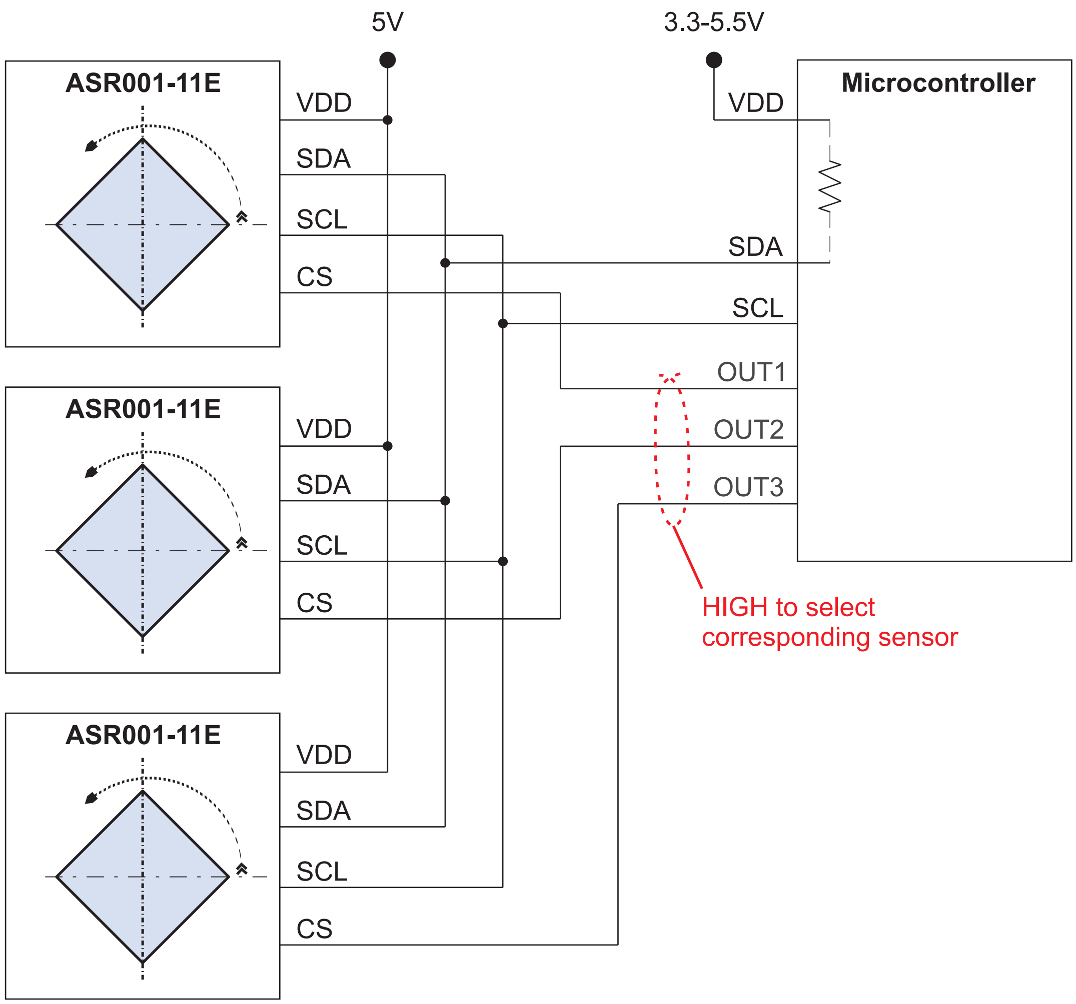

Figure 17. Hardware selection of multiple sensors.

Absolute Position Reference Using the Analog Output

ASR001 sensors detect absolute, rather than relative position, which eliminates the need for a second sensor to detect an angular reference point. If a hardware reference is needed, it can be generated using the Analog Output.

