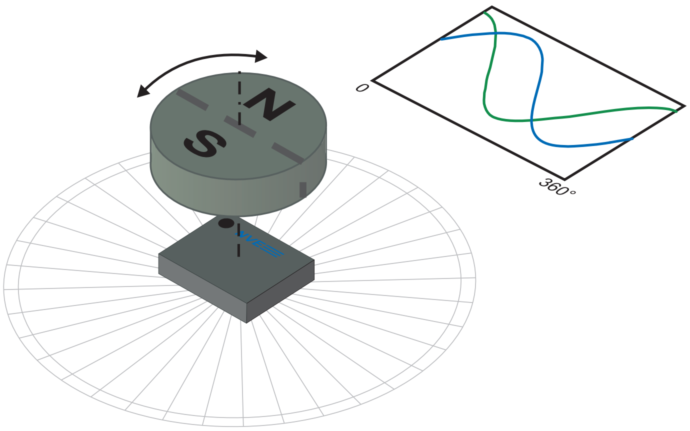
AAT006 Low-Field TMR Angle Sensor



Features

- Tunneling Magnetoresistance (TMR) technology
- Extremely low power (as low as sub microamps)
- High output signal without amplification
- Immune to airgap variations
- Operates with as little as 15 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
- Automotive rotary position sensors
- Motor shaft position sensors

Description

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

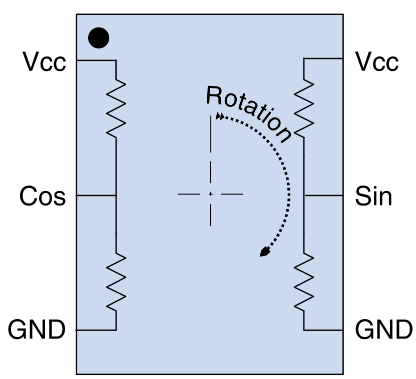
The sensors provide sine and cosine signals defining the angle of rotation. Outputs are proportional to the supply voltage and peak-to-peak output voltages are much larger than conventional sensor technologies.

The AAT006 is a high-sensitivity member of the AATxxx family, operating with as little as a 15 Oersted magnetic field.

AAT006 sensors consist of two half-bridges, with a typical bridge resistance of 1.25 MΩ for ultralow power.

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		0.8	1.5	3	MΩ	25°C with required magnetic field.
Peak-to-peak output signal	$V_{PP\text{-}SIN}$ $V_{PP\text{-}COS}$	130	200		mV/V	Over full rotation.
Offset voltage	$V_{OFFSET\text{-}SIN}$ $V_{OFFSET\text{-}COS}$	−10		+10	mV/V	
Supply voltage	V_{CC}	0		5.5	V	
Required applied magnetic field		15		100	Oe	
Repeatability, fixed bias[2]				±0.5	deg.	
Repeatability, variable bias[3]				±3	deg.	
Nonsinusoidality[4]			±1.5%		% of peak-to-peak output; 25 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:

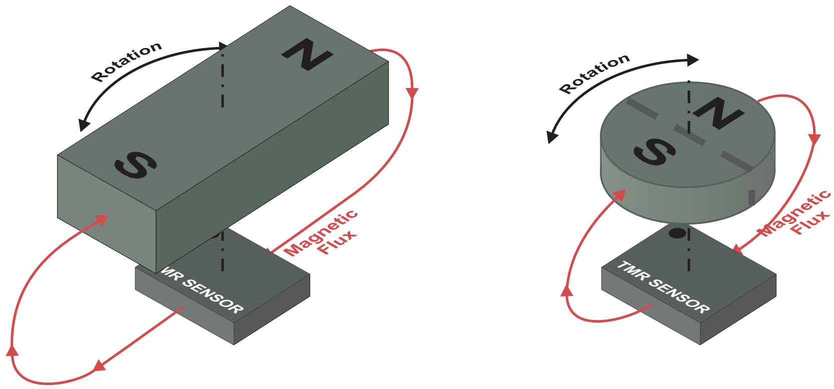

Figure 1. Sensor operation.

