MPS 新一代磁角度传感器MA600介绍与应用

Dec 2022

rev 20180504

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  - Latency
- MA600 Application and Design Note
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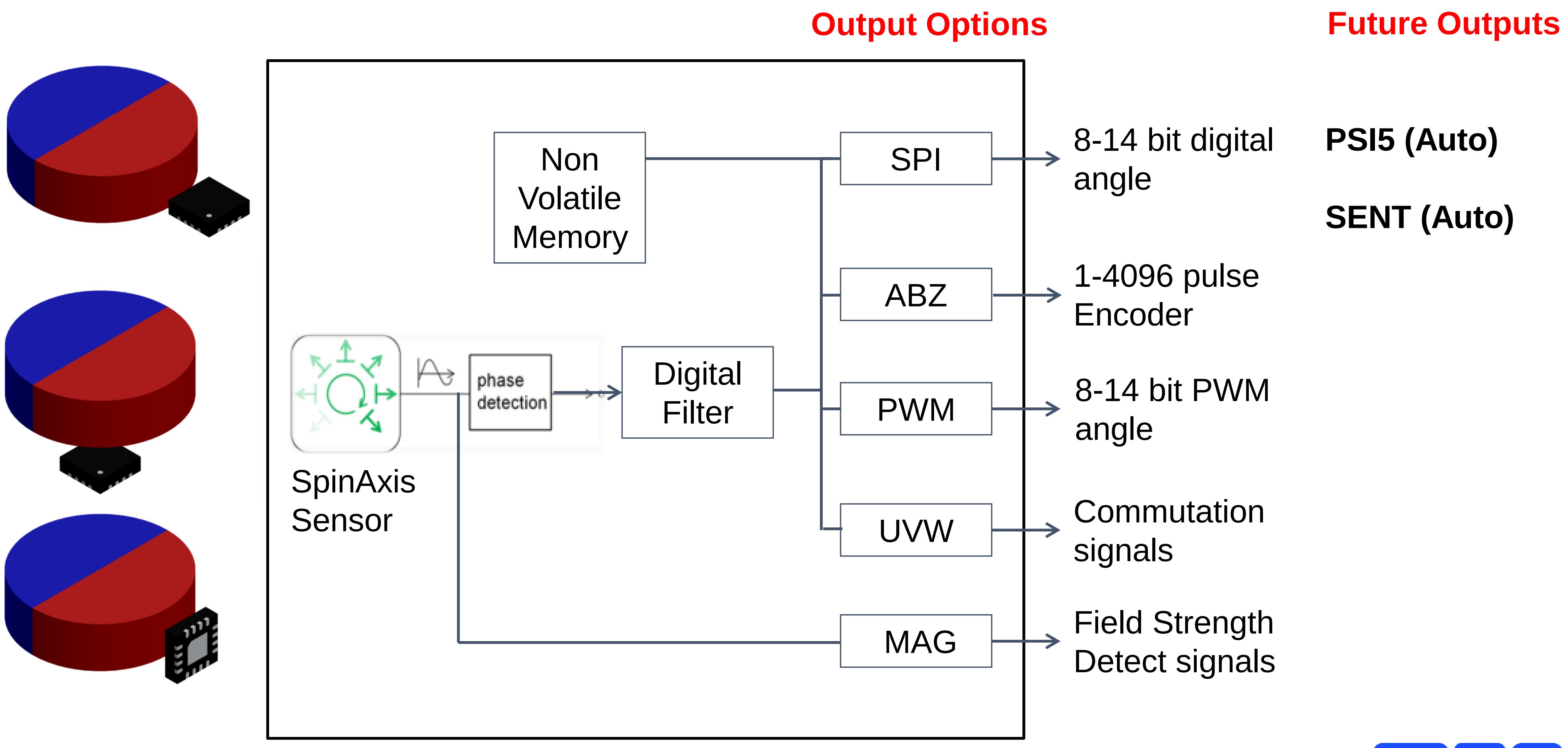
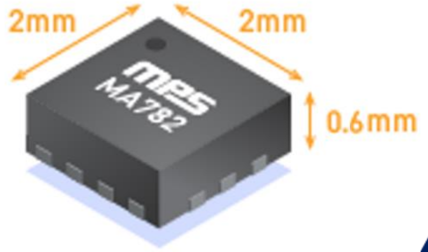
  - Side of shaft
  - BCT compensation
  - User calibration