A comparator on the analog output can be used to detect the analog output discontinuity at the transition from 360° to 0° set by θ_0. The comparator can be used to drive other hardware. In the following circuit, positive comparator transitions provide extremely precise indications of the zero-degree reference position:

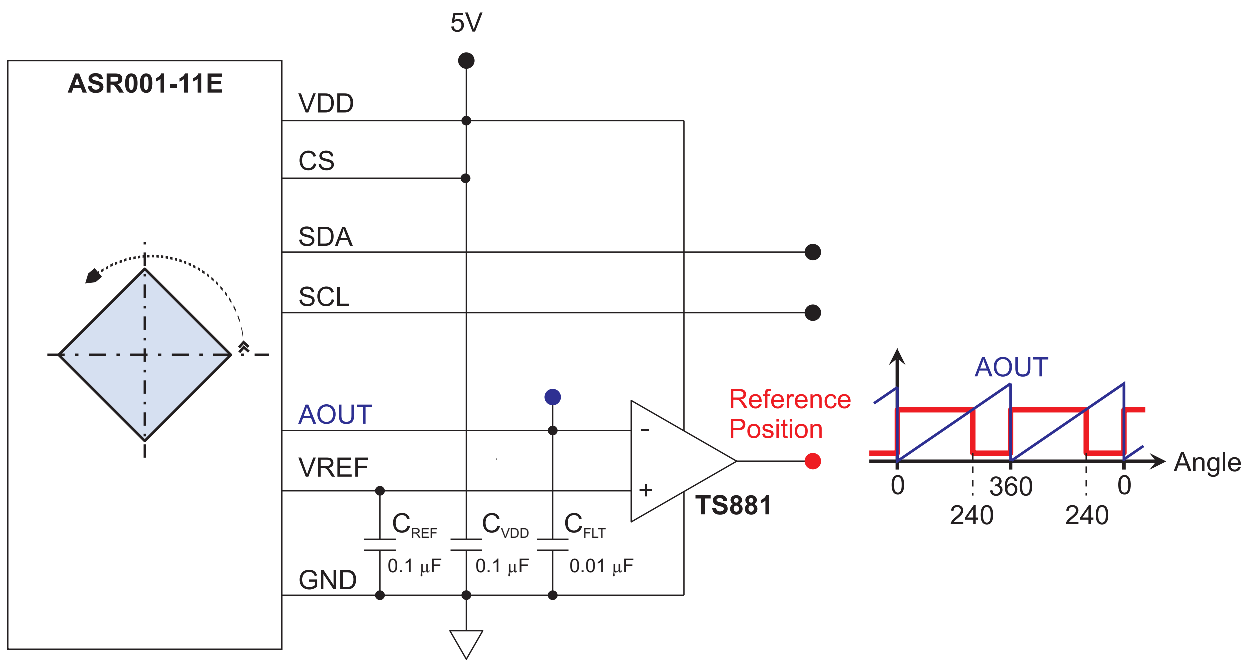

Figure 18. Generating an absolute position reference.

Because it is detecting a discontinuity, the zero-degree accuracy (the positive comparator transition in the illustration above) does not depend on comparator hysteresis or the exact threshold. A low-hysteresis comparator such as a TS881 improves the precision of the negative transition. With a full-scale analog output (5 volts at 360°), the negative transition point is at 240°. The output can be scaled to 5 volts at 360°, and although it will not quite swing rail-to-rail, the circuit above will still operate properly. The negative transition point can be adjusted by scaling the analog output in the ASR001, or by adding a voltage divider to one of the comparator inputs.

If a precise negative transition point is not required, the analog output can simply drive a CMOS gate as a reference.

A similar function can also be implemented with the PWL so that the analog output switches at particular angles, although continuous angle information would no longer be available.

