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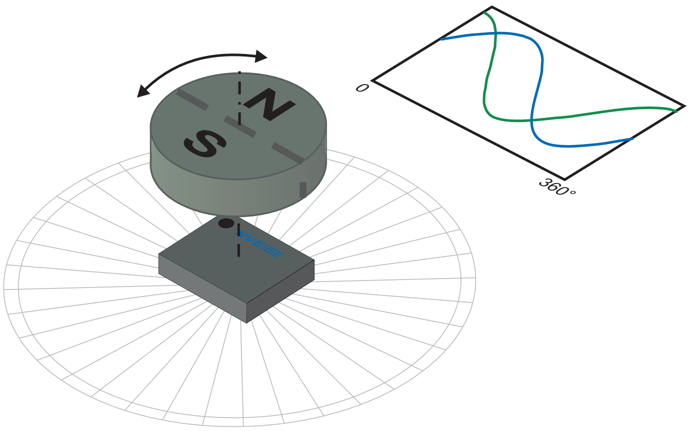
AAT003 Low-Resistance TMR Angle Sensors



Features

- Tunneling Magnetoresistance (TMR) technology
- Low power
- High output signal without amplification
- Immune to airgap variations
- Operates with as little as 30 Oersted field
- Sine and cosine and outputs
- −40°C to +125°C operating temperature
- Ultraminiature TDFN6 packages

Applications

- Battery-powered applications
- Knob position sensors
- Rotary encoders
- Direct microcontroller interfaces
- Automotive rotary position sensors
- Motor shaft position sensors

Description

AAT00x angle sensors use unique Tunneling Magnetoresistance (TMR) elements for large signals and low power consumption.

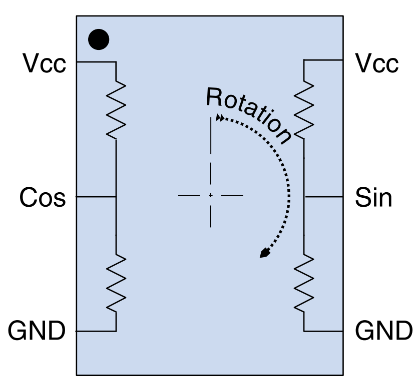
The AAT003 is a low-resistance member of NVE's ground-breaking AATxxx family, with a typical bridge resistance of 40 kilohms versus the megohm range for the AT001 and AAT009.

The lower device resistance reduces Johnson noise, and is also ideal for direct microcontroller interfaces because its lower output impedance can quickly charge microcontroller sample-and-hold input stages.

The sensors provide sine and cosine signals defining the angle of rotation. Outputs are proportional to the supply voltage and peak-to-peak output voltages are much larger than conventional sensor technologies.

Parts are packaged in NVE's 2.5 mm x 2.5 mm x 0.8 mm TDFN6 surface-mount package.

Functional Diagram



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Absolute Maximum Ratings

Parameter	Min.	Max.	Units
Supply voltage		7	Volts
Reverse supply voltage		−12	Volts
Storage temperature	−40	170	°C
ESD (Human Body Model)		2000	Volts
Applied magnetic field		Unlimited[1]	Oe

Operating Specifications

Parameter	Symbol	Min.	Typ.	Max.	Units	Test Condition
Operating temperature	T_{min}; T_{max}	−40		125	°C	
Device resistance		20	40	60	kΩ	25°C with required magnetic field.
Peak-to-peak output signal	V_{PP-SIN} V_{PP-COS}	130	200		mV/V	Over full rotation.
Offset voltage	$V_{OFFSET-SIN}$ $V_{OFFSET-COS}$	−10		+10	mV/V	
Supply voltage	V_{CC}	0		5.5	V	
Required applied magnetic field		30		200	Oe	
Repeatability, fixed bias[2]				±0.5	deg.	
Repeatability, variable bias[3]				±3	deg.	
Nonsinusoidality[4]			±1.5%		% of peak-to-peak output; 50 Oe applied field; 25°C	
Temperature coefficient of resistance	TCOR		+0.09		%/°C	
Output voltage temperature coefficient	TCOV		−0.13		%/°C	Constant supply voltage.