MagAlpha™ Generic Block Diagram



MagAlpha™ Advantages



Low Power: <0.5µA idle current and fast wake-up

Wide Magnetic Field Range: <15mT to unlimited

±3σ Resolution: from 8-bit to 14-bit

Robust Design Immune to dust and debris

Flexible Magnet Topologies: end- & side -of-shaft supported

Most Cost Effective Solution Spinaxis™ requires smallest silicon area

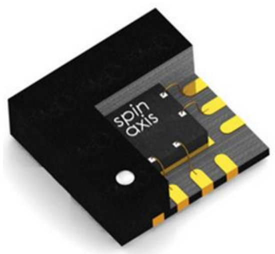
Fast Angle Sensing: No latency, Up to 50kHz BW

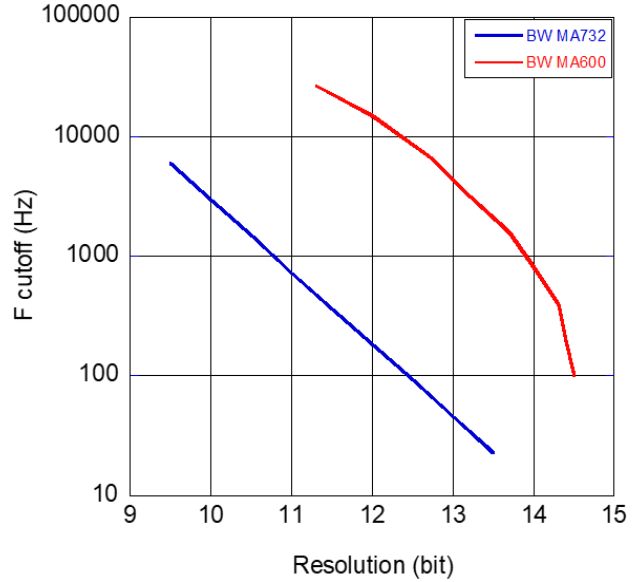
TMR

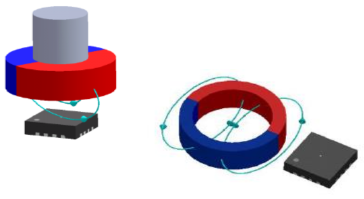
High Accuracy: <0.5° (0.1°) INL over temp, **after** reflow

TMR

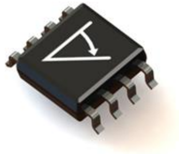
Smallest Footprint: UTQFN14 2*2mm² and QFN16 3*3mm²







Position Product Portfolio



MagAlpha™ (Motors & Rotary Encoders)

MA102/302
12-bit Res
SPI, ABZ, UVW
1 to 8 Pole Pair Emulation

MA310/330
12-14 bit Res
ABZ, UVW
Configurable Filter for Res & BW

MA702/4/10
10-12 bit Res
SPI, ABZ
1 to 256 Pulse Per Revolution (PPR)

MA730/2/4
12-14 bit Res
SPI, ABZ, PWM
1 to 1024 PPR
3µs low latency
Prog Filter

MA735/6
12-14 bit Res
SPI, ABZ
1 to1024 PPR
3µs Latency
UTQFN 2x2mm²

MA600 TMR
14.5-bit,
0.5°(0.1°) INL
High BW,
No Latency,
SPI, SSI, UVW,
ABZ, PWM

MagAlpha™ (HMI, low-power angle detection)

MA800/20/50
8-bit Res
SPI, SSI, ABZ, PWM
1.64 ppr
Dial & Push Button

MA780/2
8-14 bit Res SPI
auto wake/sleep;
<0.5µA idle
QFN 3x3 / UTQFN 2x2
Angle Detection

MagDiff™ MagProfile™

Q2 2023
MA900
Differential
Immune to Stray Mag Fields
12-bit data
flex. Interface

2H 2023
MA95x
12-bit, Linear & Angular Motion,
Hi-Resolution
Multi-Pole Pair
Flex. Interface

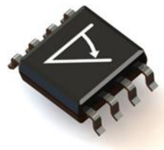
MagVector™ (3D Position Sensors)

MV300
3D Mag Sensing
12-bit data
Comp Output
I²C, SPI
Temp. Sensor
SOT23-6

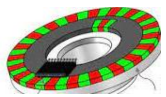
Released | Newly Released | Sampling | Preview

