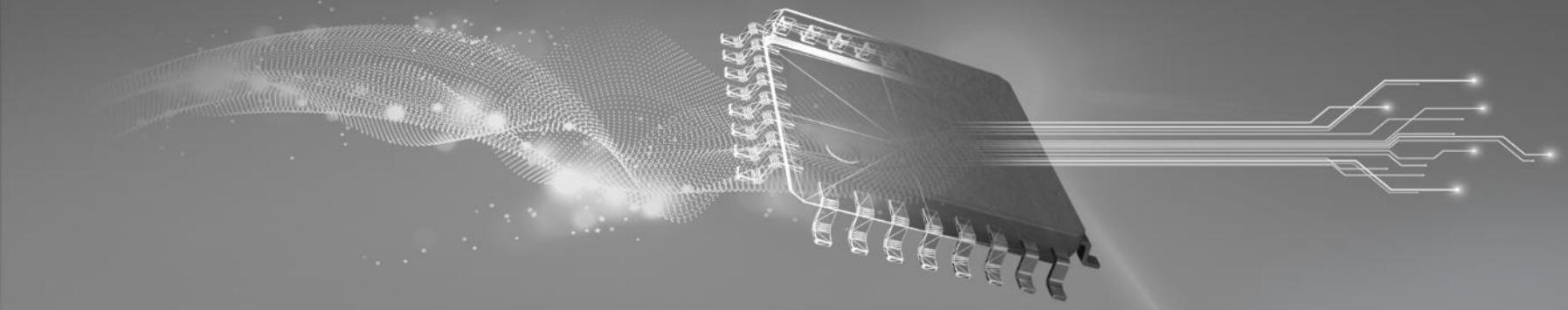
TI TECH DAYS



# TMAG5170 3D Hall-effect sensor for contactless designs

**Scott Bryson**

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Texas Instruments

# Target applications

- Lever position measurement
  - Stalk gear shifters, turn signals
  - Industrial joysticks
- Angle measurement
  - e-Shifter knob, electronic power steering, braking systems, steering wheel control, steering angle sensor, gas/brake/clutch pedals, electronic throttle control, EGR valves
  - Robotic Arm, appliance multifunction knobs – cooking top, oven, washer & dryer
- Linear movement
  - Actuators, fluid measurement, factory automation linear mover
- Ambient current sensing
  - HEV/ EV
  - Isolated AC motor drive


# TMAG5170 Product preview

3-Axis linear Hall-effect sensor with **SPI** output interface

**Samples: 2Q20**
**Production: 4Q20**

## Features

- Measures magnetic flux density in 3-axis and digitizes the outputs
- SPI output interface
- Low-power options:
  - **1uA Sleep Mode** (Retains User Defined Configuration)
  - **10nA Deep Sleep Mode** (Reverts to Factory Mode)
- Selectable magnetic temperature compensation
- High accuracy with temperature stable sensitivities
- **< ±2% sensitivity error over operating range**
- 12-bit ADC with selectable full-scale ranges:
  - A1 (±25mT, ±50mT, ±100mT) and A2 (±133mT, ±200mT, ±300mT)
- Designed in accordance with Automotive ASIL **Safety Systems**
- Primary supply voltage of 2.3V to 5.5V with additional supply (**1.65V to 5.5V**) for microcontroller SPI interface
- 8 pin MSOP (3mm × 5mm) package
- -40°C to 125°C commercial ambient temperature range

## Applications

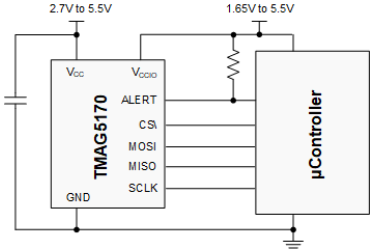
- Lever position measurement:
  - Industrial joysticks
  - Toner cartridge
- Linear movement:
  - Liner conveyer belt
  - Fluid measurement
- Angle measurement
- Ambient current sensing

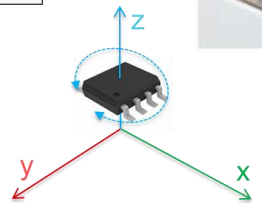
## Tools & Resources


- TI Designs
- TMAG5170EVM
- 2D Angle Error Calculator

## Benefits

- Best-in-class sensitivity allows system designers optimize the system design to improve accuracy, and/ or reduce system cost
- Freedom to position magnet and printed circuit board in 3D space
- Selectable sensitivity ranges allows last minute design adjustments
- Best-in-class sensitivity error allows precision system design
- Flexible ASIL safety scheme enables system specific implementation for end applications
- Grade-0 rating allows operation in harsh temp conditions



