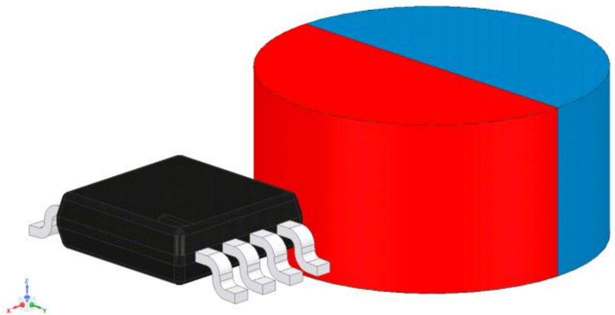
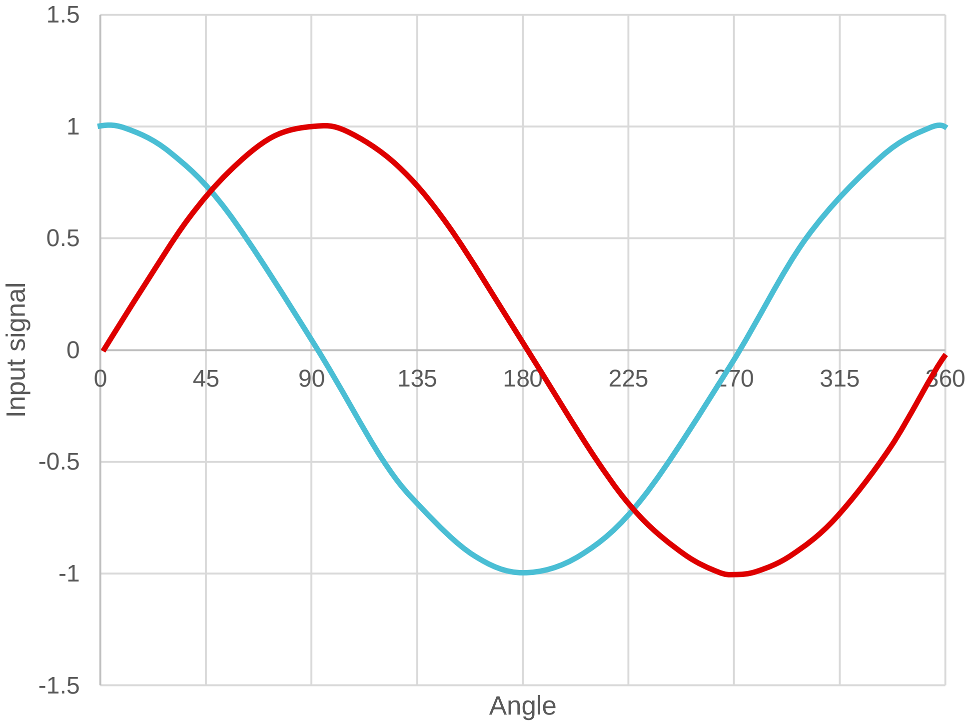
CORDIC algorithm for angle calculations