MPS

Automotive AEC1 & ASIL Compliant Position Sensors



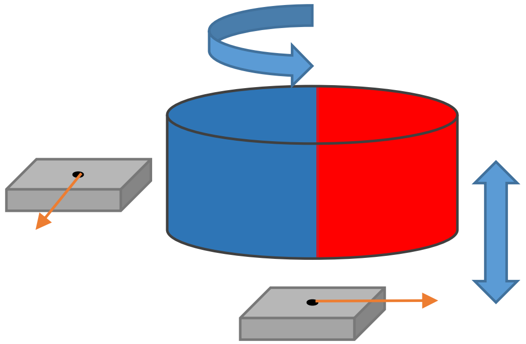
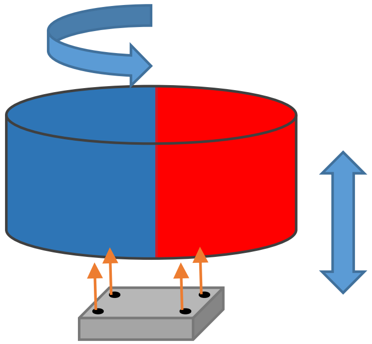
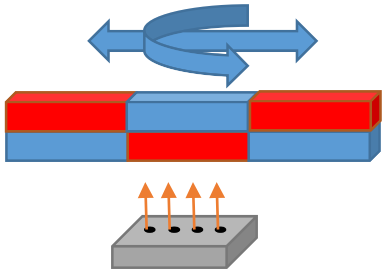
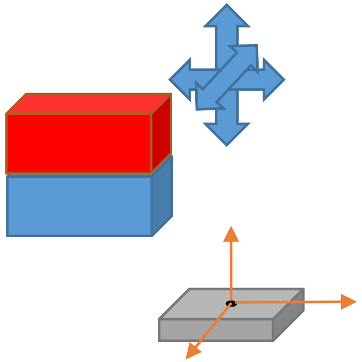
MagAlpha™ (Motors, Rotary Encoders)	**MAQ430** 12-bit, SPI, UVW, 1 to 8 Pole-Pair Emulation, 150°C, AEC1
	MAQ470/3 14-bit, SPI, ABZ, 1 to 1024 Pulse Per Revolution, 150°C, AEC1
	S: Now; P: Q1 23 — **MAQ600** (TMR) 14.5-bit, 0.5°(0.1°) INL, No Latency, High BW, SPI, SSI, UVW, ABZ, PWM Selectable Outs
	S: 2024 — **MAQ650** Gen2 (TMR) 3.3V, 5V, 18-bit, No Latency, 0.3° INL, High BW
MagAlpha™ (Contactless HMI)	S: Now: P: Q4 22 — **MAQ8x0** 8-bit, SPI, SSI, ABZ, PWM; 1.64 ppr, 150˚C, AEC1, Dial & Push Button
MagDiff™ MagProfile™	S: Q2 23; P: Q1 24 — **MAQ79010** (MPSafe) 12-bit, Differential; Immune to Stray Fields, flexible Interface, 150°C, ASIL B(D) Compliant
	S: Q3 23; P: Q2 24 — **MAQ79xxx** (MPSafe) 12-bit, Linear & Angular Motion, Multi-Pole Pair, ASIL B(D)
MagVector™ (3D Position Sensors)	S: Now; P: Q4 23 — **MVQ300** 3D Magnetic Sensor, Comp Out, 12-bit Data, I²C, SPI, 125˚C, AEC1, Component Out w/ Temp Sensor



Released | Newly Released | Sampling | Preview

MPSafe = Functional Safety

What Technology Goes Where?

MagAlpha™	MagDiff™	MagProfile™	MagVector™
			
• One sensor area on silicon (Orthogonal Vertical Hall Devices) • Detects rotary movements • Allows Push-button (except MA600) • Applicable for end-of-shaft and side-shaft applications	• Four sensor on corners of silicon for max separation (Planar hall elements) • Differential measurement for sensors in opposite corners • Detects rotary movements • Eliminates homogenous magnetic stray fields • Allows Push-button • Applicable for end-of-shaft applications only	• Sensor elements in a row on silicon (Planar hall elements) • Differential measurement possible – possibility to eliminate homogeneous magnetic stray fields • Detects linear movements • Detects rotational movement	• One Sensor area on silicon • Detects field strengths in each direction (x-y-z) • Requires external processing to determine movement/angle