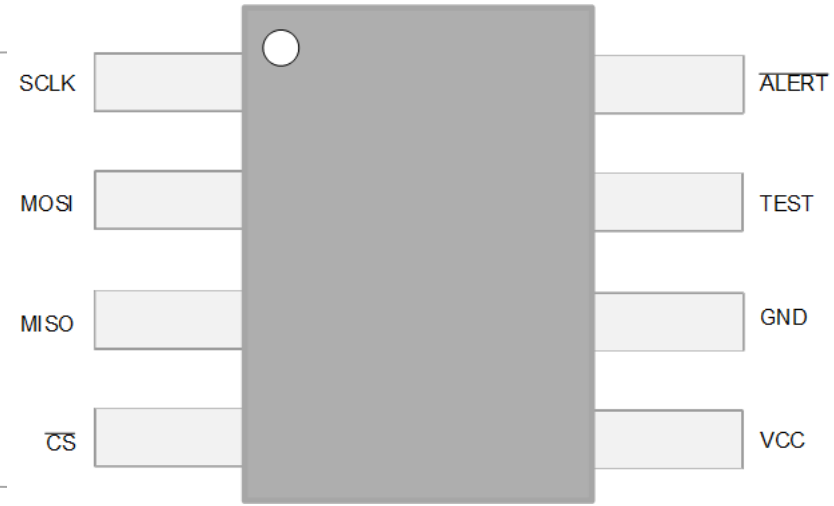



# Overview

- Device specifications and features
- Modes of operation
- 3 axes of sensitivity
  - Independently programmable ranges and sample patterns
  - Up to 32x Averaging for improved resolution and reduced noise
- Programmable temperature compensation
- Digital SPI output
- Programmable alert thresholds
- Integrated angle calculator using CORDIC algorithm
- Compatibility for on and off-axis angle measurement
  - Single channel attenuation allows for amplitude matching for precise angle calculations

# TMAG5170 (-Q1) package and pinout

**SPI bus**




VSSOP DGK package
(5mm × 3mm)

**Alert pin functionality**:

- In *low power mode*, the TMAG5170 wakes up periodically to check the system status, and wakes up the MCU only if the system status changes.
- Used to *trigger* a new conversion.
- Indicates *functional safety failure.*
- Used as a *magnetic switch* to indicate a specific magnetic threshold has been crossed.

# TMAG5170 key features

**High accuracy**

Sensitivity error <±2% from -40°C to 150°C

**Input referred noise**

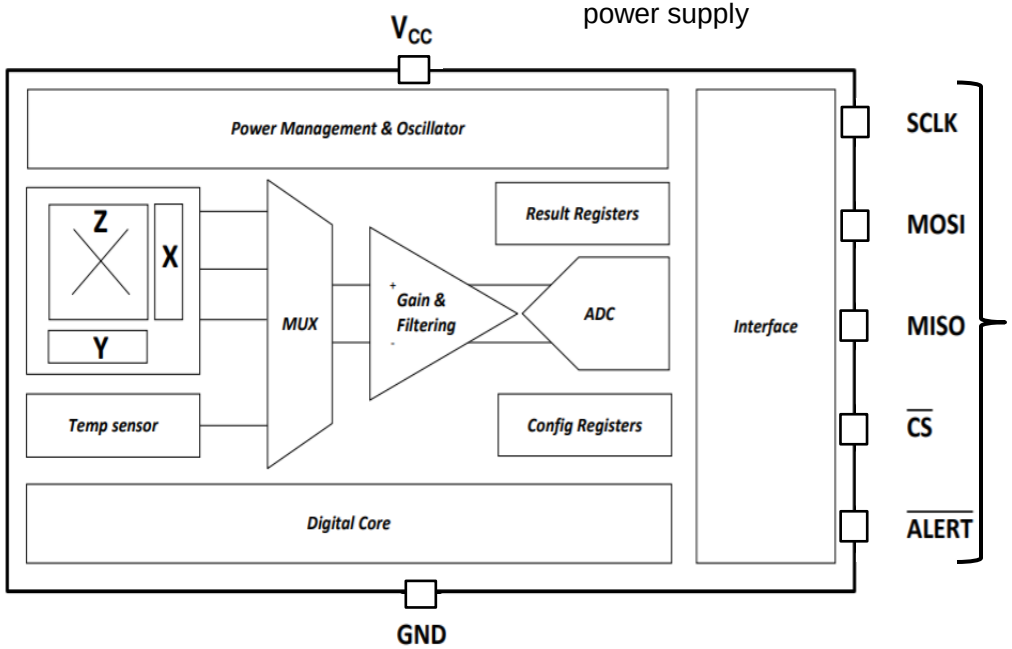
- Maximum sample rate: ±140 µT (X,Y) ; ±64 µT (Z)
- Maximum averaging: ±25 µT (X,Y) ; ±11 µT (Z)

**High configurability**

- Selectable magnetic sensitivity ranges (mT):
  - A1: ±25, ±50, ±100
  - A2: ±133, ±200, ±300
- Multiple operation modes
- Variable update rate
- Temperature compensation for multiple magnet types
- Configurable diagnostics

**Supply voltage range**

- Supports 2.3V to 5.5V power supply




**High Integration**

- 3-axis magnetic sensing
- On-board temp sensor
- Integrated angle CORDIC calculation (with gain and offset adjustment)
- And more!