Notes:

1. Large magnetic fields CANNOT damage NVE sensors.
2. "Fixed Bias" means a fixed airgap between the bias magnet and sensor so the magnetic field at the sensor is constant.
3. "Variable Bias" means the magnetic field strength at the sensor can vary across the specification range.
4. Maximum deviation of either output from an ideal sine wave.

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Operation

Overview—Unique TMR technology
The heart of the unique sensor is an array of four Tunneling Magnetoresistance (TMR) elements in each quadrant. TMR technology enables low power and miniaturization, making the sensors ideal for battery operation.

In a typical configuration, an external magnet provides a saturating magnetic field in the plane of the sensor, as illustrated below for a bar magnet and a radially-magnetized disk magnet:

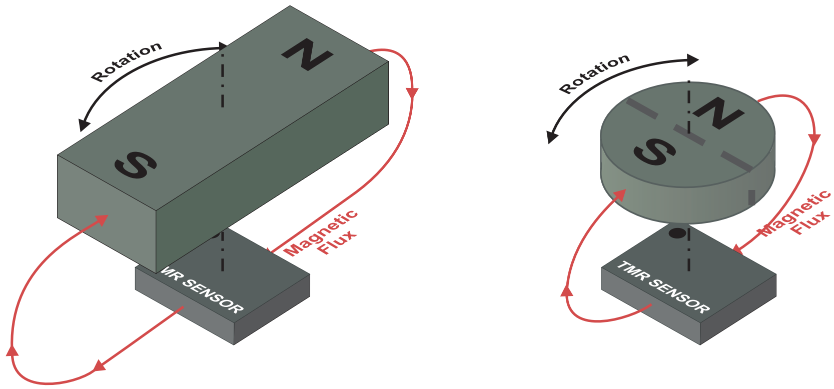

Figure 1. Sensor operation.

The device contains four sensing resistors at 90 degree intervals. The resistors are connected as two half-bridges, providing the sine and cosine voltage outputs. For each half bridge, the resistance of one element increases and the other decreases as the field rotates. Thus the bridge resistance, device resistance, and output impedances remain constant with rotation.

Transfer function
The half-bridge configuration provides a simple interface and can simplify external circuitry such as amplifiers and comparators. Outputs are sinusoidal, centered around half the supply, and ratiometric with supply voltage. Mathematically, the outputs can be expressed as:

$$V_{SIN} = [V_{CC\text{-}SIN}][(V_{SIN\text{-}MAX} - V_{SIN\text{-}MIN}) / 2)\text{Sin}\,\theta + V_{CC\text{-}SIN} / 2 + V_{OFFSET\text{-}SIN}]$$

$$V_{COS} = [V_{CC\text{-}COS}][(V_{COS\text{-}MAX} - V_{COS\text{-}MIN}) / 2)\text{Cos}\,\theta + V_{CC\text{-}COS} / 2 + V_{OFFSET\text{-}COS}]$$

Where:

θ is the magnetic field angle;

V_{COS} and V_{SIN} are the sensor output voltages (mV/V);

$V_{CC\text{-}SIN}$ and $V_{CC\text{-}COS}$ are the sensor supply voltages (normally tied together);

$V_{SIN\text{-}MAX}$, $V_{COS\text{-}MAX}$, $V_{SIN\text{-}MIN}$, and $V_{COS\text{-}MIN}$ are the sensor output peak signal levels (mV/V); and

$V_{OFFSET\text{-}SIN}$ and $V_{OFFSET\text{-}COS}$ are the sensor offset voltages (mV/V),
defined as the average of the maximum and minimum outputs minus half the supply voltage.

Wide range of magnets and magnet locations
The sensors operate with fields from 30 Oe 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 radially-magnetized ferrite disk magnets can be used with these sensors in production. Bar magnets are also used in some configurations.

Ideal for battery-powered applications

AAT-Series sensors are resistive devices with no active components, so they have no minimum voltage and can be powered from single cells.

