Application Bulletin

NVE Angle Sensors in Off-Axis Configurations

A Range of Angle Sensors

NVE's ASR002 Smart Angle Sensor offers a world-class combination of speed and accuracy with integrated digital signal processing and an SPI interface. Built with NVE's unique Tunneling Magnetoresistance (TMR) technology, it is fast, accurate, and ultraminiature. Key specifications for the world's first smart TMR angle sensor are summarized in Table 1:

Interface/Programming	Speed (samples/sec)	0 to 85°C Accuracy (degrees)	Operating Field (mT)	Size (mm)
SPI	12500	±2	6-20	2.5 x 2.5 TDFN

Table 1: ASR002 Smart TMR Angle Sensor key specifications.

NVE AAT-Series analog bridge sensors are ultralow power and accurate. Their ground-breaking TMR technology gives them high device resistance, large output signal without amplification, and operation in fields as low as 1.5 mT. Available parts are summarized in Table 2:

Part Number	Configuration	Typ. Output (ea. Output; p-p)	Operating Field (mT)	Typ. Device Resistance
AAT001-10E	Half-bridge	200 mV/V	3-20	1.25 MΩ
AAT003-10E	Half-bridge	200 mV/V	3-20	30 KΩ
AAT006-10E	Half-bridge	200 mV/V	1.5-10	1.5 MΩ
AAT009-10E	Half-bridge	200 mV/V	3-20	6 MΩ
AAT101-10E	Full-bridge	400 mV/V	3-20	625 KΩ

Table 2: AAT-Series Angle Sensors.

This Application Note describes the use of NVE's angle sensors in three popular configurations, an on-axis configuration and two so-called off-axis configurations.

1. *On-Axis Magnet Configuration*

In the typical rotation sensing configuration, an NVE angle sensor is placed on the rotational axis of a shaft, and the shaft is fitted with a diametrically-magnetized ring or disk magnet. This configuration is shown in Figure 1.

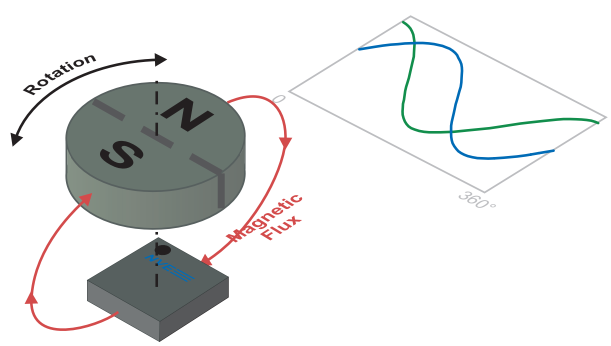

Figure 1. NVE angle sensor arranged on magnet rotation axis.
Sensor outputs are supply ratiometric sine and cosine proportional voltages.

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As the magnet rotates, the direction of the magnetic field changes, and the sensor detects the angle. High accuracy is achieved because the magnitude of the magnetic flux is constant throughout the rotation. The sensor provides sine and cosine outputs with positive defined as clockwise. Figure 2 shows the sensor output and magnetic flux vector in 90° intervals for a clockwise magnet rotation.