TI Precision Labs – Magnetic sensors

Presented and prepared by Scott Bryson

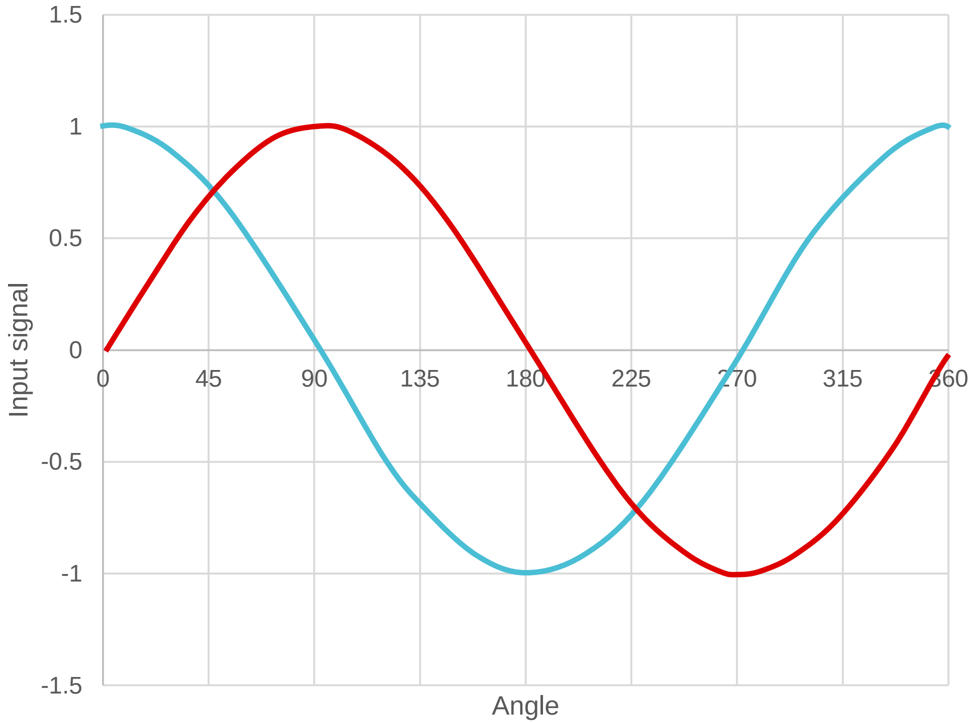
Angle calculation

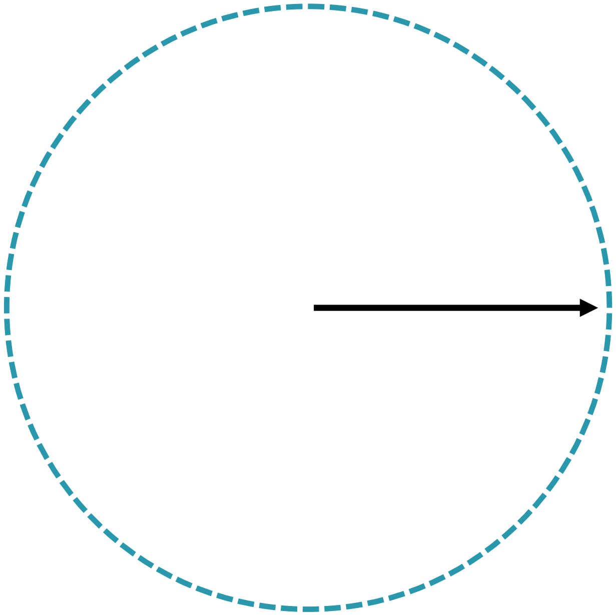