The following chart shows a typical sensor output versus the angle of applied field at different air gaps:

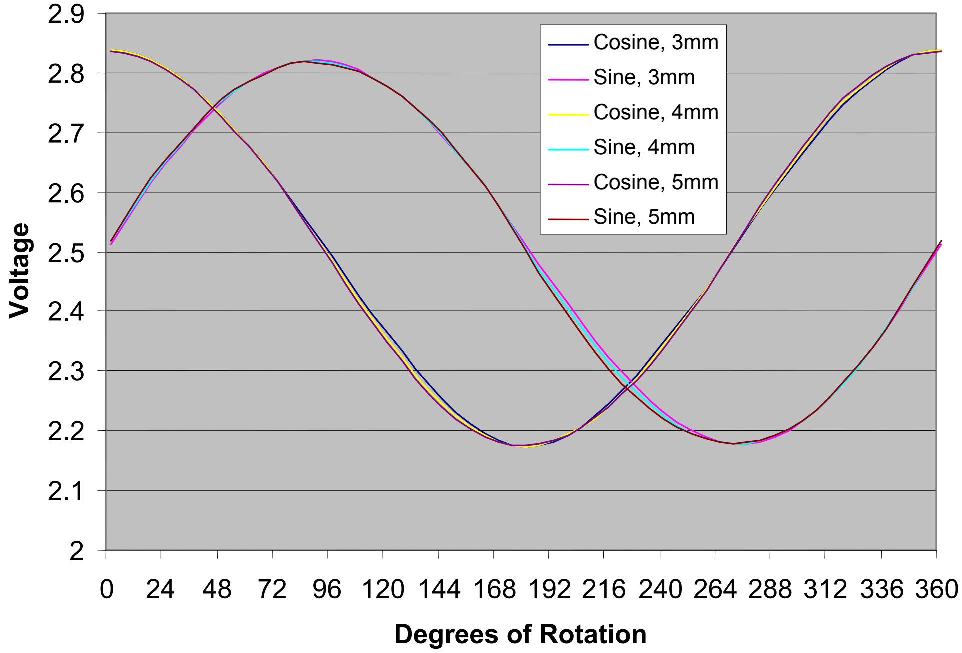

Figure 2. AAT003 Typical Output with Variations in Airgap (5V supply; 12 mm diameter, 4 mm thick split-pole ferrite magnet; 5 V supply).

One cycle per revolution

Other sensor types such as AMR have two cycles per revolution, so they cannot determine absolute position for 360-degree rotation. AAT-Series sensors output one cycle per revolution and can unambiguously determine position within a full rotation.

Detects absolute position

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

Application Circuitry

External comparators

A dual comparator can provide digital outputs from AAT angle sensors. Low-power comparators and large resistors are used to avoid adding power consumption to low-power applications:

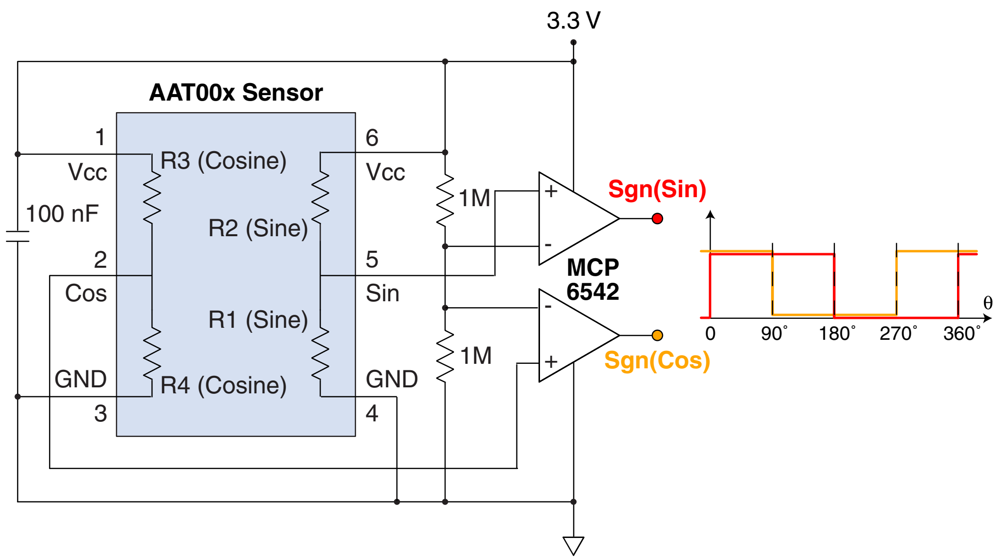

Figure 2. External dual comparator for digital outputs.