**Digital interface**

- SPI bus up to 10 MHz
- Dedicated ALERT pin:
  - Enables low-power system operation
  - Used by MCU to trigger a new conversion.

**Diagnostics**

- Designed for functional safety applications according to ISO 26262

# TMAG5170 (-Q1) accuracy

- Industry’s first to offer 2% sensitivity accuracy at multi-axis points across the entire temperature range.

| Feature | Benefit |
|---|---|
| **Low drift across full temperature range** | Simplifies system level calibration and ability to potentially eliminate need for temperature calibration |
| | Enables use of cheaper magnets and reduce system cost |
| **Lower drift in sensitivity mismatch amongst all axes (X, Y and Z)** | Allows better orientation and placement of magnet and sensor IC allowing for higher levels of mechanical flexibility in product design |
| **Adjustable input scaling for angular measurements** | Allows for the highest accuracy measurements when performing off axis angle detection |

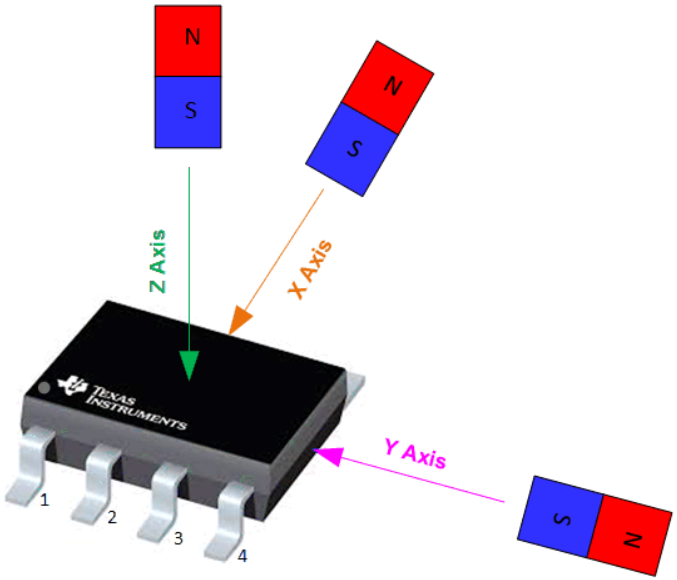
# Modes of operation

| | Time Start New Measurement* | Average Current | Operating Mode Description | Trigger Mode# Active | SPI Bus and User Registers Accessible | Measurement Result Retained | Configuration Retained |
|---|---|---|---|---|---|---|---|
| **Configuration Mode (Default at Power-up)** | 70µs | 60µA | Allows register configuration | ✓ | ✓ | ✓ | ✓ |
| | | | | | | | |
| **Active Conversion Mode** | 10µs | 3.4mA | Continuously performs magnetic field or temperature measurements | ✓ | ✓ | ✓ | ✓ |
| | | | | | | | |
| **Standby Mode** | 35µs | 0.84mA | Ready to start a measurement by having support circuitry active for fast turn ON | ✓ | ✓ | ✓ | ✓ |
| | | | | | | | |
| **Wake-up & Sleep Mode** | 160µs | 1.5µA | Sleeps and wakes at specified intervals to take measurements | | ✓ | ✓ | ✓ |
| | | | | | | | |
| **Sleep Mode** | 160µs | 1.5µA | In low-power state. Wakes up upon Master's $\overline{CS}$ / $\overline{ALERT}$ assertion or via SPI bus | | | ✓ | ✓ |
| | | | | | | | |
| **Deep-sleep Mode** | 170µs | 5nA | Powered-down state which is initiated by $\overline{CS}$ pin. | | | | |

Notes:
* All values are typical values
\# While in Trigger Mode, a Master can trigger a conversion via a SPI command, $\overline{ALERT}$ pin or $\overline{CS}$ signal.

