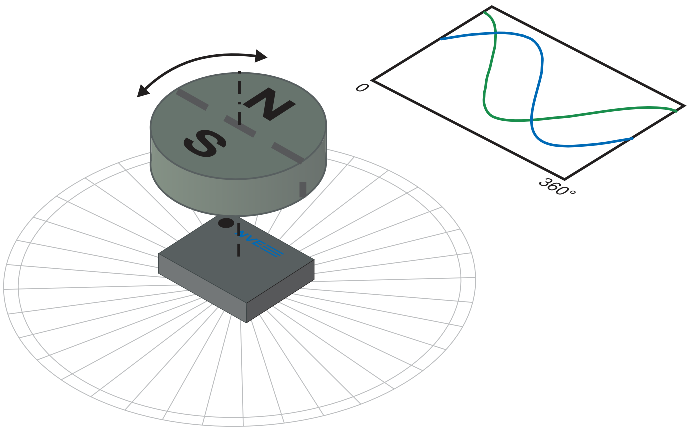
AAT101 Full-Bridge TMR Angle Sensor



Features

- Tunneling Magnetoresistance (TMR) technology
- Extremely low power (as low as sub microamps)
- Full-bridge (differential) configuration
- 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
- 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.

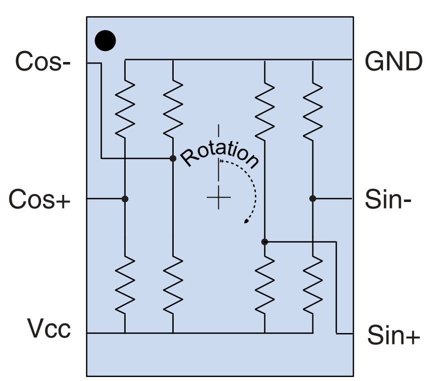
The AAT101 is a full-bridge version of NVE's ground-breaking half-bridge angle AAT001 sensors. The full-bridge configuration provides two differential outputs for easier interface in certain applications, twice as much signal, and less supply voltage or temperature dependence.

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 typical device resistance of 625 kΩ enables low power, and is ideal for battery-powered applications.

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		−1	Volt
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		0.5	0.625	2	MΩ	25°C with required magnetic field.
Peak-to-peak output signal	$V_{PP\text{-}SIN}$ $V_{PP\text{-}COS}$	260	400		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		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:

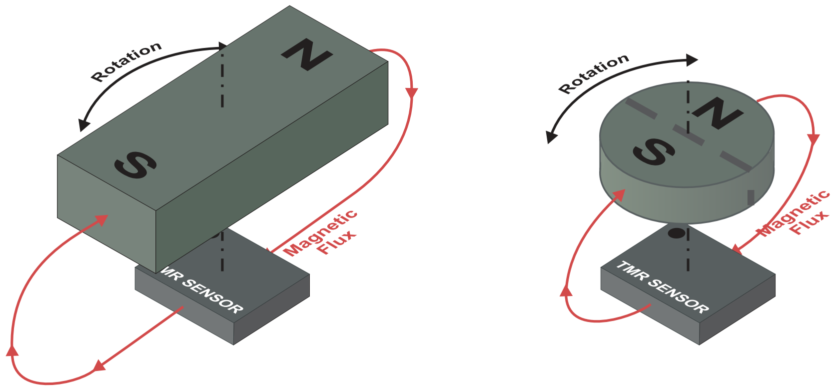

Figure 1. Sensor operation.

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 resistances, device resistance, and output impedances remain constant with rotation.

Transfer function

Full-bridge devices (AAT10x) provide two differential outputs for twice the signal and inherent temperature and supply voltage compensation. This configuration can also be used for drop-in upgrade of AMR sensor designs. Mathematically, the outputs are:

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

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

Where:

θ is the magnetic field angle;

V_{CC} is the supply voltage;

V_{COS} and V_{SIN} are the differential sensor output voltages ($V_{COS+} - V_{COS-}$ and $V_{SIN+} - V_{SIN-}$ in mV/V);

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

$V_{OFFSET\text{-}SIN}$ and $V_{OFFSET\text{-}COS}$ are the sensor offset voltages (mV/V), defined as $(V_{SIN\text{-}MAX} + V_{SIN\text{-}MIN}) / 2$, and $(V_{COS\text{-}MAX} + V_{COS\text{-}MIN}) / 2$.

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 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.