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 15 Oe to 150 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 and harvested power

AAT-Series sensors are resistive devices with no active components, so they have no minimum voltage and can be powered from single cells. With their low power, the sensors are well-suited for operation from batteries or harvested power, and can run continuously for many years on small alkaline, silver oxide, or lithium button cells.

Harvested power is often intermittent, and AAT-Series sensors detect and maintain absolute position information. The sensors immediately powers up indicating the correct position after power is restored.

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.

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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:

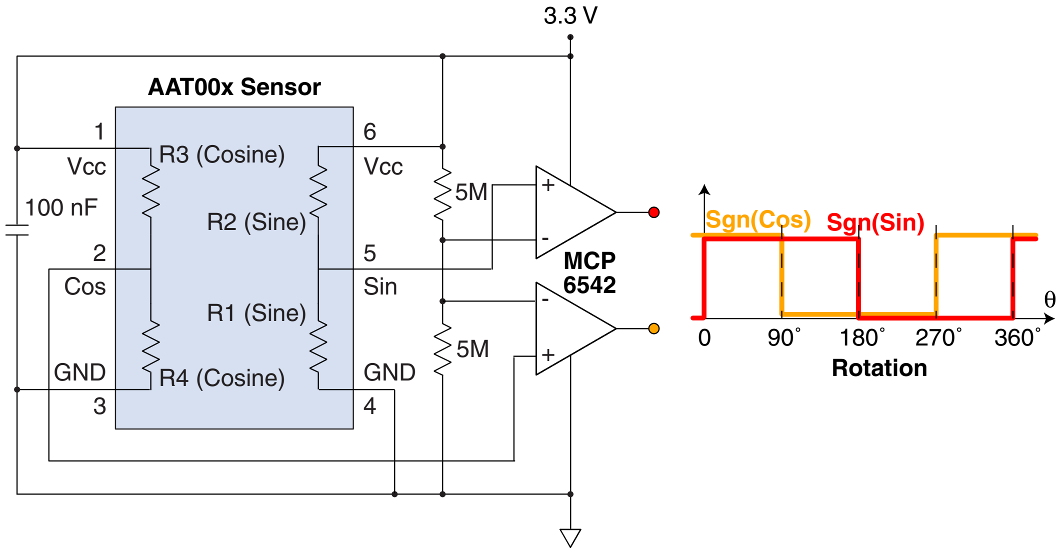

Figure 2. External dual comparator for digital outputs.

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:

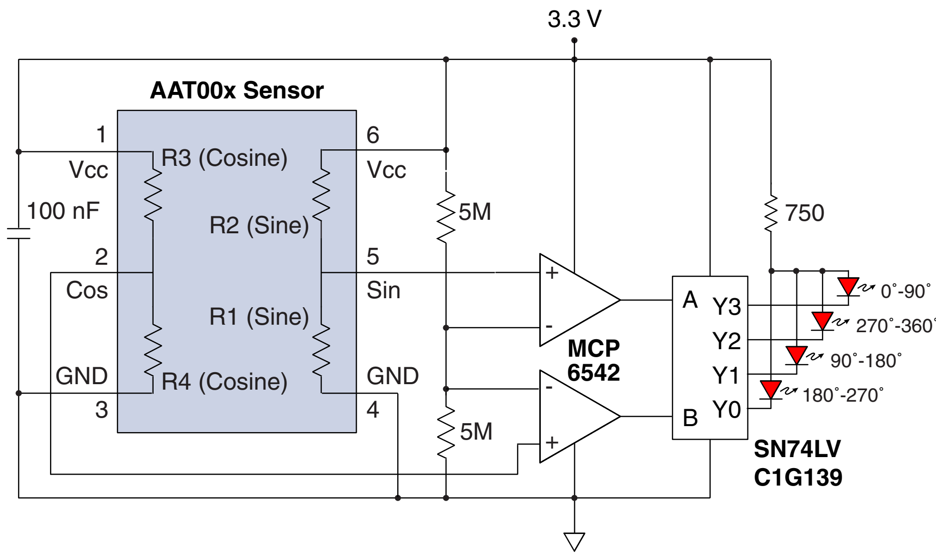

Figure 3. Digital Quadrant Outputs.