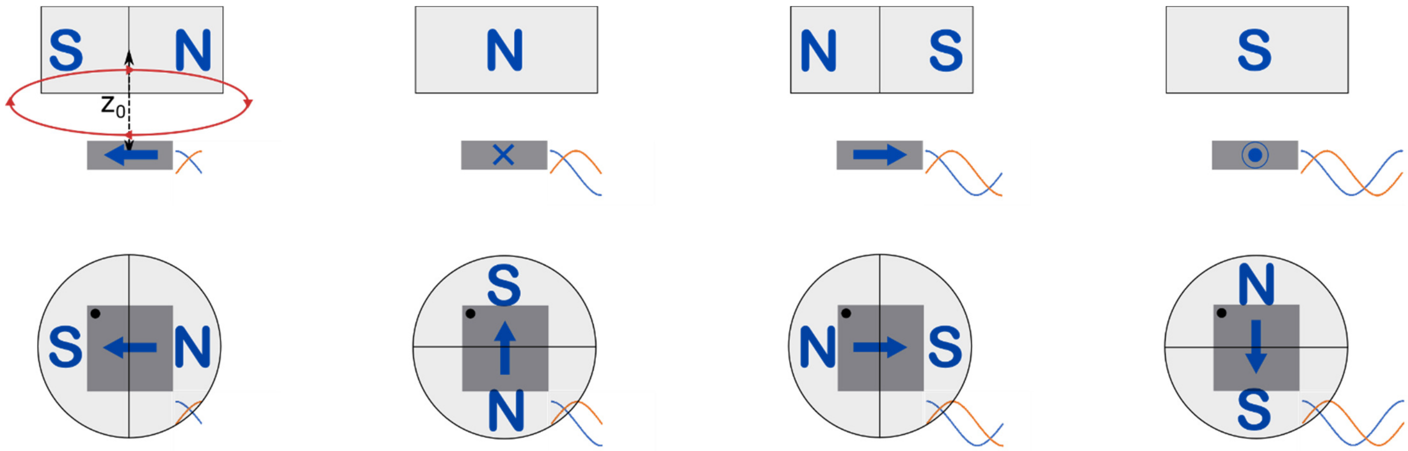

Figure 2. Top Row: a side view of a diametrically magnetized disk magnet rotating clockwise, with the magnetic field direction indicated by the blue arrow. Bottom Row: a top-down view of the same system. In this configuration, the magnetic flux vector at the sensor rotates in the same direction as the magnet's poles.

2. *Parallel Plane Off-Axis Magnet Configuration*

With proper magnet placement, NVE angle sensors can be used off-axis with the same accuracy as the standard on-axis configuration. Figure 3 shows a popular system, with a diametrically magnetized ring magnet mounted on a shaft; an angle sensor is displaced vertically and radially to detect the rotating field.

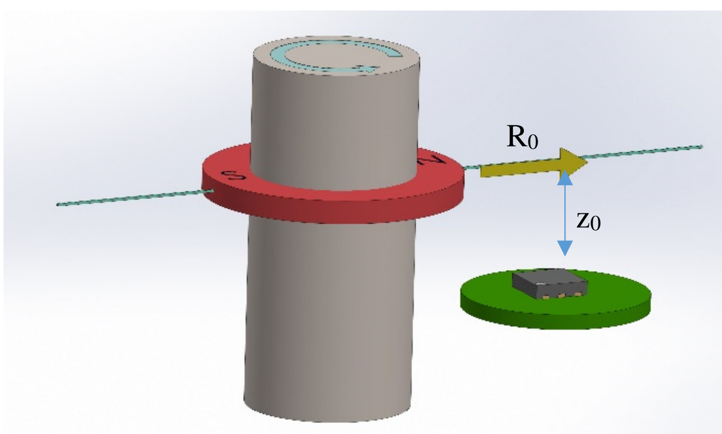

Figure 3. The sensor out-of-plane with the ring magnet, with the sensor plane and magnet planes parallel. Distances R_0 and z_0 are measured center-to-center.

In order to maintain the highest possible accuracy, the sensor must be placed where the rotating magnetic flux is a constant magnitude. This can easily be achieved by choosing R_o and z_0 such that:

$$R_o = \sqrt{2} \cdot z_0$$

Figure 4 shows data from an AAT001-10E placed with $R_0 = 21.2$ mm $z_0 = 15$ mm and a grade N42 ring magnet. Similar results can also be achieved for diametrically magnetized disks or bar magnets built into or mounted on the shaft.

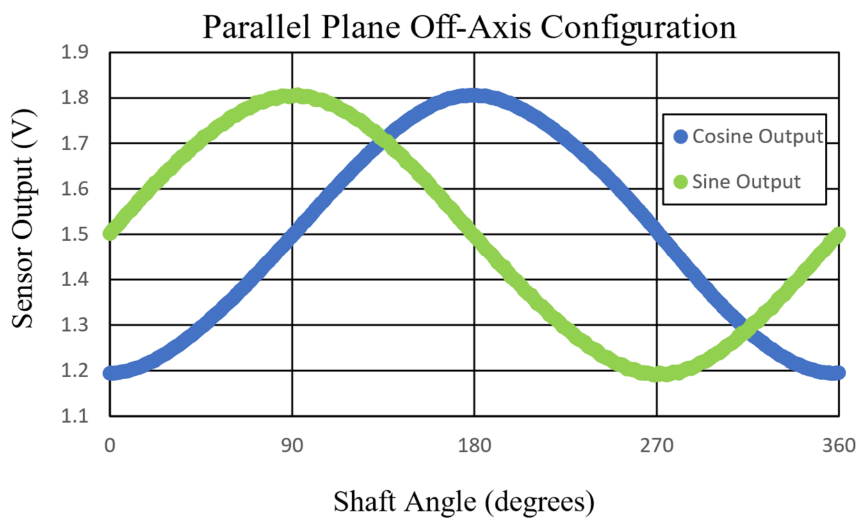

Figure 4. Excellent accuracy with an AAT001-10E placed off-axis of a rotating shaft, as in Figure 2. The sensor was located $R_0 = 21.2$ mm $z_0 = 15$ mm from a12.7 mm diameter, 6.35 mm thick neodymium ring magnet.