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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 are used to avoid adding power consumption to low-power applications:

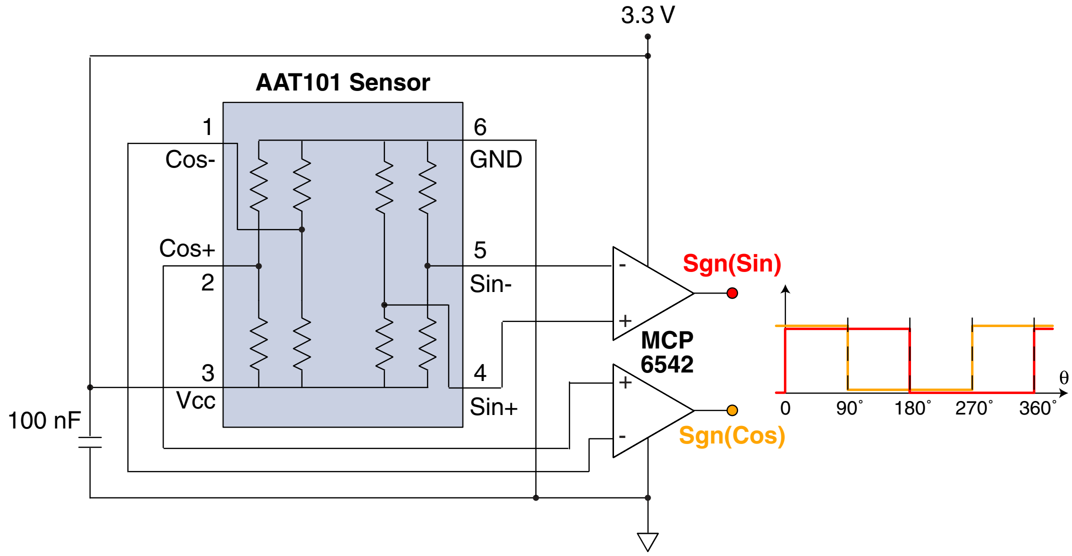

Figure 2. External dual comparator for digital outputs.

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 angular 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:

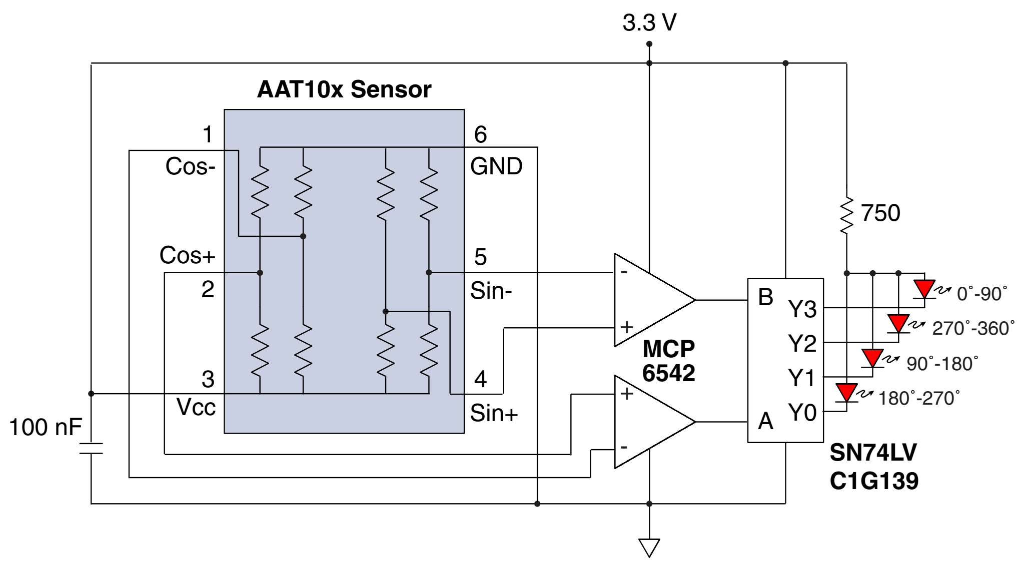

Figure 3. Digital quadrant outputs.