# 3 axis sensitivity

- 3 integrated sensors offer the ability to capture each component of the magnetic field
- Any combination of the three axes may be enabled
- Pseudo-simultaneous sampling is available to correct for delay resulting from pipelined sampling
- 1x – 32x averaging reduces noise impact on overall measurement
- Placement of the sensor is versatile, and alignment of each sensor is inherently orthogonal

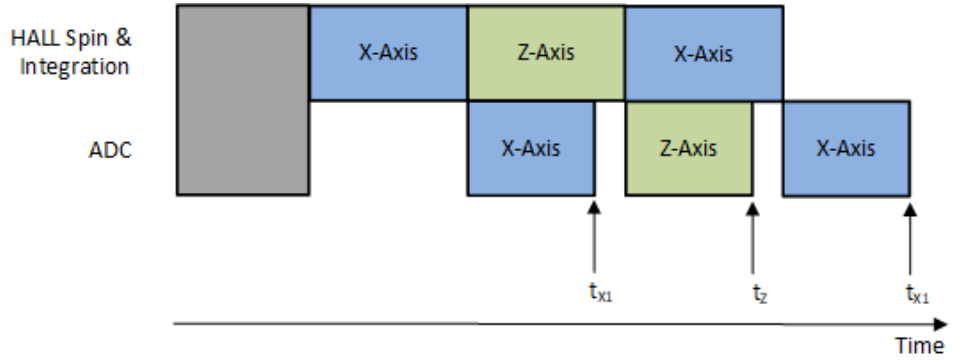


# Pseudo simultaneous sampling

Conversion process is two parts:
1. Hall spin & integration
2. ADC conversion

Pseudo simultaneous sampling will repeat first measurement to average out the difference in sample time.

Assuming that changes in B-Field are linear over small intervals, this creates a result similar as if both channels were sampled at the same time.




$$t_Z = \frac{t_{X1} + t_{X2}}{2}$$

Patterns Available:

- XYX
- YXY
- YZY
- ZYZ
- ZXZ
- XZX
- XYZYX
- XYZZYX

# Programmable temperature compensation

- As temperature increases, the magnetic field produced by magnetic materials weakens. This predictable behavior can be compensated for by the sensor to provide a flatter response for more reliable performance.

| Common magnet types | Mag. Remanence, Br (kGs) | Coercivity HC (oer.) | Curie Temp (ºC) | Max Operating Temp (ºC) | Reverse Tempco of Br (%/ºC) |
|---|---|---|---|---|---|
| Neodymium N35 | 12 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N38 | 12.4 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N40 | 12.7 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N42 | 13 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N45 | 13.5 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N50 | 14.3 | >11.0 | 310 | 80 | -0.12 |
| Neodymium N52 | 14.6 | >11.2 | 310 | 80 | -0.12 |
| Ceramic-5 | 3.95 | 2.4 | 450 | 250 | -0.2 |
| Ceramic-8A | 3.9 | 2.95 | 450 | 250 | -0.2 |
| Alnico-5, cast | 12.3 | 0.6 | 900 | 520 | -0.02 |
| Alnico-8, cast | 8 | 1.38 | 860 | 520 | -0.02 |
| SMCo22 (1:5 series) | 9.4 | 9 | 700 | 250 | -0.045 |
| SMCo2625 (2:17 series) | 10.3 | 9.7 | 810 | 350 | -0.03 |

- TMAG5170 offers three temperature compensation settings.

$$0.0\ \frac{\%}{°C}, \quad +0.12\ \frac{\%}{°C}, \quad +0.2\ \frac{\%}{°C}$$

# Digital interface

- In many applications, the sensor is physically removed from the MCU.
- When devices transmit data back to host across longer distances, analog signals become subject to greater amounts of noise.
- Digital SPI interface allows for greater noise immunity.
- TMAG5170 also employs CRC error checking to assist with detection of communication faults.
  - CRC polynomial = $X^4+X+1$
- SPI communication reserves 12 bits for continual device status feedback.
  - CRC, alert status, power reset, conversion count, etc.

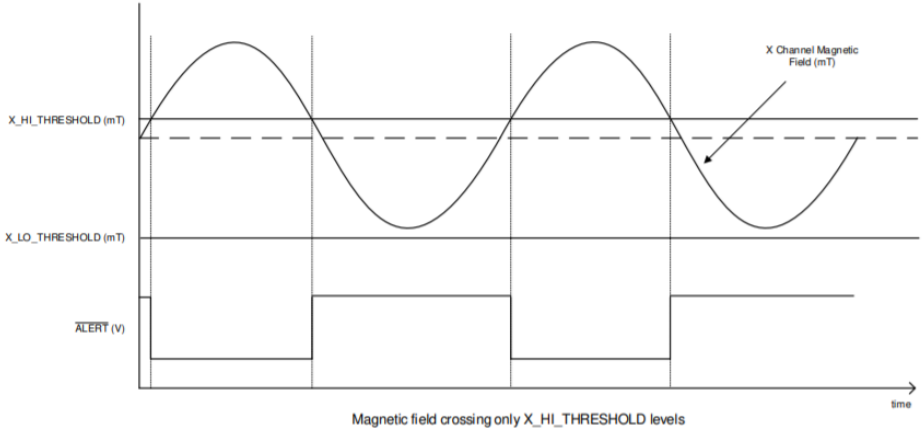
# Programmable thresholds and tamper detection