As shown in Figure 4, the sensor's cosine output is 180° out of phase, compared to the on-axis configuration. This is because displacing the sensor radially causes the magnetic flux vector to rotate in reverse. The difference is illustrated in Figure 5, as compared to the on-axis configuration in Figure 2.

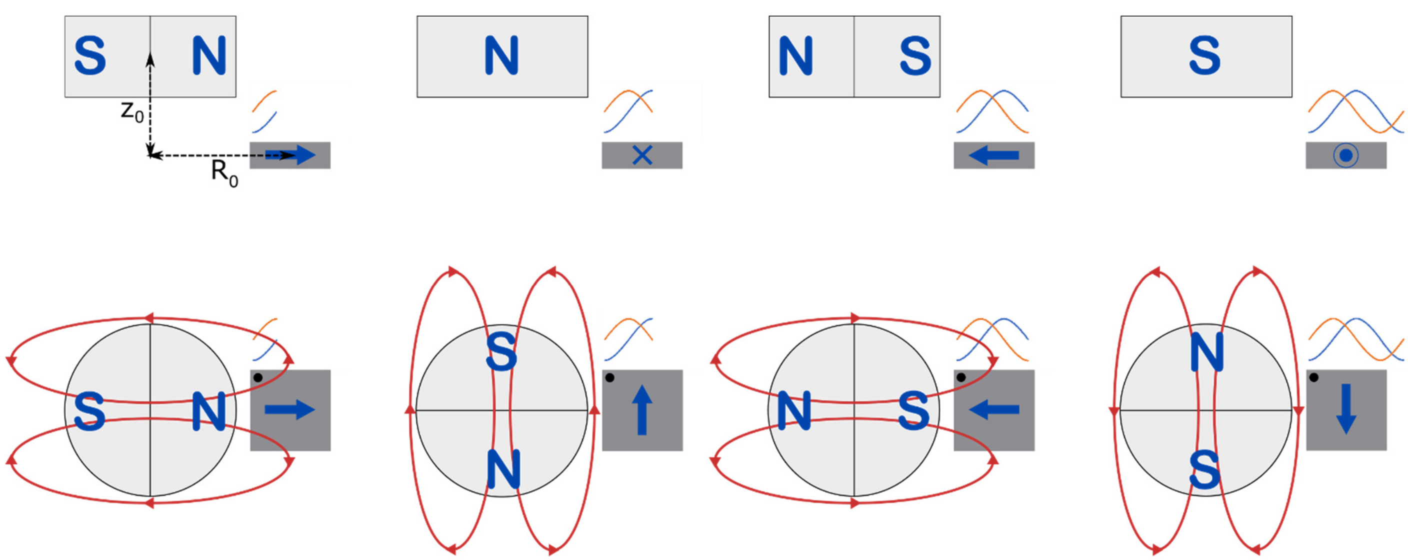

Figure 5. Top Row: a side view of a diametrically magnetized disk magnet placed off-axis. Bottom Row: the same system viewed top-down. In this configuration, the magnetic flux at the sensor rotates in the opposite direction of the magnet's poles, so the sensor's cosine output is 180° out of phase.

3. Perpendicular Plane Off-Axis Magnet Configuration

A second useful configuration is possible with the magnet plane perpendicular to the plane of the sensor, as shown in Figure 6.