Inherent comparator hysteresis eliminates noise at the transition points. The MCP6542 comparator hysteresis of 3.3 mV corresponds to about 1 angular degree of hysteresis. Higher hysteresis comparators can be used for more noise immunity at the expense of hysteresis.

NVE also offers ADT-Series sensors that include integrated comparators to replicate the circuit of Figure 2.

Quadrant outputs

A 2-to-4 line decoder can provide digital signals to indicate the quadrant of rotation:

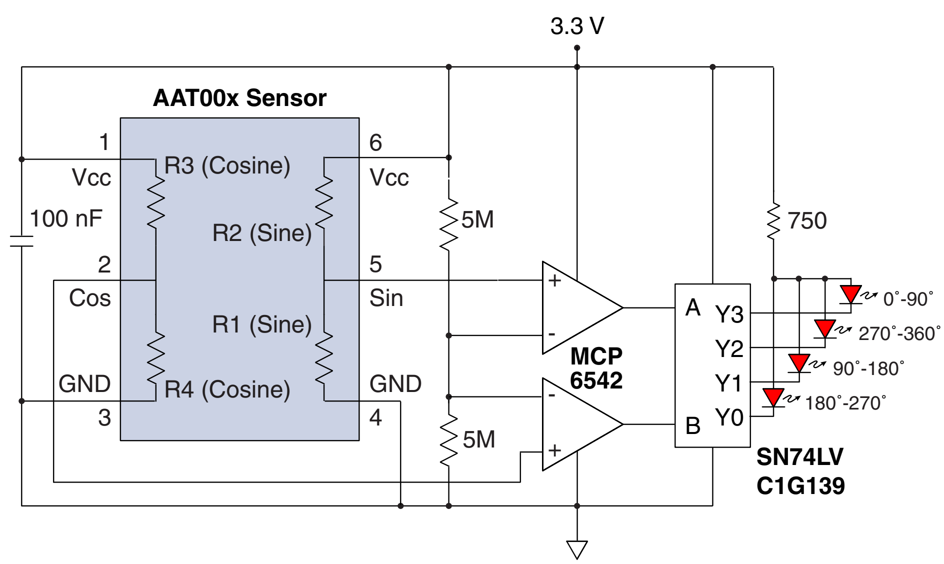

Figure 3. Digital Quadrant Outputs.

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Speed and direction signals
Commodity CMOS circuits can be added to create a precise encoder with direction and speed outputs. A flip-flop determines direction by detecting the phasing between the two outputs. An exclusive-OR gate provides a digital signal with two cycles per revolution, and transitions every 90 degrees:

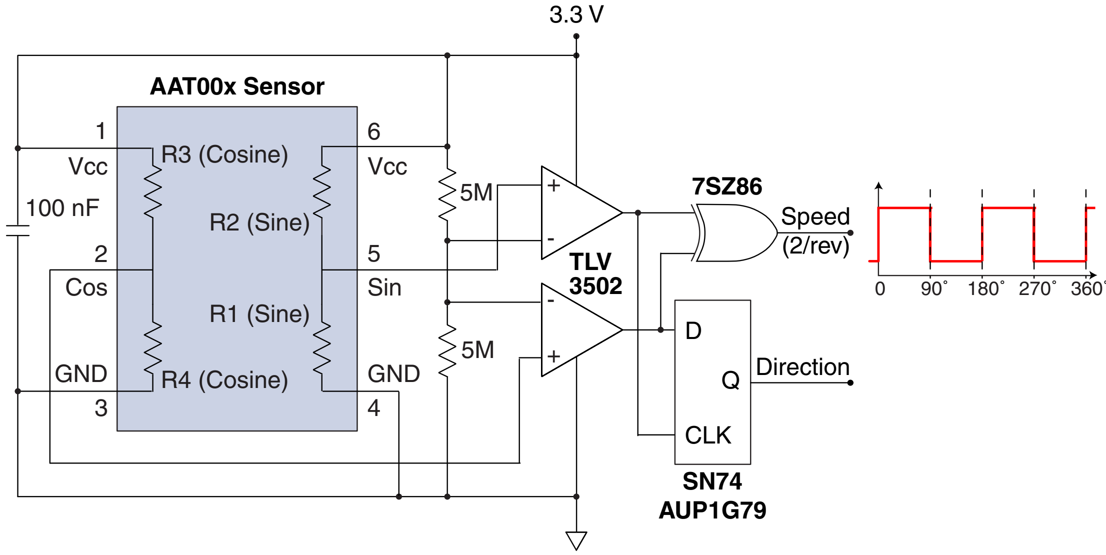

Figure 4. Speed and direction signals.