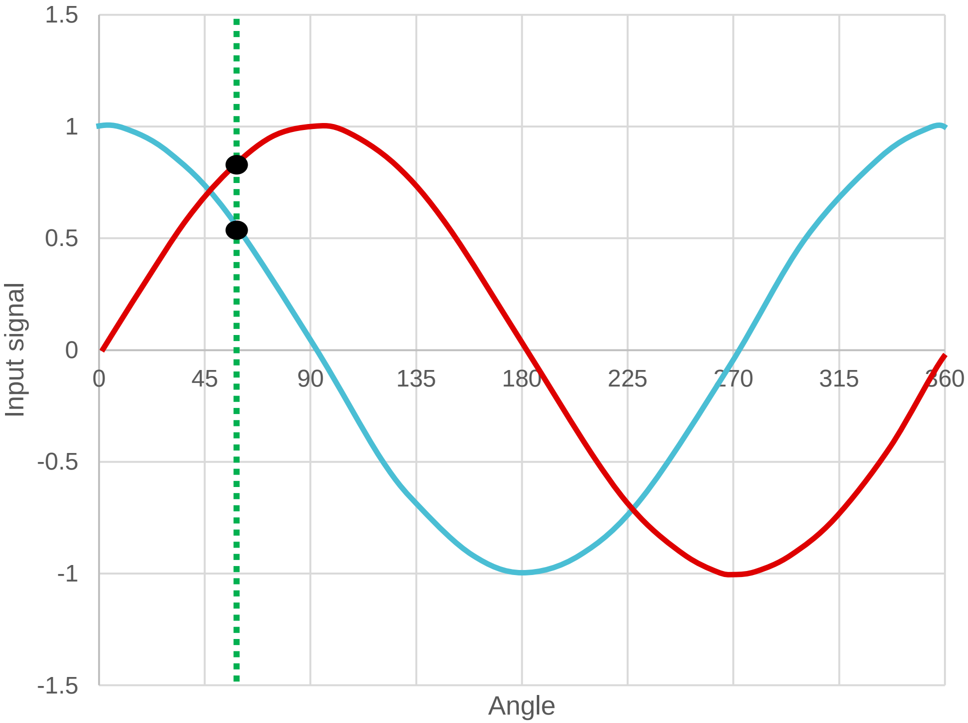
Angle calculation

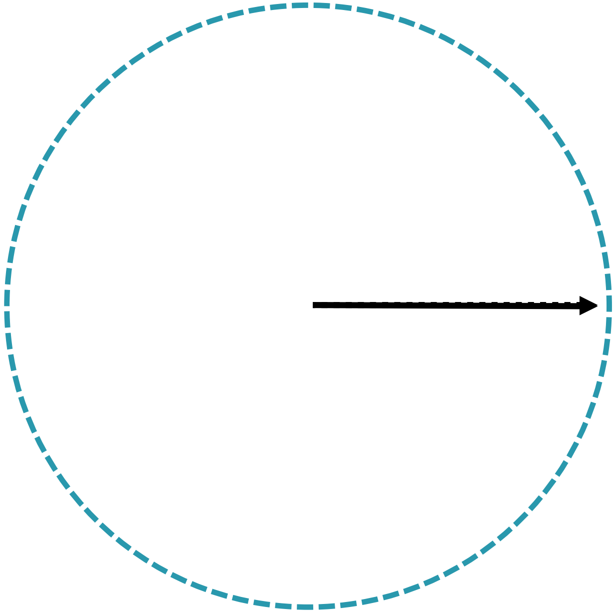
$$\tan\theta = \frac{\sin\theta}{\cos\theta}$$