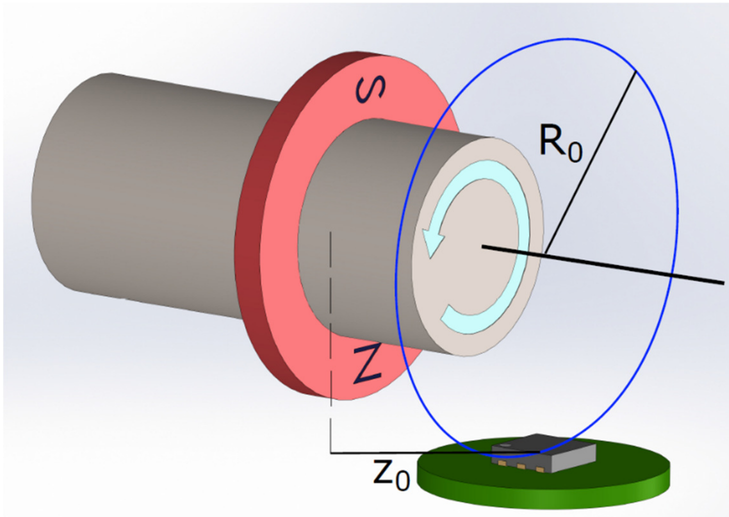

Figure 6. The second off-axis configuration, with the sensor plane perpendicular to the magnet plane. The plane of the sensor must be tangential to the blue circle, as shown.

In this configuration, the sensor has high accuracy at two locations:

$$R_0 = \sqrt{\frac{7-3\sqrt{5}}{2}} \cdot z_0 \qquad \text{or} \qquad R_0 = \sqrt{\frac{7+3\sqrt{5}}{2}} \cdot z_0$$

Figure 7 shows data from an AAT001 placed at $R_0 = 9.5$ mm $z_0 = 25$ mm and a grade N42 ring magnet.

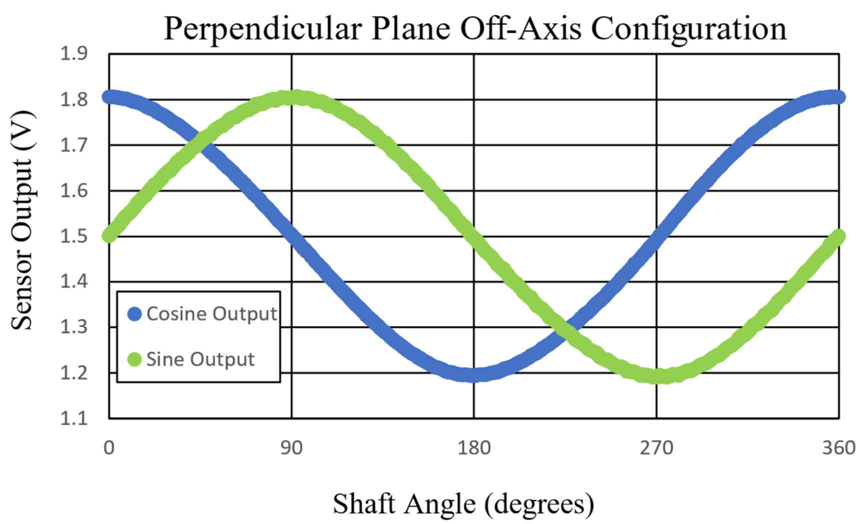

Figure 7. Excellent accuracy with an AAT001-10E placed off-axis of a rotating shaft, as in Figure 6. The sensor was located $R_0 = 9.5$ mm $z_0 = 25$ mm from a 12.7 mm diameter, 6.35 mm thick neodymium ring magnet.

The magnetic field for this off-axis configuration is illustrated in Figure 8.