- TMAG5170 offers programmable high and low thresholds by source to trigger ALRT. Multiple thresholds may be simultaneously set.
  - Temperature
  - X-Axis
  - Y-Axis
  - Z-Axis

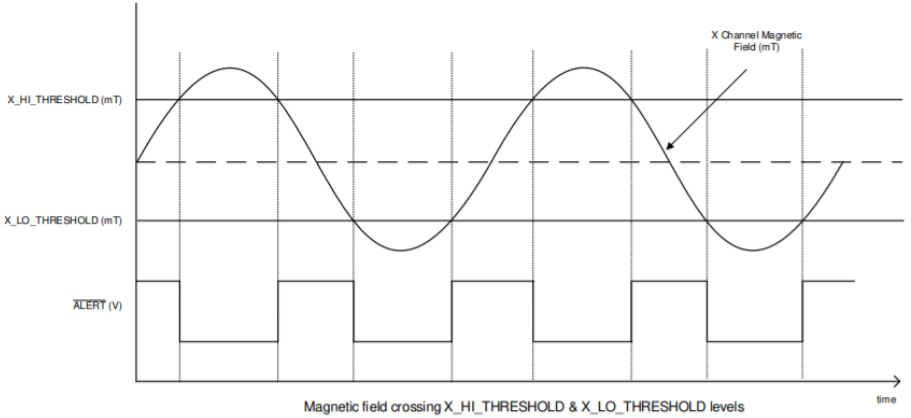
- Unused channels offer an additional input source to detect tampering or reject inputs when stray fields are present.
  - Angle calculations only require 2 axes. The third axis may be used to trigger ALRT and force the MCU to protect the system.

# TMAG5170(-Q1) switch mode

- The ALERT output can be configured as a magnetic switch for one or multiple magnetic channels.
- The magnetic switch thresholds are determined by the *_THRX_CONFIG register bits.
- If the measured magnetic field is greater than *_HI_THRESHOLD or smaller than *_LO_THRESHOLD, the ALERT output will assert low.
- Example using X-axis magnetic field below:



Magnetic field crossing only X_HI_THRESHOLD levels



Magnetic field crossing X_HI_THRESHOLD & X_LO_THRESHOLD levels

# Built in angle calculation and magnitude using CORDIC algorithm

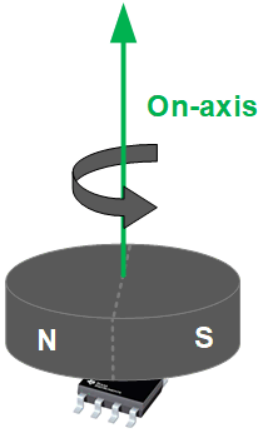
- CORDIC (Coordinate Rotation Digital Computer) performs trigonometric approximations in two dimensional space to calculate both angle and magnitude.
  - Iteratively approximates angle by rotating the point by fixed increments and determining changes in graphical quadrant.
  - TMAG5170 performs 10 iterations for to achieve 1/4º resolution.
  - Standard outputs may be read simultaneous to CORDIC calculations if needed.

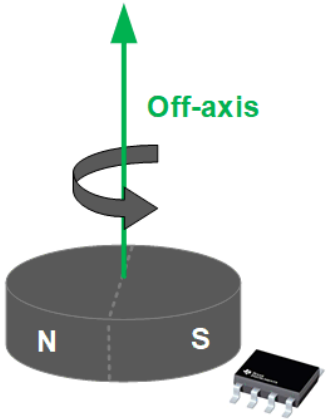
- TMAG5170 offers amplitude normalization to help minimize errors resulting from mismatched inputs common to off-axis alignment.

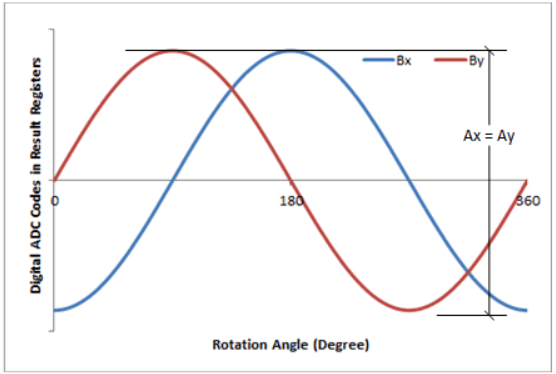
- A calculator tool is available in the product folder to help determine device settings to minimize total error
  - 2D Angle Error Calculator