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:

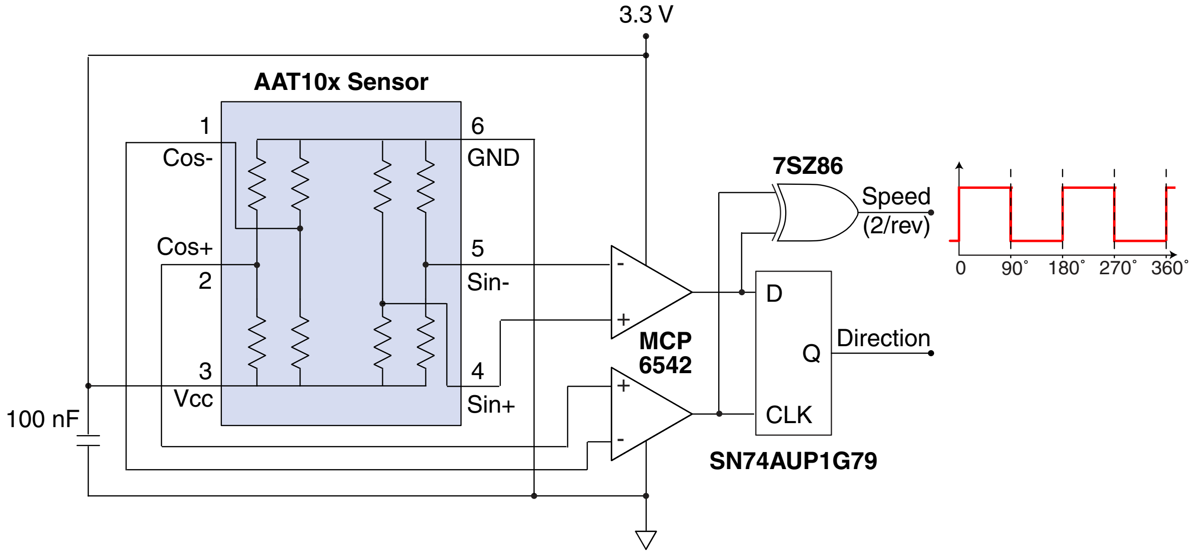

Figure 4. Speed and direction signals.

Simple amplification
AAT-Series sensors have high output signals without amplification, but if single-ended signals or amplification are needed, instrumentation amplifiers can be used to reduce amplifier parts count. The gain should be limited to approximately two to avoid saturating the amplifiers:

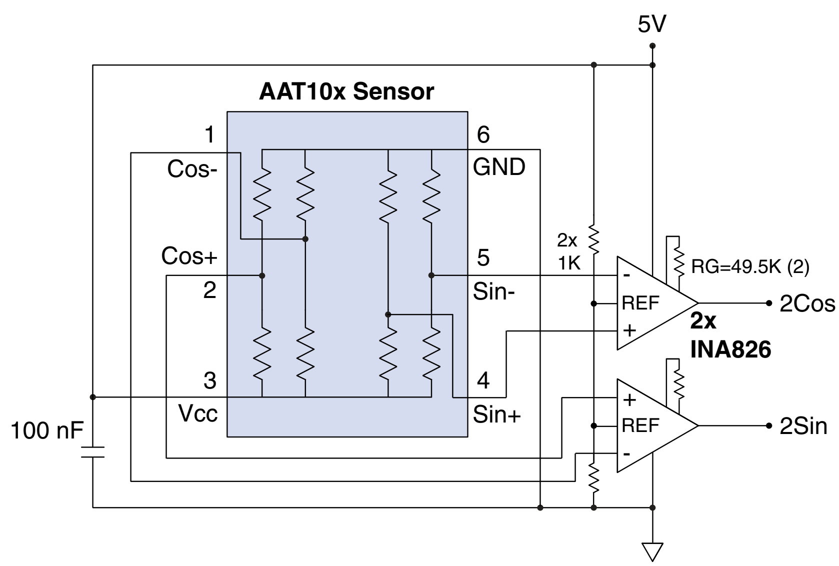

Figure 5. AAT101 with 2x instrumentation amplifiers.

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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 resistances, 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 400 mV/V).

For example, MCP6542 comparators have hysteresis of 3.3 mV, corresponding to about 0.5 angular degree of hysteresis. TLV3691 or similar comparators have hysteresis of 17 mV, corresponding to approximately 3 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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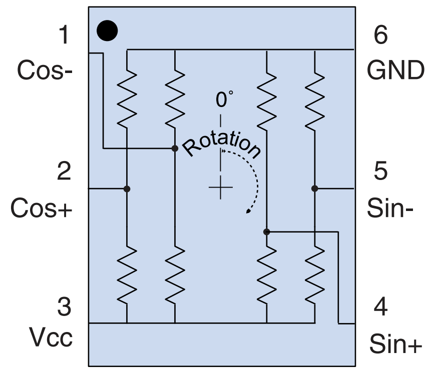
Pinout



AAT10x Pin	Symbol	Description
1	Cos-	Corresponds to the negative-sine of the rotation angle.
2	Cos+	Corresponds to the sine of the rotation angle.
3	V_{CC}	Supply voltage (up to 5.5 V).
4	Sin+	Corresponds to the cosine of the rotation angle.
5	Sin-	Corresponds to the negative-cosine of the rotation angle.
6	GND	Ground.