Angle calculation





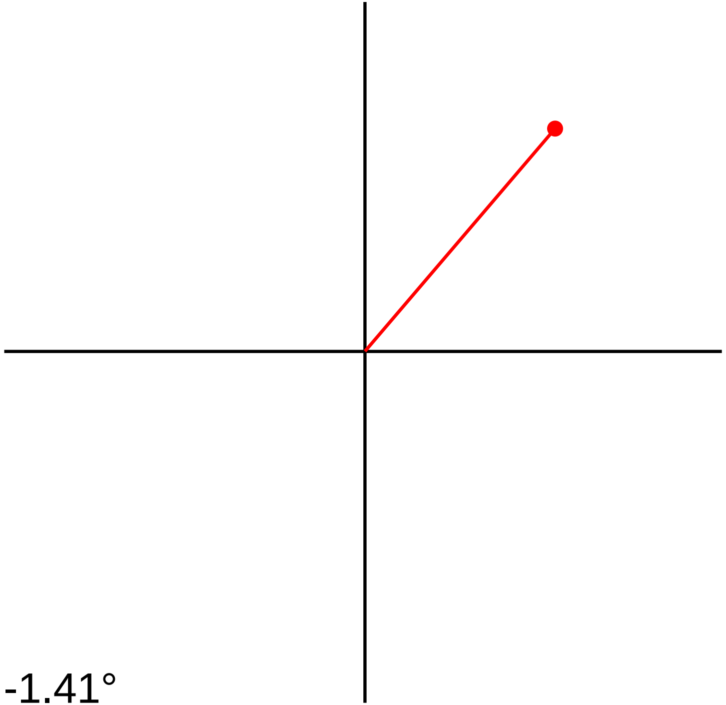
CORDIC

Coordinate

Rotation

Digital

Computer



Error = 49.5° -45° -22.5° +11.25° +5.63° +2.81° -1.41°

= 0.28°

Vector rotation

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix} \text{x}$$

$$x' = x\cos(\alpha) - y\sin(\alpha)$$

$$x' = \cos(\alpha) \times (x - y\tan(\alpha))$$

$$y' = x\sin(\alpha) + y\cos(\alpha)$$

$$y' = \cos(\alpha) \times (y + x\tan(\alpha))$$

Vector rotation

$$x' = \cancel{\cos(\alpha)} \times (x + y\tan(\alpha))$$

$$y' = \cancel{\cos(\alpha)} \times (y - x\tan(\alpha))$$

$$m = \frac{1}{\prod_{n=0}^{i} \cos(\alpha_i)}$$

Vector rotation

$$x' = x + y\tan(\alpha)$$

$$y' = y - x\tan(\alpha)$$

α		
45		
22.5		
11.25		
5.625		
2.8125		

Vector rotation

$$x' = x + y\tan(\alpha)$$

$$y' = y - x\tan(\alpha)$$

α	tan(α)	
45	1	
22.5	0.414	
11.25	0.199	
5.625	0.098	
2.8125	0.049	

Vector rotation

$$x' = x + y\tan(\alpha)$$

$$y' = y - x\tan(\alpha)$$

α	tan(α)	2^{-n}
45	1	1
22.5	0.414	0.5
11.25	0.199	0.25
5.625	0.098	0.125
2.8125	0.049	0.0625

Vector rotation

$$let\ d_n = \begin{cases} 1\ for\ CW\ rotation \\ -1\ for\ CCW\ rotation \end{cases}$$

$$m = \frac{1}{\prod_{n=0}^{i} \cos(\alpha_i)}$$

$$x_{n+1} = x_n - y_n \times d_n \times 2^{-n}$$

$$y_{n+1} = y_n + x_n \times d_n \times 2^{-n}$$

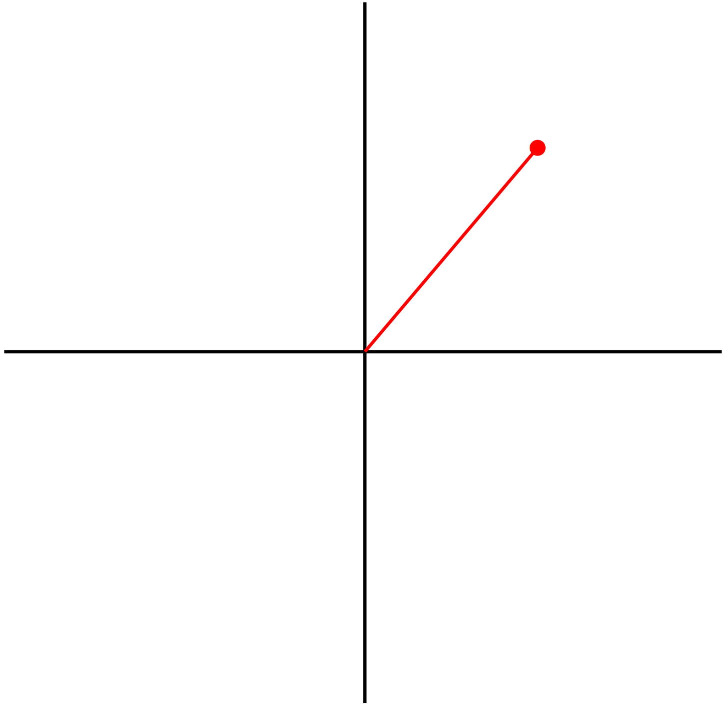
$$\theta = \sum_{n=0}^{i} d_n \times \alpha_n$$

$$\alpha_n = \mathrm{atan}(2^{-n})$$

$$magnitude = \frac{x_i}{m}$$

CORDIC using rightward shifts

Error = 49.5°
- 45°
- 26.56°
+ 14.04°
+ 7.13°
+ 3.58°
- 1.79°
- 0.90°
≅ 0°



Benefit of CORDIC

- Simpler to implement in an end system
- Reduces burden on microcontroller
- Reduces calculation time

Microcontroller calculations

$$2 * 6.4\ \text{us} + T_{read\text{-}delay} + T_{atan2} > 12.8\ \text{us}$$

CORDIC calculations

$$3\ \text{us} + 6.4\ \text{us} = 9.4\ \text{us}$$

Resources

Application Brief

Absolute Angle Measurements for Rotational Motion Using Hall-Effect Sensors

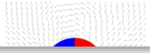
TEXAS INSTRUMENTS

Scott Bryson

Current and Position Sensing

Rotation-based devices such as dials, joysticks, thermostats, electronic steering assemblies, and motor-controlled joints typical to gimbals or robotic arms all rely on the ability to accurately define angular position. While there are means to monitor rotation angle using mechanical contacts, these types of sensors are prone to wear out with use and can suffer performance loss in cases where dirt and grime are present. Hall-effect sensors are a contactless sensing alternative which can offer longer product life, improved reliability, and higher performance for angle sensing.