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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:

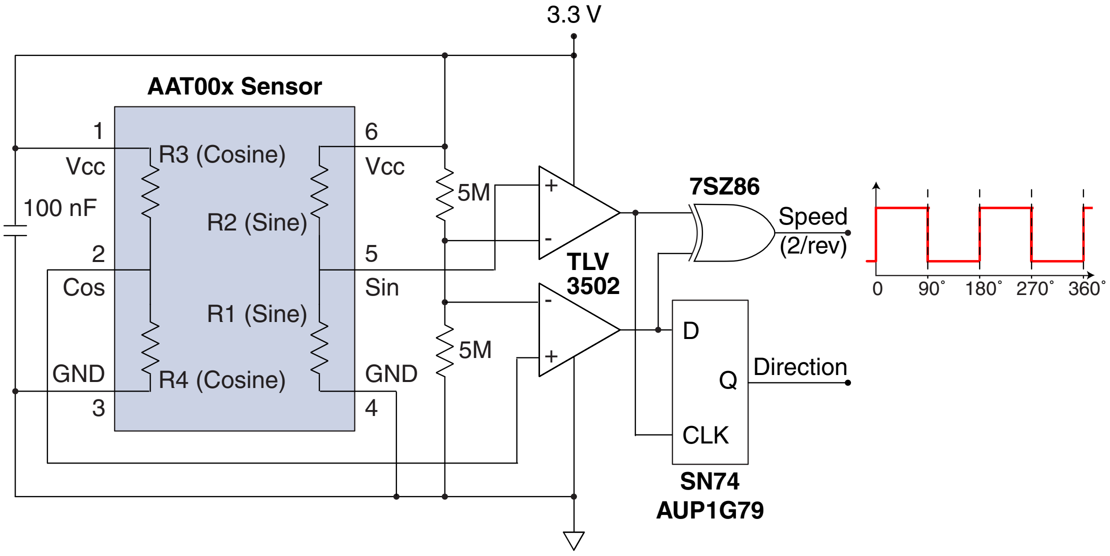

Figure 4. Speed and direction signals.

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.

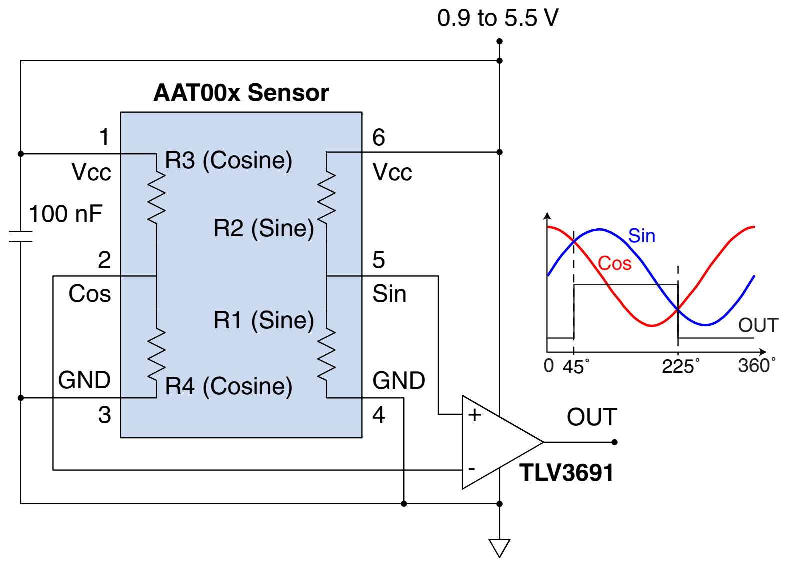

Figure 5. Angular Reference Point Rotation Signal.

In this circuit, the output is high from nominal 45 to 225 degrees, and low from 225 to 45 degrees. 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.