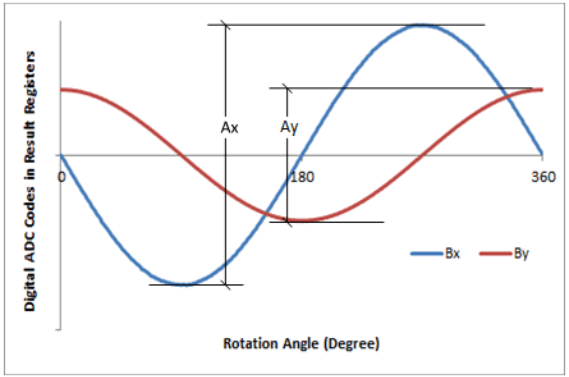
# TMAG5170 input matching

- Perfectly aligned on-axis configuration produces ideal inputs for CORDIC calculations.
- Mismatched off-axis inputs generate least error at zero crossings. 45º intervals produce maximum error.
- TMAG5170 allows for correction of mismatch to eliminate error from this effect.



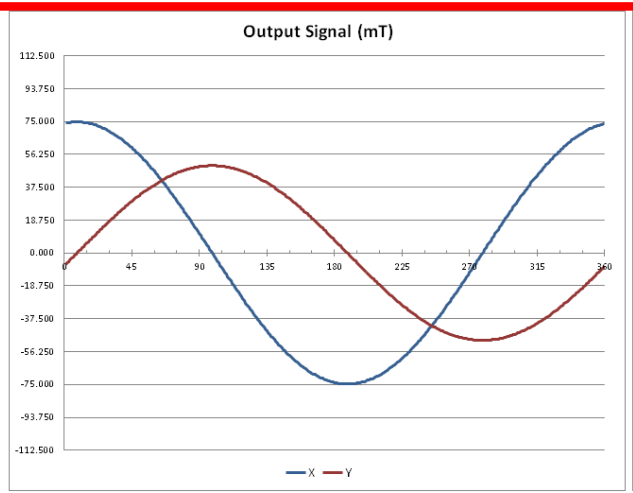



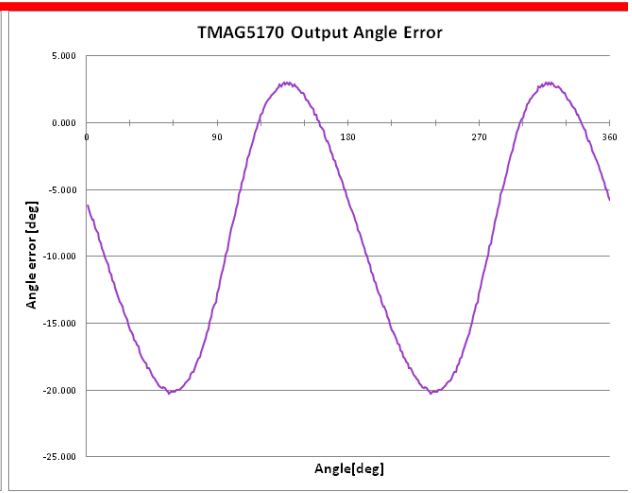



# Calculator tool

TEXAS INSTRUMENTS — TMAG5170 - 2D Angle Error Calculator

| | | | | |
|---|---|---|---|---|
| $B_X$ Peak | 75 | | | mT |
| $B_Y$ Peak | 50 | | | mT |
| Channel | | X | Y | |
| Device Settings | Input Range | 100 | 100 | mT |
| | Output Target | 75% | | of FS |
| | Single Channel Latency | 25 | | us |
| | CONV_AVG Register Code | 101 | 32 | Samples |
| | Rotation Speed | 10 | | Hz |
| | Rotation Speed (RPM) | 600 | | RPM |
| | Sampling Mode | XYZZYX | | |
| | X - Offset Correction | OFF | 0 | |
| | Y - Offset Correction | OFF | 0 | |
| | Channel Gain Attenuation | OFF | 342 | |
| | Sensitivity Error | 0.0% | 0.0% | |
| | Offset Error | 0 | 0 | mT |
| | Phase Lag error | 17.28 | | deg |
| | Rotational Latency | 0.05 | | Cycles |
| | Input Referred Noise,rms | 0.025 | 0.025 | mTrms |




Consider a magnet rotating at 10 Hz (600 RPM) and maximum averaging

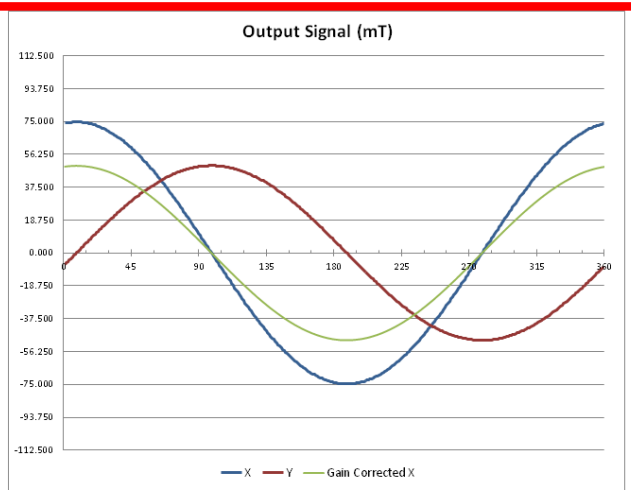
- X-input is 50% greater than Y-input
- Peak error is greater than 20º
- There is a fixed angular latency due to rotation speed and conversion time