In applications where angular rotation is present, feedback to a controller can provide valuable insight to the device configuration. This might be user input from a knob or steering wheel, or exact position control for motor-driven configurations. Implementing this solution using a Hall-effect sensor normally requires placing a magnet on the rotating body with a nearby sensor capable of detecting the magnetic flux density produced by the magnet. Monitoring angles with linear Hall-effect sensors can be most easily achieved when using a diametric cylinder magnet installed along the axis of rotation.



surface of the magnet. Consider the following curves representing each component produced by a rotating magnet.

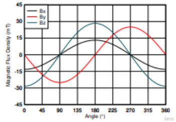
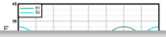


Figure 2. Magnetic Flux Density vs Magnet Angle

If a sensor element is oriented in the XZ plane, we would be able to monitor B_y which is the component of the vector directed in the Y direction. Using this input, it is possible to resolve up to 180° of rotation using the following relationship.

$$\text{Device Output} = \alpha \sin(\theta) \quad (1)$$

Adding a second sensor 90° out of phase from the first enables expanding the absolute angle sensing solution to a full 360°.



Application Report

Angle Measurement With Multi-Axis Linear Hall-Effect Sensors

TEXAS INSTRUMENTS

ABSTRACT

As the demand for automated precision control systems increases there is a similar increase to design systems that are more reliable and less likely to fail from mechanical wear. Many of these applications require the detection of angular rotation. While this function can be implemented using multiple one-dimensional sensors, a new class of three-dimensional sensors offers more flexibility and accuracy while allowing more compact solutions.

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Trademarks

TEXAS INSTRUMENTS

Application Report

SLYA036A–July 2018–Revised August 2018

Linear Hall Effect Sensor Angle Measurement Theory, Implementation, and Calibration

Mitch Morse

Current and Magnetic Sensing

ABSTRACT

This application report discusses how linear Hall effect sensors can be used to measure 2D angles, including both limited-angle and 360° rotation measurements. This report provides details on some calibrated and uncalibrated implementations to help meet angle measurement accuracy requirements. This report also covers the number of sensors needed, and the preferred magnet types for each method.