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Low-power 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 10 megohm resistors and nanopower TLV522 op-amp minimize the added power consumption of the amplifier. A gain of three amplifies the 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:

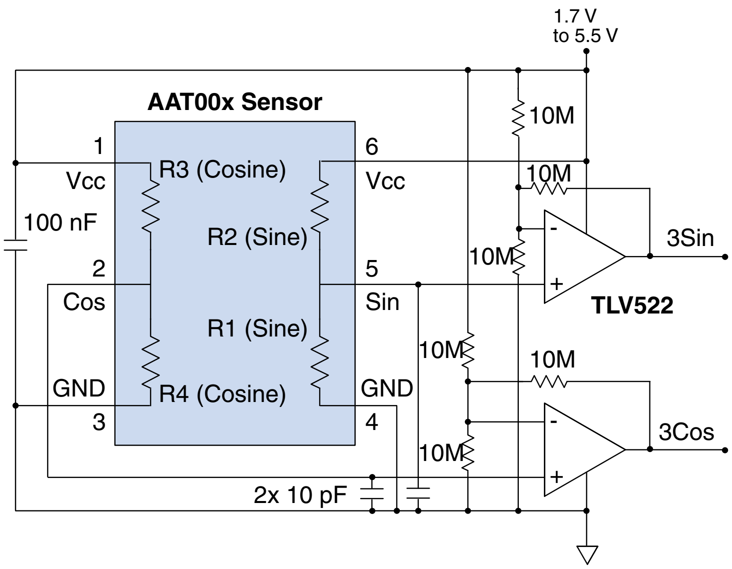

Figure 6. AAT006 3x Preamplifier.

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:

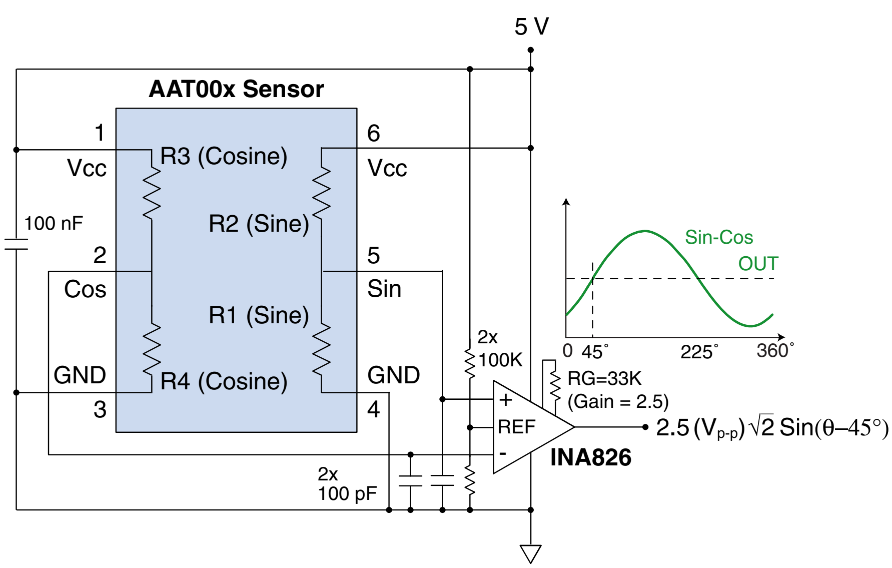

Figure 7. 2.5x AAT006 Sensor Differential Amplifier.

The differential ($V_{SIN} - V_{COS}$) voltage has an amplitude of 1.41 times the amplitude of either output, or typically 282 mV/V peak-to-peak. Therefore the amplifier gain of 2.5 provides a typical peak-to-peak output of 71% of rail-to-rail (one volt/volt). Note that the zero crossing is at 45 degrees, versus to 0 degrees for the Sin output and 90 degrees for the Cos output. An instrumentation amplifier can be used to minimize parts count when power consumption is not critical.

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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.

Ultralow power external CMOS

Any of the application circuits described in this section can use 74AUP-family logic rather than 74LVC if lower power is required and five-volt operation is not needed.

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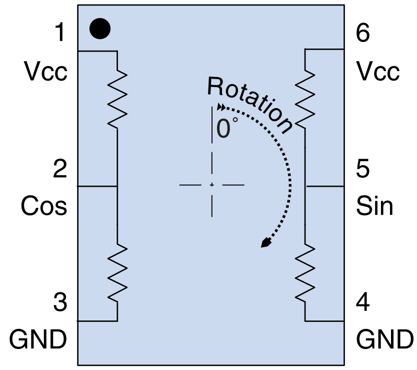
Pinout



Part Marking: "FDSe"

AAT00x Pin	Symbol	Description
1	V_{CC-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-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.