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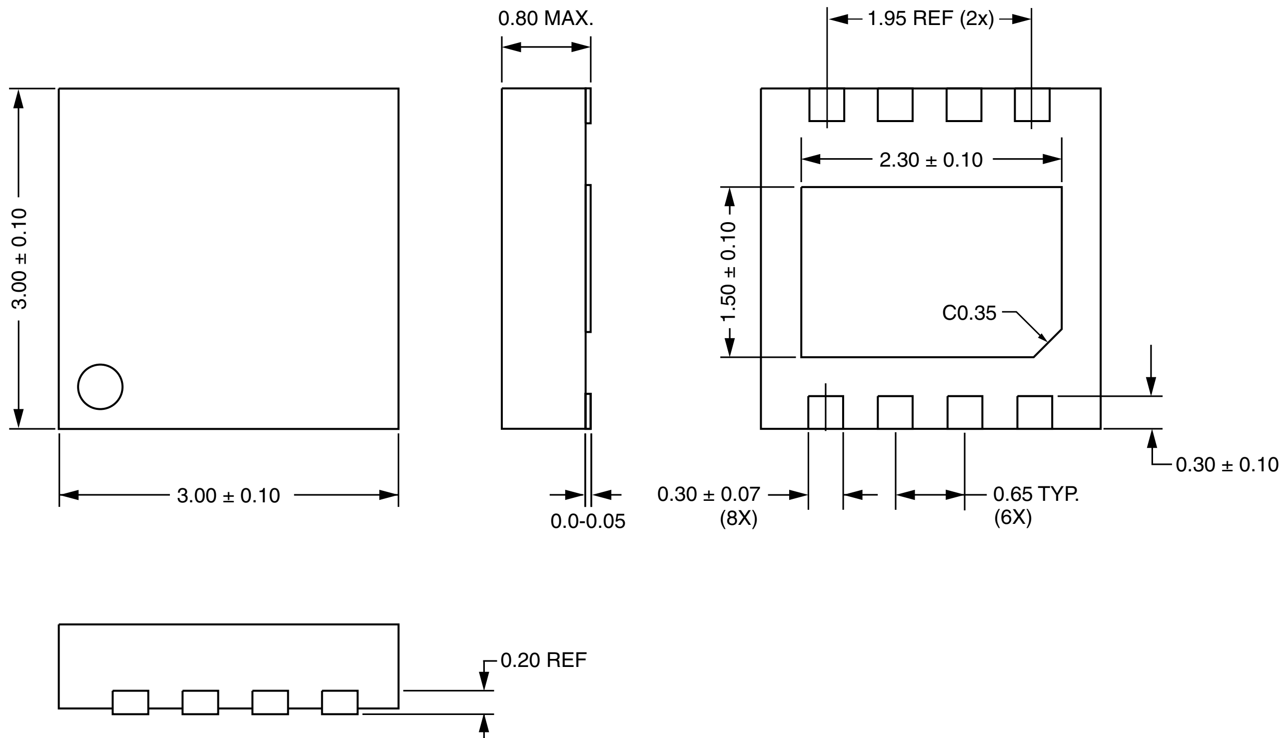
3 x 3 mm TDFN8 Package (approx. 15x actual size)



RoHS COMPLIANT

Pin	Symbol	Description
1	VDD	Power Supply (bypass with a 0.1 µF capacitor).
2	VREF	Voltage Reference Output (bypass with a 0.1 µF capacitor).
3	AOUT	Analog Output (filter with a 0.01 µF capacitor if used).
4	GND	Ground / V_{SS}.
5	PWM	PWM Output.
6	CS	Chip Select input. LOW disables the Sensor from the bus; tie HIGH for normal operation.
7	SCL	I^2C Clock (input).
8	SDA	I^2C Data (bidirectional/open drain).

Notes:

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

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Ordering Information

ASR 001 B - 11E TR13

Product Family
ASR = Smart Sensors

Base Part Number
001 = Rotational Sensor

Field Range Identifier
Blank = General Purpose (30-200 Oe)
A = Optimized for 30-70 Oe
B = Optimized for 70-150 Oe
C = Optimized for 140-200 Oe

Part Package
11E = RoHS-Compliant 3 x 3 mm TDFN8 Package

Bulk Packaging
TR13 = 13" Tape and Reel Bulk Packaging

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Revision History

SB-00-057-PRELIM2
May 2018

Change
- Corrected package drawing dimensions.
- Additional specifications.

SB-00-057-PRELIM
April 2018

Change
- Preliminary release.

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SB-00-057_ASR001-11_Prelim2

May 2018