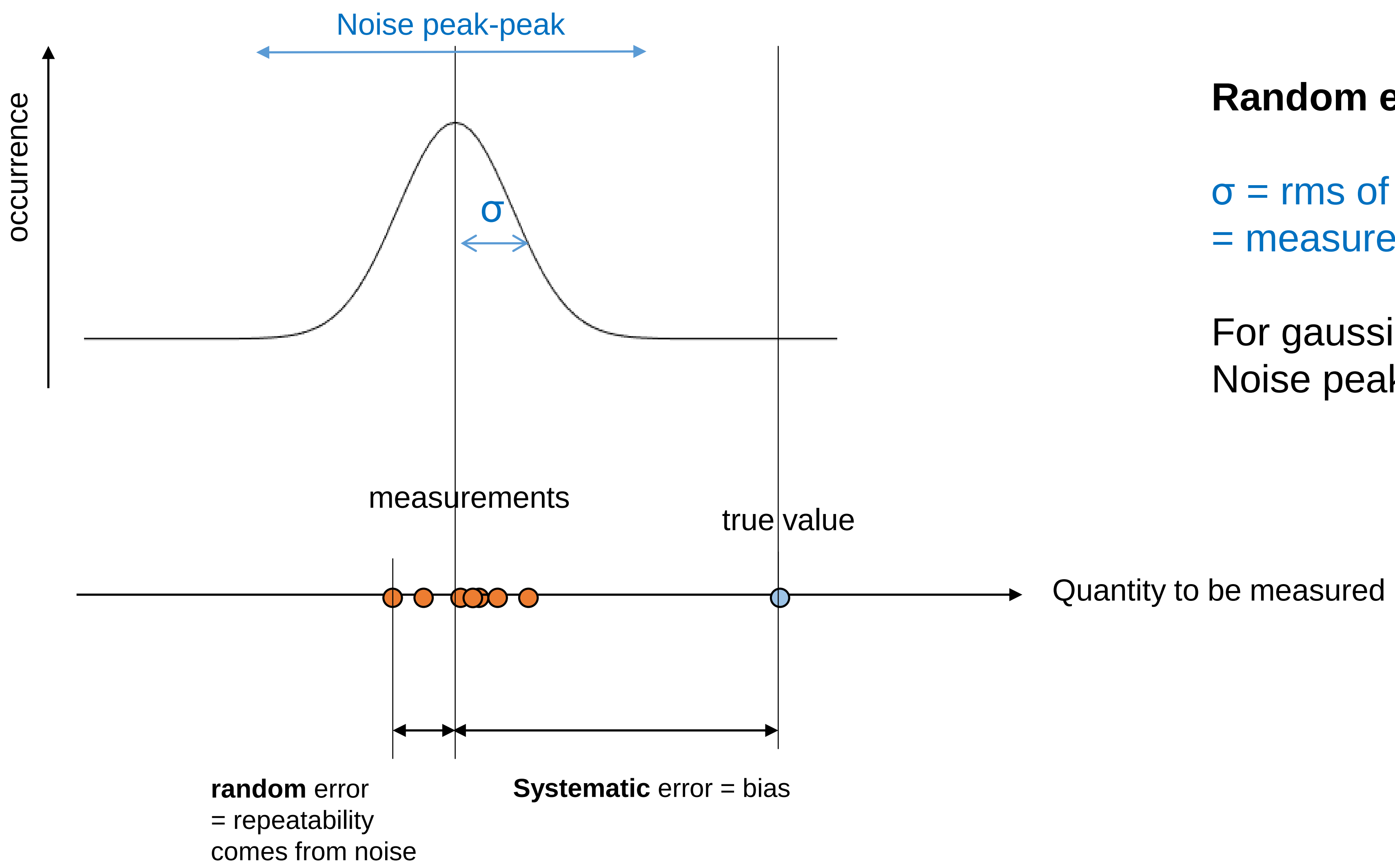
Legend:
= Magnetic Field Direction Sensed
= Sensing Motion Detected

Main Features of MA600

What is resolution?