Rotation reference signals
An AAT angle sensor and a single comparator can provide a precise angular reference point and a one cycle-per-rotation signal. Comparing the sine and cosine outputs is more precise than comparing either to a reference because it corrects for temperature.

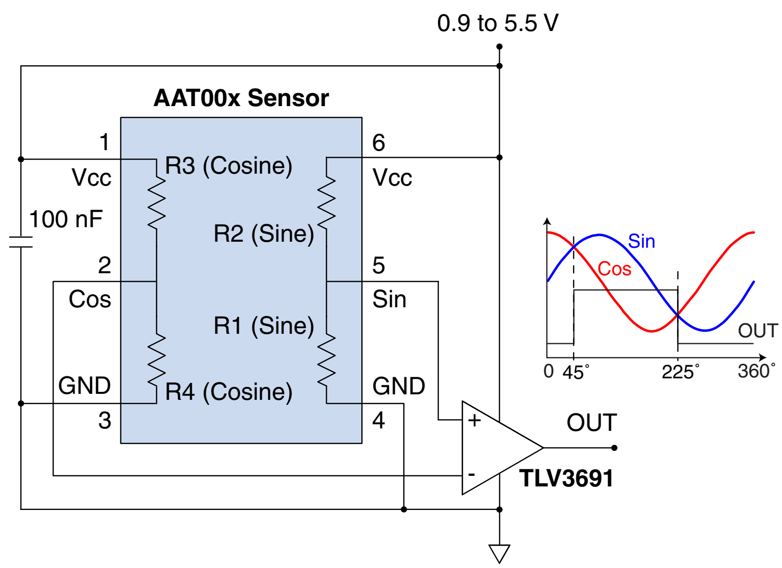

Figure 5. Angular Reference Point Rotation Signal.

In this circuit, the output is high from nominal 45 to 225 degrees, and low from 225 to 45 degrees. The TLV3691 comparator hysteresis of 17 mV corresponds to approximately 6 degrees of hysteresis with a 1.5 V supply. A TS881 or similar comparator has a typical hysteresis of 4 mV, corresponding to 1.5 angular degrees of hysteresis.

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Simple amplification

AAT-Series sensors have high output signals without amplification, but if amplification is required, a circuit like the one below can be used. The gain of three amplifies the AAT006 sensor's typical peak-to-peak signal level of 200 mV/V to 60% of rail-to-rail (one volt/volt), providing more usable signal without risk of saturating the amplifier for a sensor at the high end of the output signal range:

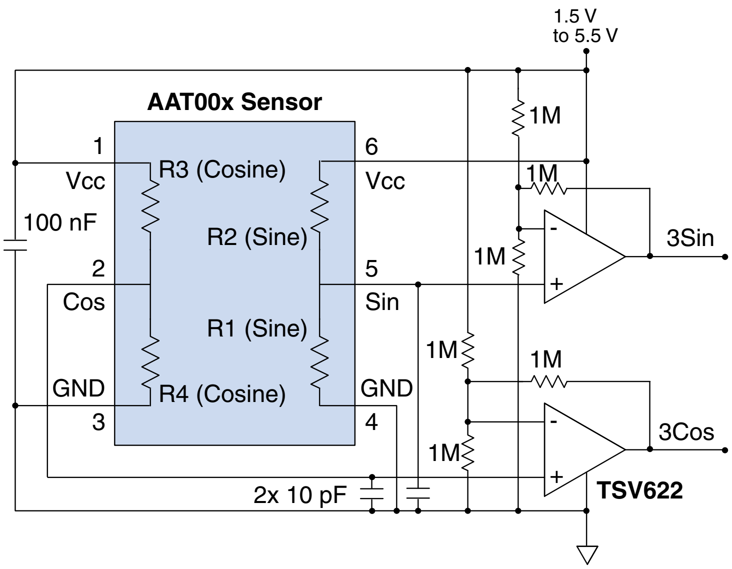

Figure 6. 3x Preamplifier.