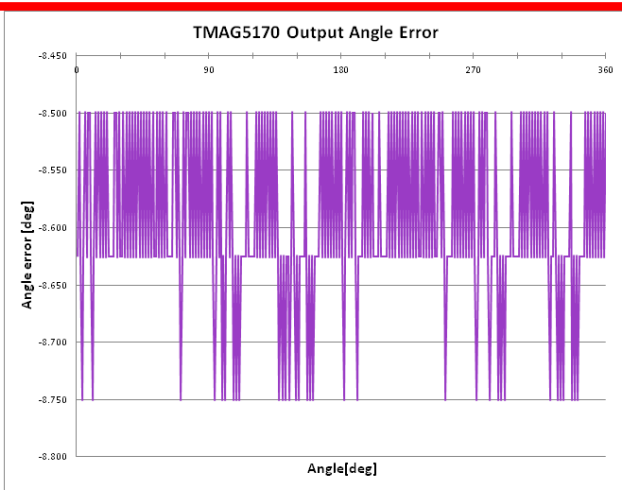
# Calculator tool – magnitude correction

TEXAS INSTRUMENTS

TMAG5170 - 2D Angle Error Calculator

| | | | | |
|---|---|---|---|---|
| $B_X$ Peak | 75 | | | mT |
| $B_Y$ Peak | 50 | | | mT |
| Channel | | X | Y | |
| Device Settings | Input Range | 100 | 100 | mT |
| | Output Target | 75% | | of FS |
| | Single Channel Latency | 25 | | us |
| | CONV_AVG Register Code | 101 | 32 | Samples |
| | Rotation Speed | 10 | | Hz |
| | Rotation Speed (RPM) | 600 | | RPM |
| | Sampling Mode | XYZZYX | | |
| | X - Offset Correction | OFF | 0 | |
| | Y - Offset Correction | OFF | 0 | |
| | Channel Gain Attenuation | X | 342 | 0.666 |
| | Sensitivity Error | 0.0% | 0.0% | |
| | Offset Error | 0 | 0 | mT |
| | Phase Lag error | 17.28 | | deg |
| | Rotational Latency | 0.05 | | Cycles |
| | Input Referred Noise,rms | 0.025 | 0.025 | mTrms |




Correcting peak amplitude results in a fixed error at approximately -8.6º

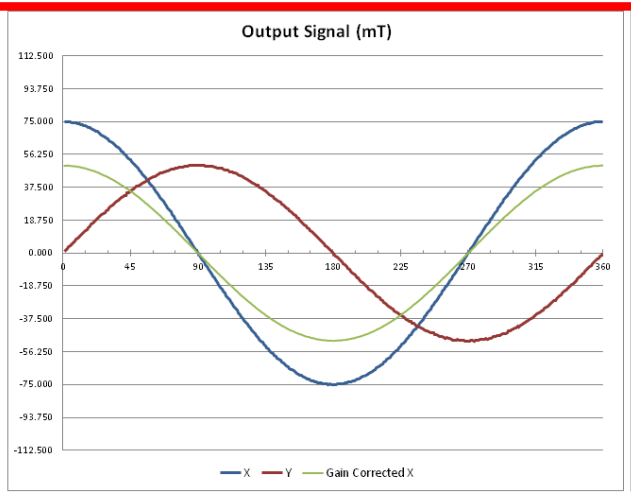
- With 32x averaging enabled and XYZZYX conversion pattern selected the output code will not reflect the actual magnet position at time of capture.

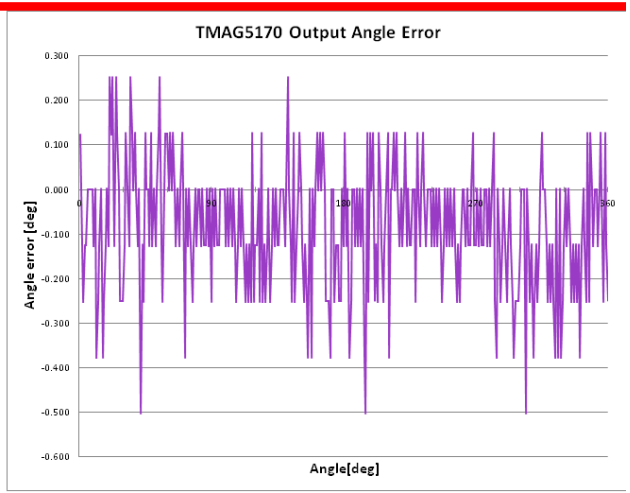
# Calculator tool – sampling time correction