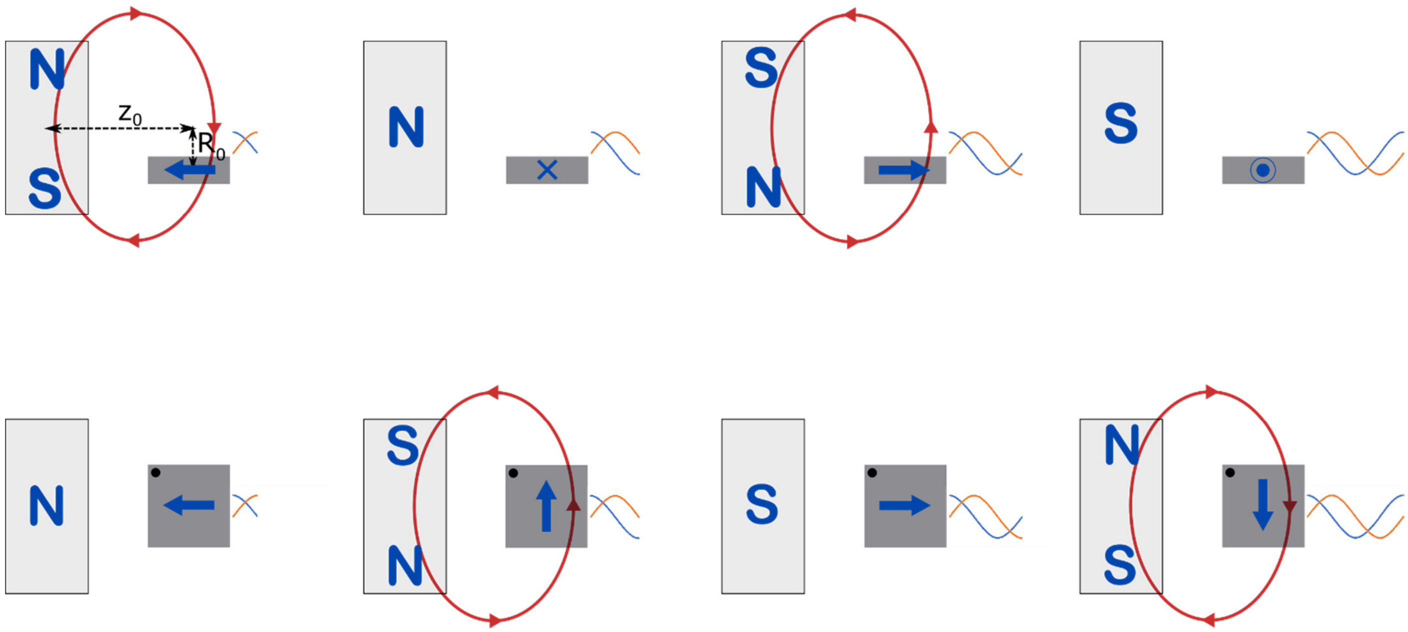

Figure 8. Top Row: a side view of a diametrically magnetized disk magnet placed off-axis. Bottom Row: the same system viewed top-down. The sensor detects the clockwise motion of the magnet.

Minimizing Distortions Near Magnets

In most applications, the sensor should be placed near the ideal locations to minimize distortions. An exception occurs when the sensor is placed close the magnet, where the magnet's shape can affect the field lines significantly. In this case, the ideal sensor location changes slightly. To help make off-axis angle sensing design easy, we have a free Web application to calculate the perfect R_0 and z_0 for both off-axis configurations and any size magnet:

https://www.nve.com/spec/calculators.php#tabs-Off-Axis-Angle-Sensing

For a live demonstration of off-axis angle sensing and other angle sensing demonstrations, check out our Youtube channel:

https://youtu.be/FcM1Q3N6Atw
https://www.youtube.com/NveCorporation

The NVE Advantage

The magnetic field for off-axis geometries is significantly smaller than on-axis, which requires sensitive sensors. NVE offers high accuracy angle sensors that operate in as little as 1.5 mT, significantly less than competitors can offer. Our high sensitivity sensors make off-axis angle sensing possible with small, inexpensive magnets. Some common magnets are listed in Table 3, as well as the ideal R_0 and z_0 locations at the operate point of our most common angle sensors.

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Magnet Parameters				3 mT Sensor Position: Off-Axis Configuration 1		3 mT Sensor Position: Off-Axis Configuration 2	
Magnet Material	Magnet Inner Diameter (mm)	Magnet Outer Diameter (mm)	Magnet Thickness (mm)	Sensor z_0 Position (mm)	Sensor R_o Position (mm)	Sensor z_0 Position (mm)	Sensor R_o Position (mm)
Ceramic (C5)	NA	4	4	4.6	6.5	7.6	2.9
Ceramic (C5)	NA	12.5	3.5	8.7	13.5	13.6	5.2
Ceramic (C5)	NA	8	8	9.2	13	14.9	5.7
NdFeB (N42)	4.8	12.7	6.4	16	22.6	19.9	7.6
NdFeB (N42)	3.2	12.7	12.7	22	31.1	35.2	13.5
NdFeB (N42)	3.2	25.4	6.4	27	38.2	42.9	16.4

Table 3. A list of common magnets and their off-axis locations for a 3 mT operate point.
Disk magnets are denoted by "NA" inner diameter.

Contact Us

NVE engineers are experts in angle sensing and eager to help. Please contact sensor-apps@nve.comfor solutions to the most demanding rotation sensing designs.

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SB-SA-02 Rev. C August 2019