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.

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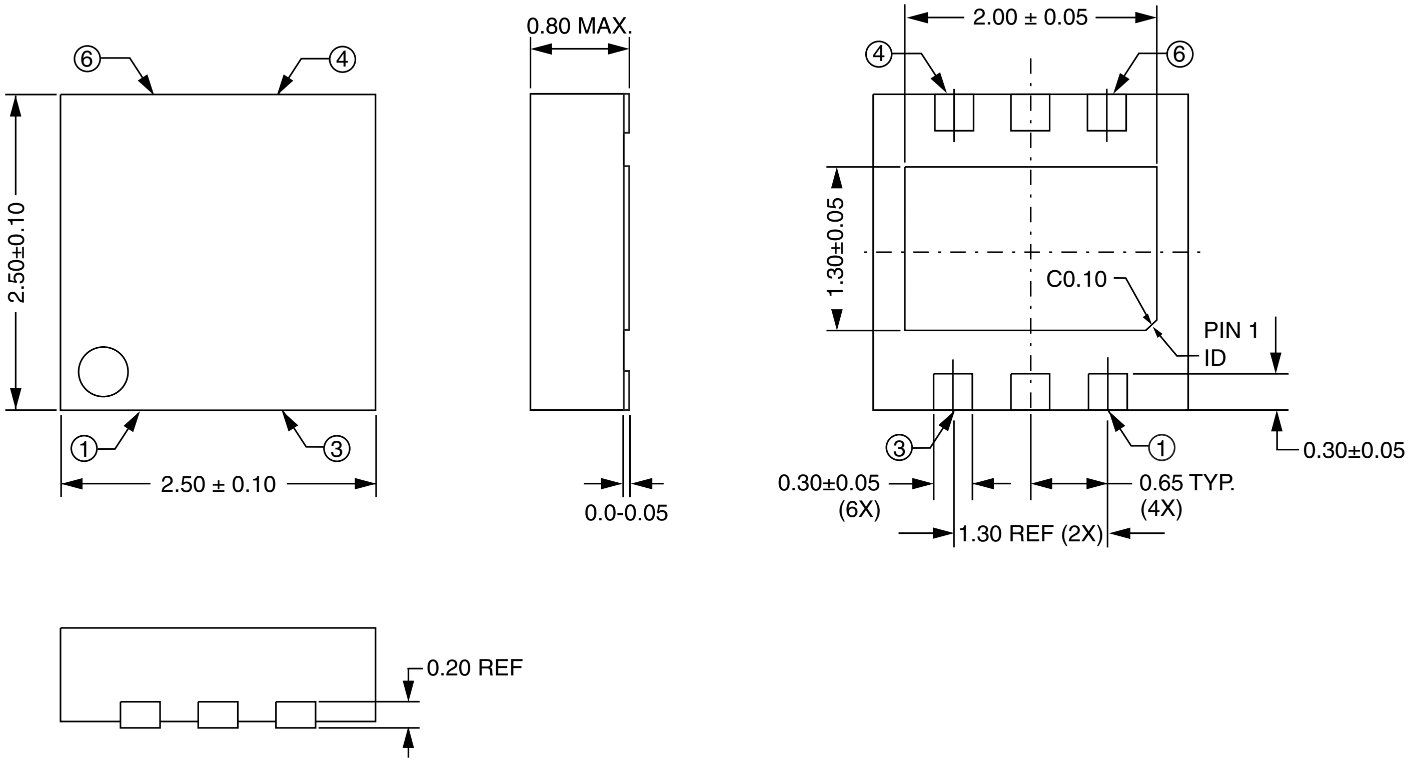
2.5 mm x 2.5 mm TDFN6 Package



RoHS COMPLIANT

Notes:

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

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.

Revision History

June 2017

Changes
- Clarified repeatability vs. accuracy (p. 2).
- Added nonsinusoidality specifications (p. 2).
- Initial release.

November 2016

Changes
- Preliminary release.

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