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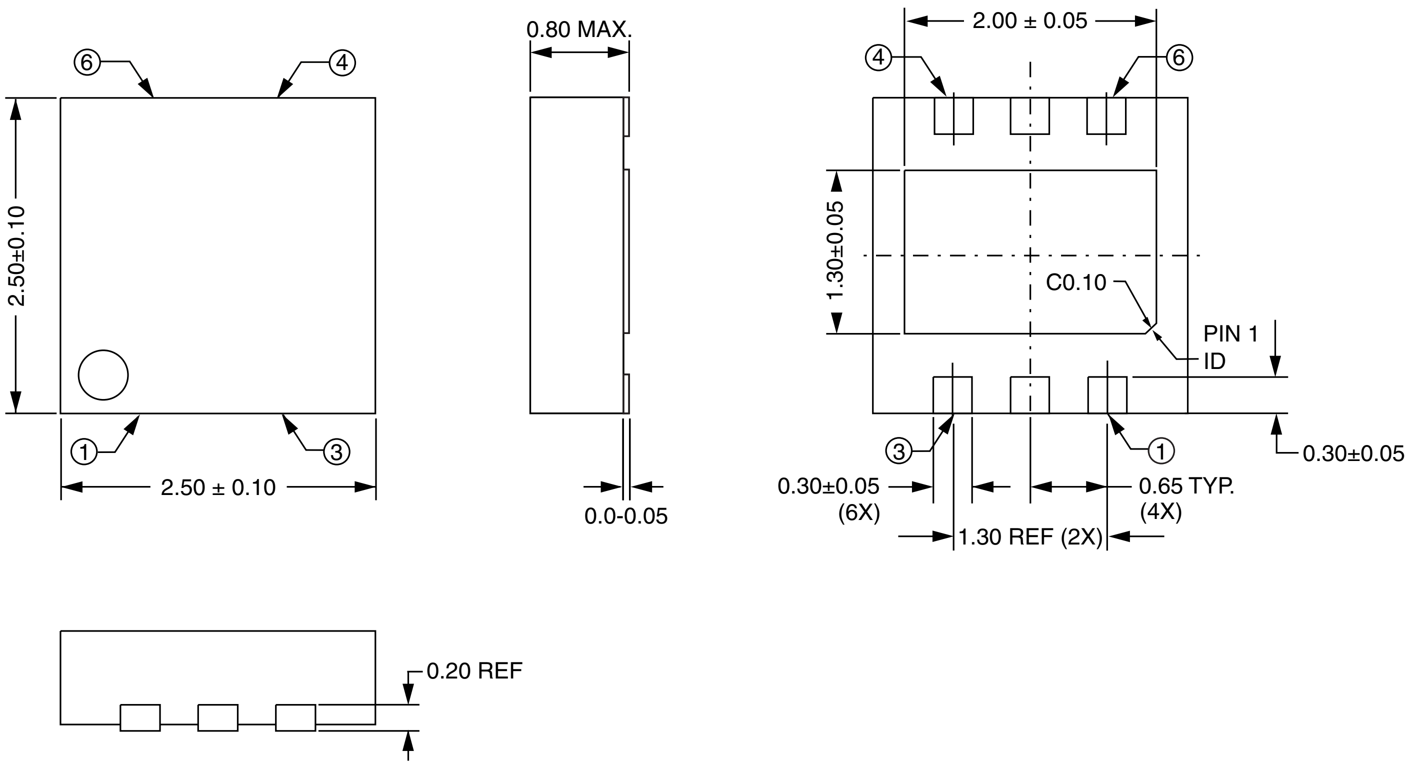
2.5 mm x 2.5 mm TDFN6 Package



Notes:

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

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Revision History

April 2017

Changes

- Improved device resistance spec. from 0.6 MΩ –2.5 MΩ to 0.8 MΩ –3 MΩ (p. 2).
- Reduced maximum applied field for operating specifications (p. 2).
- Clarified repeatability vs. accuracy (p. 2).
- Added nonsinusoidality specification (p. 2).
- Lower-power amplifier circuit (p. 7).

November 2016

Changes

- Initial release of separate AAT006 datasheet (split out from AATxxx datasheet).
- Revised applications section.

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