Although AAT006 sensors are designed to be used primarily as two half bridges, if quadrature outputs are not required, a similar differential amplifier circuit can provide a larger signal, more precision, and less temperature dependence than either the sine or cosine output alone:

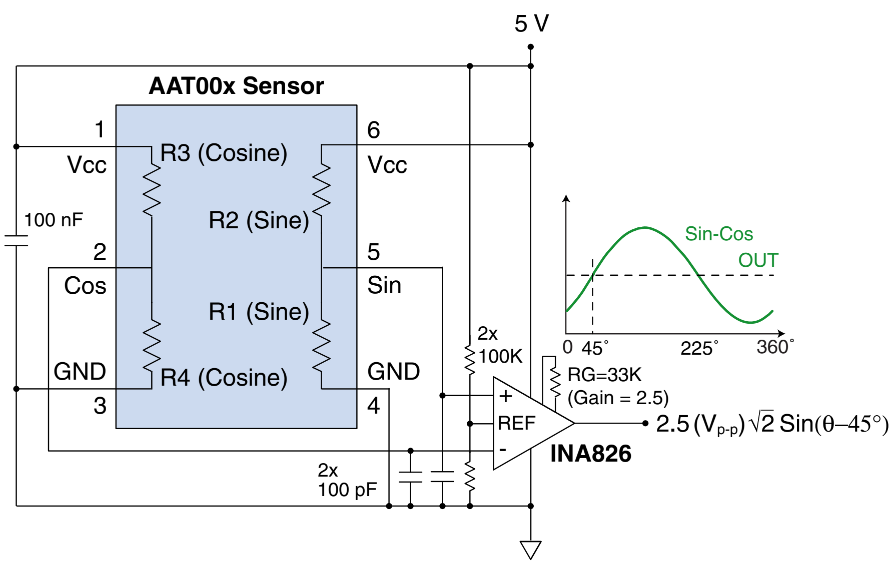

Figure 7. 2.5x Differential Amplifier.

n this circuit, the output is high from nominal 45 to 225 degrees, and low from 225 to 45 degrees. A low voltage, low quiescent current comparator is used to preserve the AAT sensors' ultra-low power and wide supply range. Inherent comparator hysteresis eliminates noise at the transition points. The TLV3691 comparator hysteresis of 17 mV corresponds to approximately 6 degrees of hysteresis with a 1.5 V supply. A TS881 or similar comparator has a typical hysteresis of 4 mV, corresponding to 1.5 angular degrees of hysteresis.

Noise mitigation

High-impedance circuitry is inherently susceptible to noise. Common noise mitigation steps include:

- Power supply decoupling capacitors near the sensor (100 nF typical).
- Limiting the sensor output bandwidth to only what is needed. Because the sensor outputs are resistive, filter capacitors can be connected directly to the outputs. The sensor output impedances are half the bridge resistance, so the cutoff frequency is:

  $$f_c = 1/(\pi R_B C)$$

  where R_B is the bridge resistance and C is the output capacitance.
- Digital filtering or averaging in microcontroller systems.

External comparator considerations

Low voltage, low quiescent current comparators are generally used to preserve the AAT sensors' ultra-low power and wide supply range.

Some hysteresis in external comparators is desirable to reduce noise and jitter at transition points. Too much hysteresis, however, may cause undesirable errors. Low-hysteresis comparators are especially important in low voltage applications, since hysteresis is a larger portion of the signals. Angular hysteresis relates to comparator hysteresis as follows:

$$\theta_H = \frac{(360/\pi)(V_{HC})}{(V_{CC})(V_{PP})}$$

Where:

θ_H the angular hysteresis in degrees;
V_{HC} is the comparator's hysteresis;
V_{CC} is the sensor power supply; and
V_{PP} is the sensor's peak-to-peak sensitivity (typically 200 mV/V).

For example, MCP6542 comparators have hysteresis of 3.3 mV, corresponding to about 1 angular degree of hysteresis. TLV3691 or similar comparators have hysteresis of 17 mV, corresponding to approximately 6 degrees of hysteresis with a 1.5 V supply.