Metrology: Measurement Error

Measurement error:



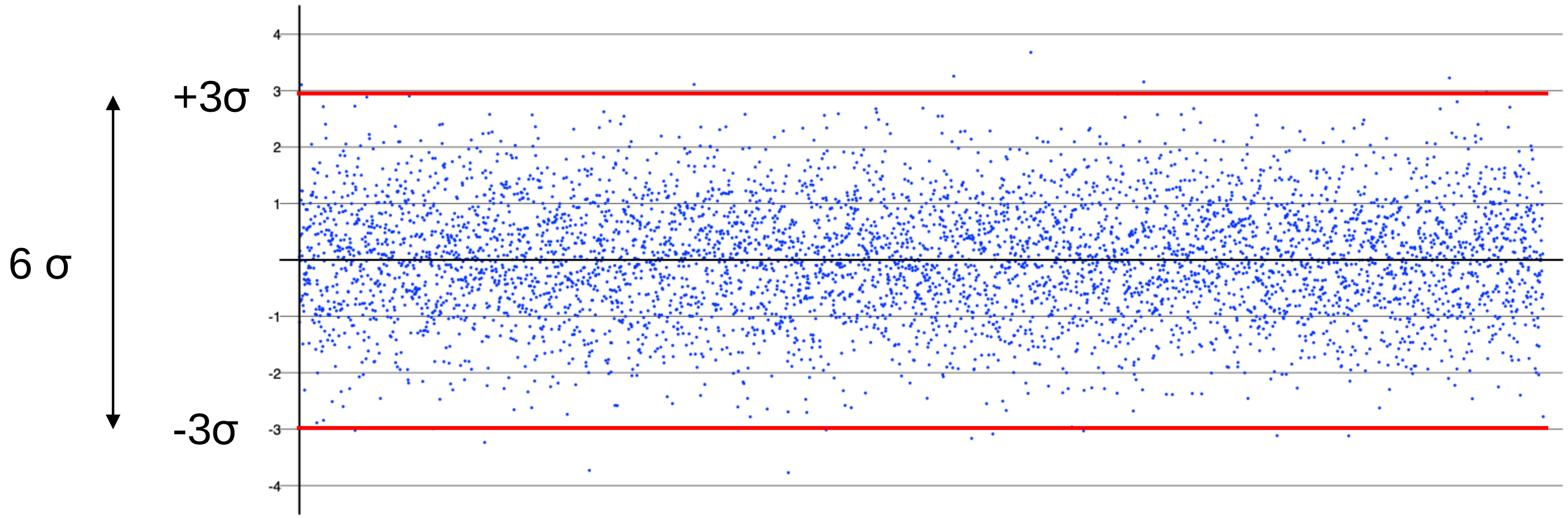
Random error:

σ = rms of measurements
= measurement precision

For gaussian noise distribution:
Noise peak-peak = 6 σ

Random Error - Why 6σ?