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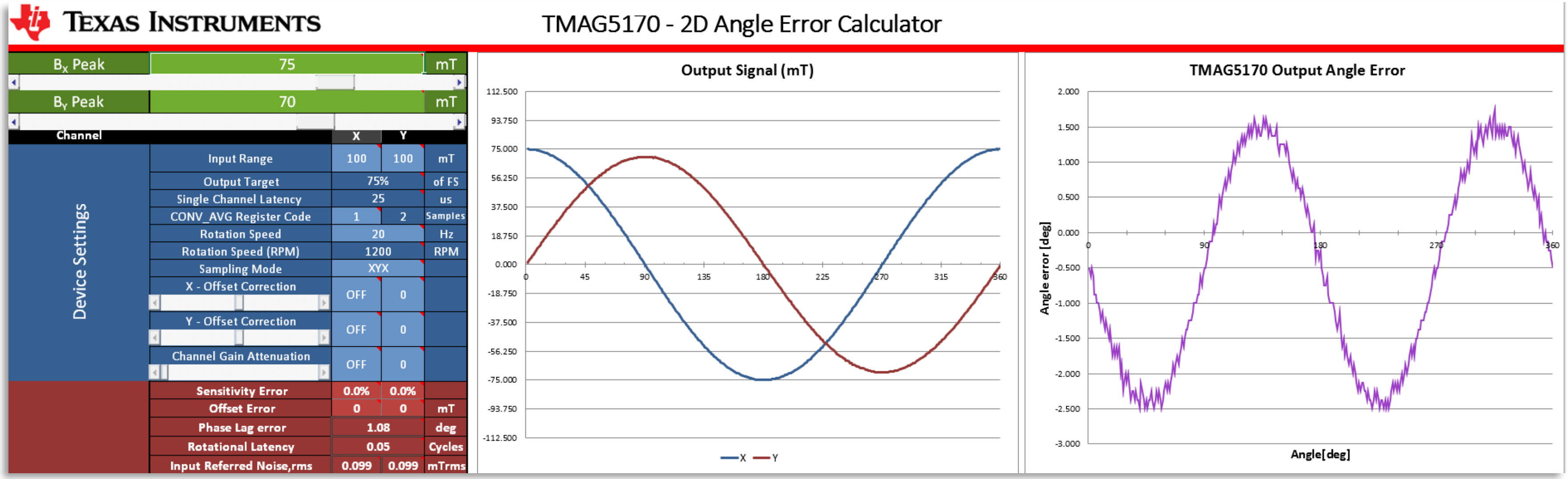
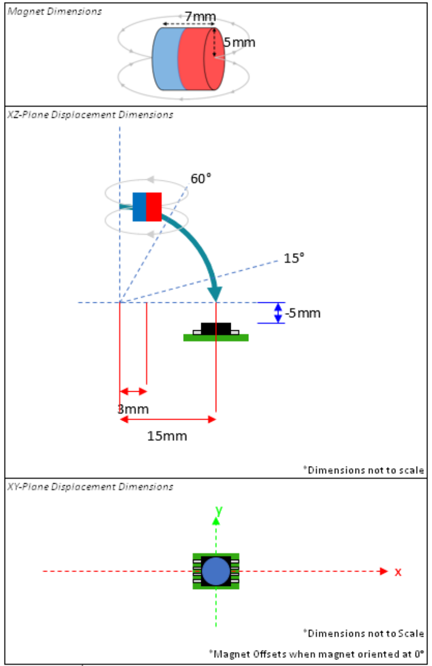

TEXAS INSTRUMENTS
TMAG5170 - 2D Angle Error Calculator
Bx Peak 75 mT
By Peak 70 mT
Channel X Y
Device Settings
Input Range 100 100 mT
Output Target 75% of FS
Single Channel Latency 25 us
CONV_AVG Register Code 1 2 Samples
Rotation Speed 20 Hz
Rotation Speed (RPM) 1200 RPM
Sampling Mode XYX
X - Offset Correction OFF 0
Y - Offset Correction OFF 0
Channel Gain Attenuation OFF 0
Sensitivity Error 0.0% 0.0%
Offset Error 0 0 mT
Phase Lag error 1.08 deg
Rotational Latency 0.05 Cycles
Input Referred Noise,rms 0.099 0.099 mTrms
Output Signal (mT)
112.500
93.750
75.000
56.250
37.500
18.750
0.000
-18.750
-37.500
-56.250
-75.000
-93.750
-112.500
0 45 90 135 180 225 270 315 360
X Y
TMAG5170 Output Angle Error
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
-3.000
0 90 180 270 360
Angle error [deg]
Angle[deg]

Tools

Texas Instruments — **Contactless Distance Measurement**

		units
General Implementation		
Magnet Movement	Hinge	
Magnet Shape	Cylinder	
Magnet Orientation	North Facing DUT	
Polarity	1	
Magnet Characteristics		
R	5.00	mm
T	7.00	mm
Magnet Material	N48	
Br (Remanence)	14000	G
Displacement Dimensions		
a1	60	degrees
a2	15	degrees
X-Offset	0	mm
Y-Offset	0	mm
Sensor Z-Offset	-5.000	mm
Magnet Z-Offset	3.000	mm
Arc Radius	15.000	mm
Sensor Operating Conditions		
Temperature Min		°C
Temperature Nominal		°C
Temperature Max		°C
VSUPPLY (nominal)	5	V
Sensor Filters		
Type of Device	3-Axis linear	
Device	TMAG5170A1EDGK	
package	VSSOP | 8	
	Calculate B-Field & Vout	
Sensor Axis	2	
Operating Region	1	
VL (MIN)	0	V



To find more magnetic position sensing technical resources and search products, visit **ti.com/halleffect**.