TEXAS INSTRUMENTS

TMAG5170 - 2D Angle Error Calculator

| | | | | |
|---|---|---|---|---|
| $B_X$ Peak | 75 | | | mT |
| $B_Y$ Peak | 50 | | | mT |
| Channel | | X | Y | |
| Device Settings | Input Range | 100 | 100 | mT |
| | Output Target | 75% | | of FS |
| | Single Channel Latency | 25 | | us |
| | CONV_AVG Register Code | 0 | 1 | Samples |
| | Rotation Speed | 10 | | Hz |
| | Rotation Speed (RPM) | 600 | | RPM |
| | Sampling Mode | XYX | | |
| | X - Offset Correction | OFF | 0 | |
| | Y - Offset Correction | OFF | 0 | |
| | Channel Gain Attenuation | X | 342 | 0.666x |
| | Sensitivity Error | 0.0% | 0.0% | |
| | Offset Error | 0 | 0 | mT |
| | Phase Lag error | 0.27 | | deg |
| | Rotational Latency | 0.05 | | Cycles |
| | Input Referred Noise,rms | 0.140 | 0.140 | mTrms |




Reducing capture pattern to XYX and using 1x averaging results in maximum angular error of about 0.5º

# TMAG5170EVM

3-Axis linear Hall-effect sensor EVM with **SPI** output interface

**Available on ti.com**

## Features

- Two-board sensor and MCU system:
  - MSP432-based PAMB controller board
  - TMAG5170 sensor board with 3D knob
- SPI interface from sensor board to MSP432 controller board
- USB interface to PC for GUI display
- Read GUI register settings for configuration, status and results:
  - CONFIG:
    - DEVICE, SENSOR, SYSTEM, ALERT, X, Y& Z MAGNETIC THRESHOLD, TEMPERATURE THRESHOLD, TEST, MAG_GAIN, and MAG_OFFSET
  - STATUS:
    - CONV, AFE, SYS, OSC_MONITOR
  - RESULTS:
    - X, Y, & Z CHANNEL, TEMPERATURE, ANGLE, MAGNITUDE

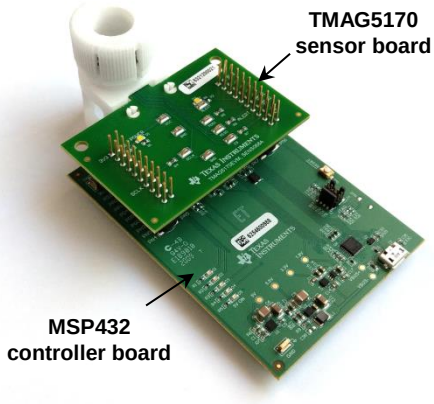
## Applications

- Lever position measurement
  - Stalk gear shifters, Turn signals
  - Industrial Joysticks
- Angle measurement
  - e-Shifter knob, Electronic power steering, Braking systems, Steering wheel control, Steering angle sensor
  - Robotic Arm, Appliance multifunction knobs – cooking top, oven, washer & dryer
- Linear movement
  - Actuators, Fluid measurement, Factory automation linear mover
- Ambient Current Sensing
  - HEV/ EV
  - Isolated AC motor drive

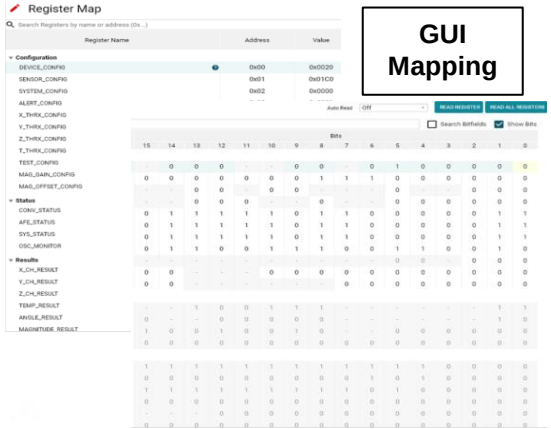
## Benefits

- Ability to test and monitor X, Y, & Z magnetic fields with 3D knob
- Freedom to position a particular magnet without 3D knob
- Selectable sensitivity ranges allows last minute design adjustments
- Best-in-class sensitivity error (<±2% over temperature and axis-to-axis) allows precision system design
- GUI allows real-time viewing of measured results

**TMAG5170EVM**




**GUI Mapping**



# Questions?

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