Gaussian noise

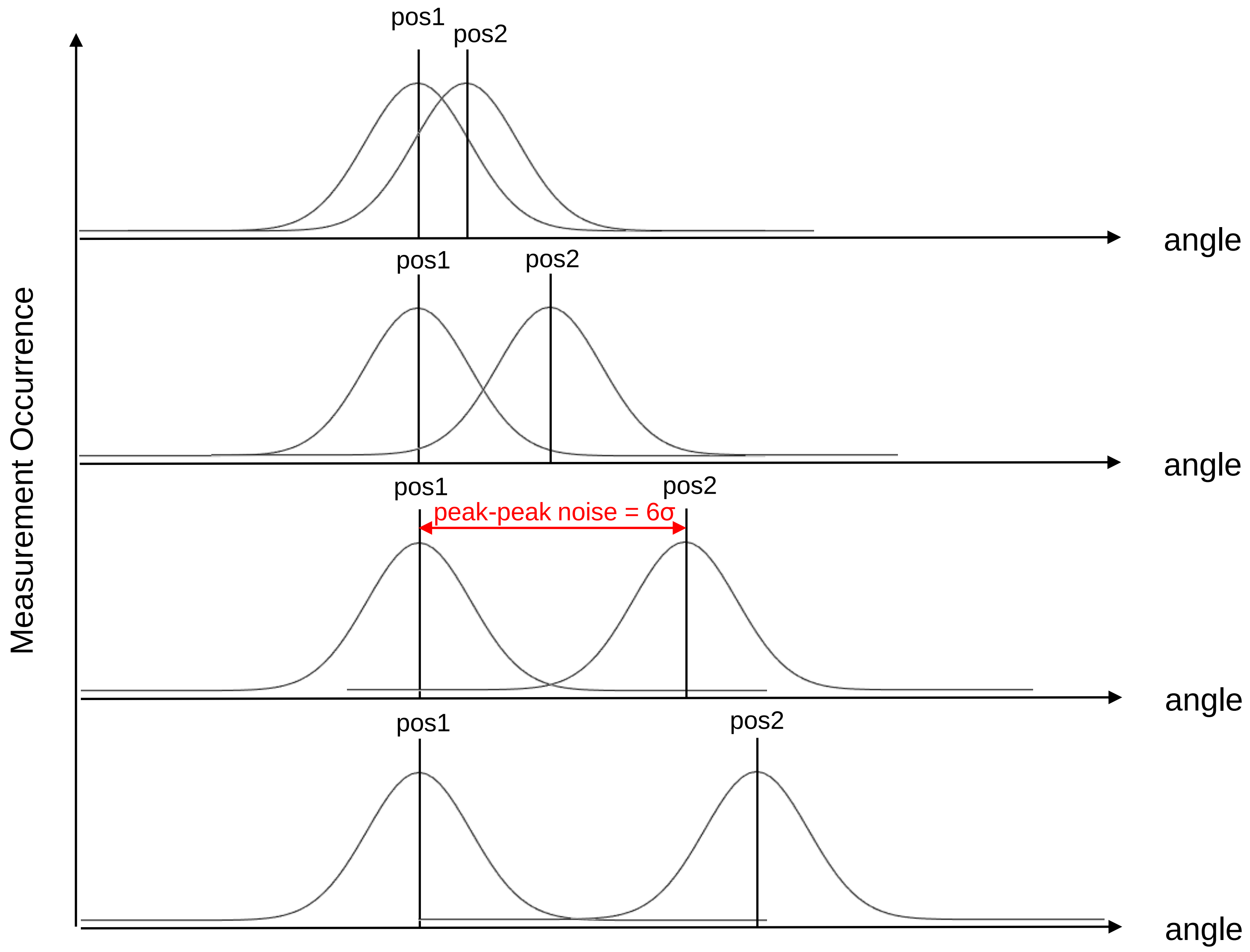


± 3σ means 99.73% of the time, the angle read is within ± 3 σ of the mean.

0.27% of data are out of the +/- 3 σ range

Definition of Resolution

Criteria: if $|\mathrm{pos2} - \mathrm{pos1}| > \mathrm{resolution}$ then with 1 measurement you can answer the question “is the system at position 1 or 2?” correctly 99.73% of the time



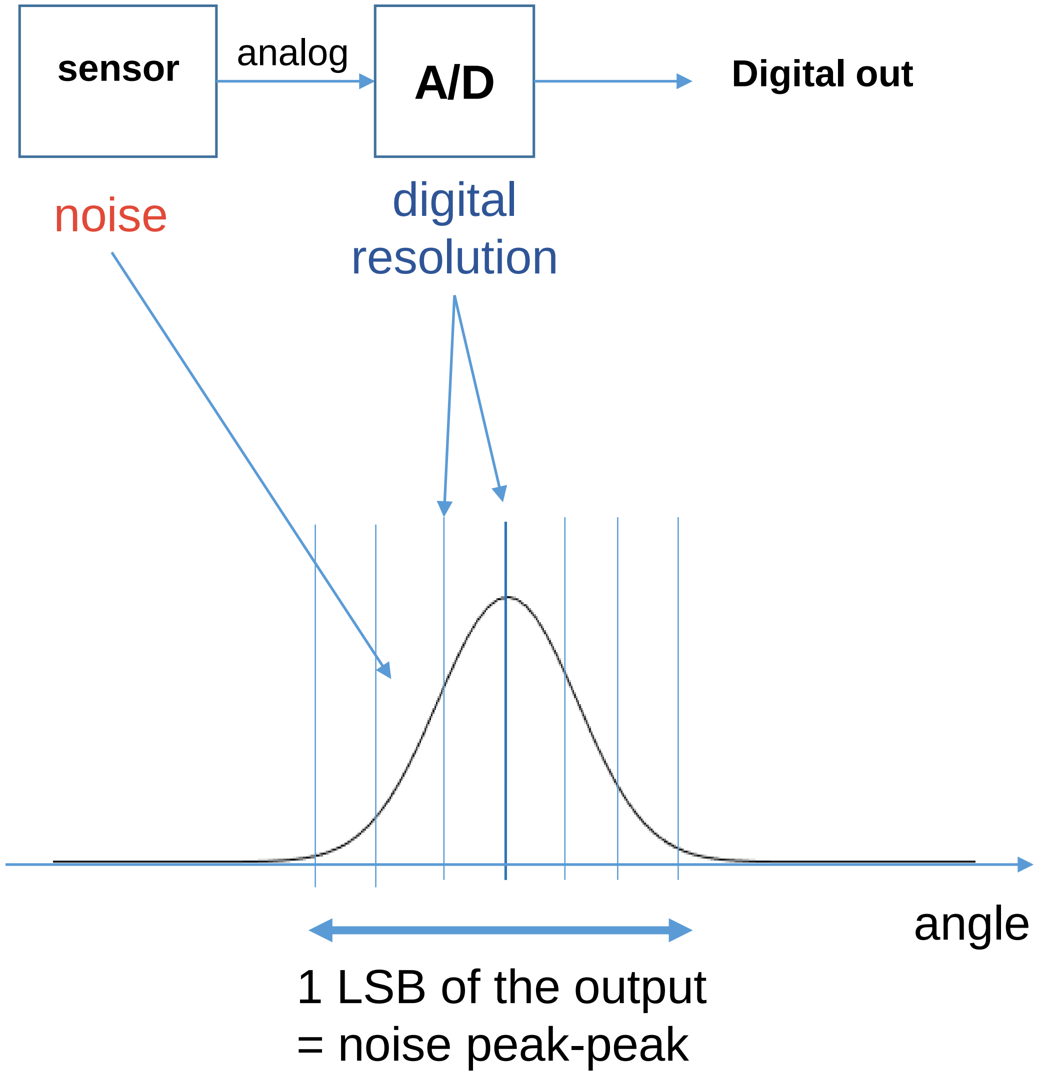
$$|\mathrm{pos2} - \mathrm{pos1}| < \mathrm{resolution}$$