Simple microcontroller interfaces

With their large output signals, AAT sensors can often interface directly to microcontrollers, even the 10-bit ADCs built into an inexpensive microcontroller such as an Atmel AVR®. Such microcontrollers are common in Arduino and other sensor interface boards:

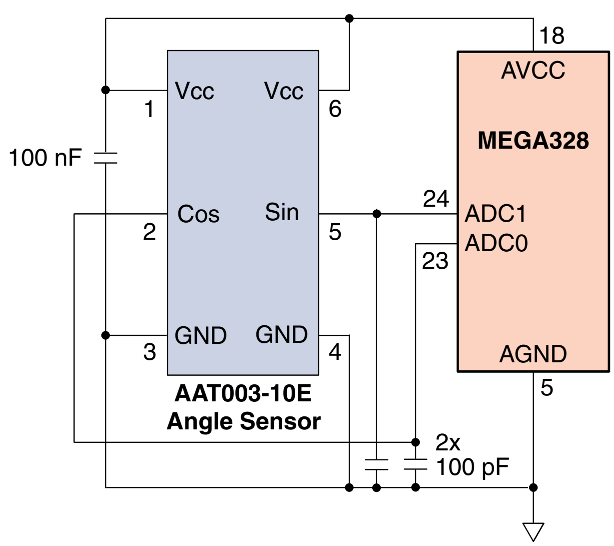

Figure 8. Typical direct microcontroller interface.

The AAT003 has a 40 kΩ typical device resistance (20 kΩ output impedances), which is ideal for direct interface to many microcontrollers. The other, higher-resistance AAT versions generally require buffering between the sensor and microcontroller to avoid slow readings and loading the sensor output.

The indicated angle can be calculated as the inverse tangent of the ratio of the sine to cosine outputs. Alternatively, the inverse sine or cosine of one of the outputs could be used with correction for amplitude. Because the arctangent calculation is a ratio, it does not require scaling, and power supply and temperature variations cancel. Also, unlike single-variable *asin*, *acos*, and *atan* functions, a *two-variable* arctangent calculation provides a full 360-degree angle range without secondary corrections.

Here is an example for a full-bridge sensor:

```
angle = atan2(float
(analogRead(0)- analogRead(1)),float(analogRead(2)- analogRead(3)))*180/pi;
```

And here is for a half-bridge sensor:

```
angle = atan2(float(analogRead(0)-256),float(analogRead(1)-256))*180/pi;
```

These program line reads the sensor outputs; subtracts the offset for the half-bridge sensors (typically half of full scale, or 256 for a 10-bit ADC); and converts from radians to degrees by multiplying by 180/π.

A program line that allows amplitude and offset calibration using the minimum and maximum of each output through a complete rotation, is as follows:

```
angle = atan2(float(analogRead(0)-(cosmin+cosmax))/(cosmax-cosmin),
   float(analogRead(1)-(sinmin+sinmax))/(sinmax-sinmin))*180/pi;
```

Of course, multipoint calibration is also possible to correct for subtle sensor and mechanical system nonlinearities and inaccuracies.

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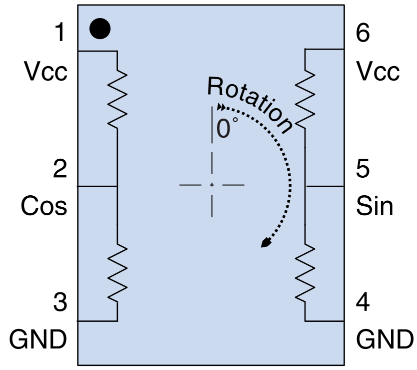
Pinout