$$|\mathrm{pos2} - \mathrm{pos1}| < \mathrm{resolution}$$

$$|\mathrm{pos2} - \mathrm{pos1}| = \mathrm{resolution}$$

$$|\mathrm{pos2} - \mathrm{pos1}| > \mathrm{resolution}$$

Resolution in Bit

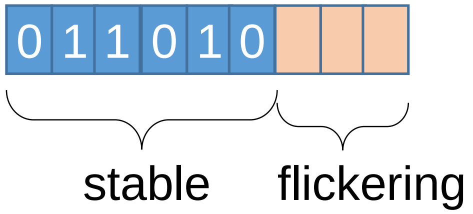


assuming that the digital steps are finer than the noise

Resolution in bit

$$\log_2 \frac{full\ scale}{peak - peak\ noise}$$

This is the analog of the *noise free code resolution* used for AD converters.
It is equal to the number of **stable bits**:



For an **angle sensor** $full\ scale = 360°$ therefore,

$$Resoluntion\ in\ bits = \log_2 \frac{360°}{6\sigma}$$

Competitor A

Because $\log_2 \frac{360}{0.01} = 15.1$

- 15 bit representation of absolute angle value on the output (resolution of 0.01°)

This is the digital grid, not the resolution!

- In this example the "resolution" in the EC table is not available
- Use RMS noise shown in EC table

Angle noise (RMS)	N_{Angle}		0.08		°	FIR_MD = 1[1)]
			0.05		°	FIR_MD = 2[1)](default)
			0.04		°	FIR_MD = 3[1)]

1) Not subject to production test - verified by design/characterization

- **Resolution is calculated with** $\boldsymbol{log_2 \frac{360°}{6\sigma}}$**, where 6σ = 6 x 0.05°**

Actual Resolution is 10.2 bits, not 15 bits

MPS

Competitor B

- In this example, resolution is only given as the internal ADC resolution

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
ADC Resolution on the raw signals sine and cosine	R_{ADC}	Slow Mode[10] Medium Mode[10] Fast Mode[10]		15 14 14		bits bits bits
Output Stage Noise		Clamped Output		0.05		%VDD
Noise pk-pk[14]		VG = 9, Slow mode, Filter=5 VG = 9, Fast mode, Filter=0		0.03 0.1	0.06 0.2	Deg Deg