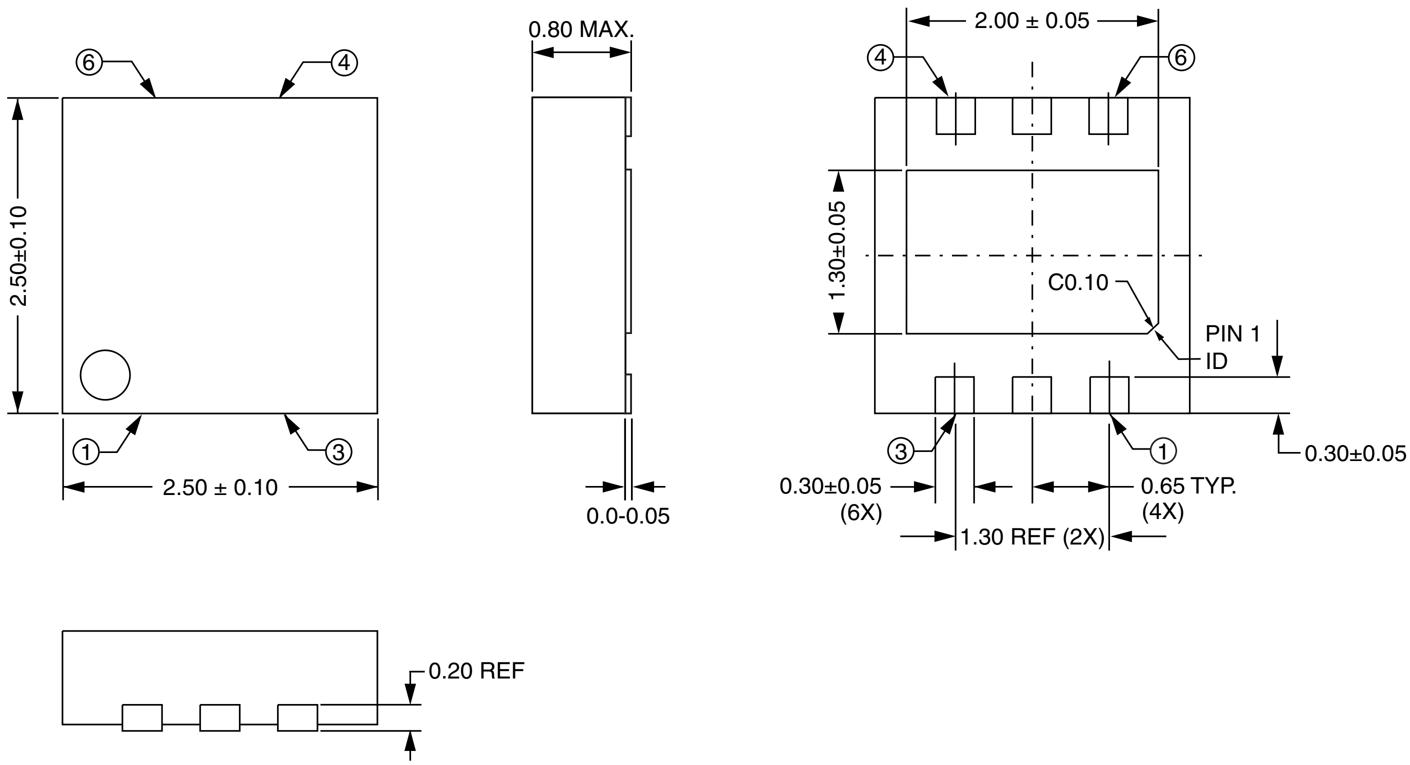
Part Marking: "FCPe"

AAT00x Pin	Symbol	Description
1	$V_{CC\text{-}COS}$	Supply voltage (up to 5.5 V) for the Cos sensor elements.
2	Cos	Corresponds to the cosine of the rotation angle.
3	GND	Ground for the Cos sensor elements.
4	GND	Ground for the Sin sensor elements.
5	Sin	Corresponds to the sine of the rotation angle.
6	$V_{CC\text{-}SIN}$	Supply voltage for the Sin sensor elements.

Notes:

- Clockwise rotation as viewed from the top of the package is interpreted as increasing angle.
- The package center pad may be left floating or connected to ground.
- This product has been tested for electrostatic sensitivity to the limits stated in the specifications. However, NVE recommends that all integrated circuits be handled with appropriate care to avoid damage. Damage caused by inappropriate handling or storage could range from performance degradation to complete failure.

2.5 mm x 2.5 mm TDFN6 Package



RoHS COMPLIANT

Notes:

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

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Revision History

April 2017

Changes

- Clarified repeatability vs. accuracy (p. 2).
- Added nonsinusoidality specification (p. 2).

November 2016

Changes

- Split out AAT003 into separate datasheet.
- Revised applications section.

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