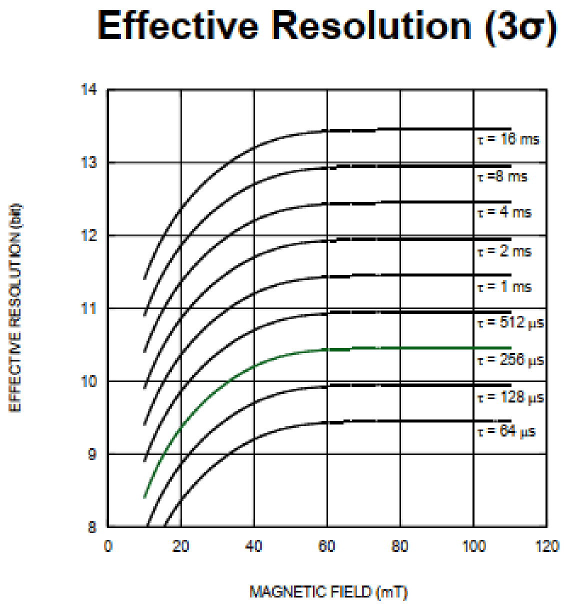
- **Resolution is calculated with $log_2 \frac{360°}{6\sigma}$, where 6σ is pk-pk noise = 0.03°**

Actual Resolution is 13.6 bits, not 15 bits

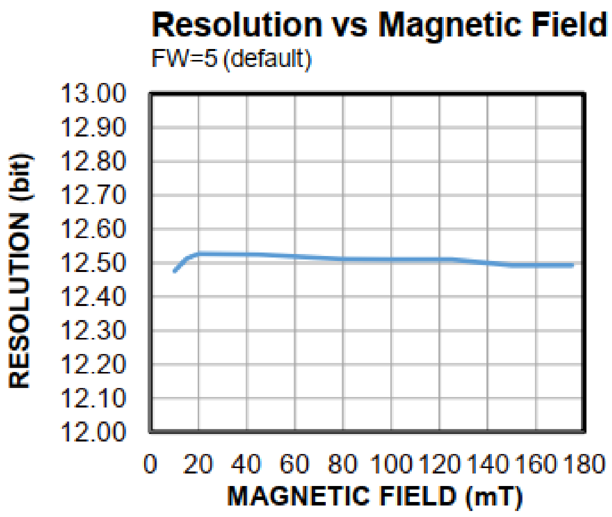
Resolution Performance

What resolution influence:
1. Position error
2. In servo motor control, high frequency vibration, noisy sound

What will affect the resolution:
1. Magnetic field strength (not for MA600)
2. Internal digital filter

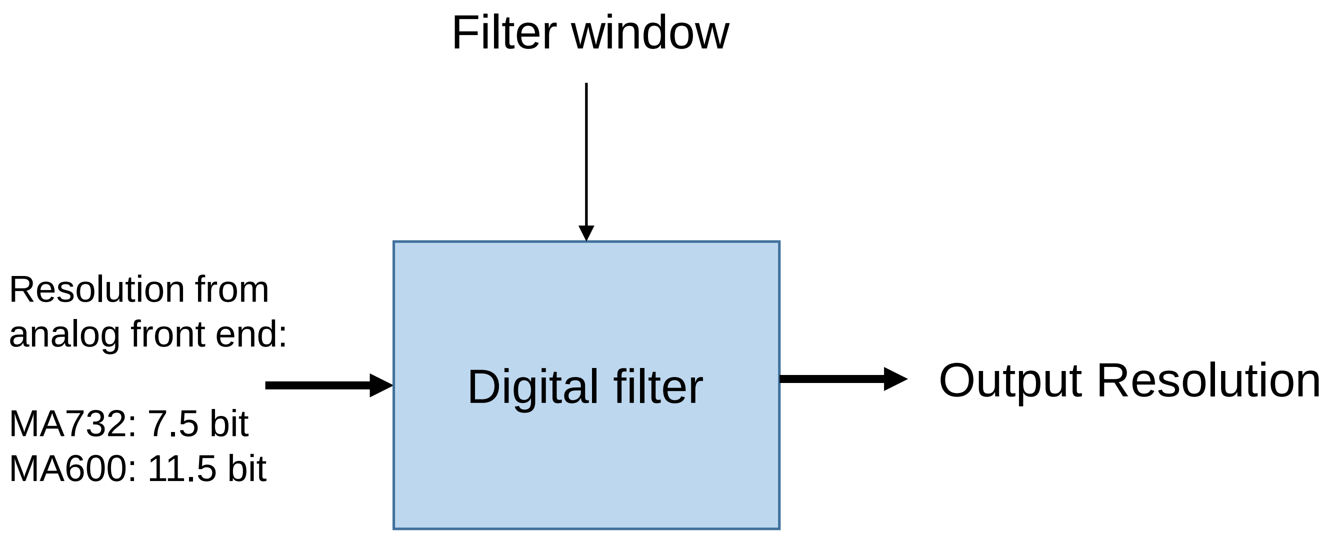


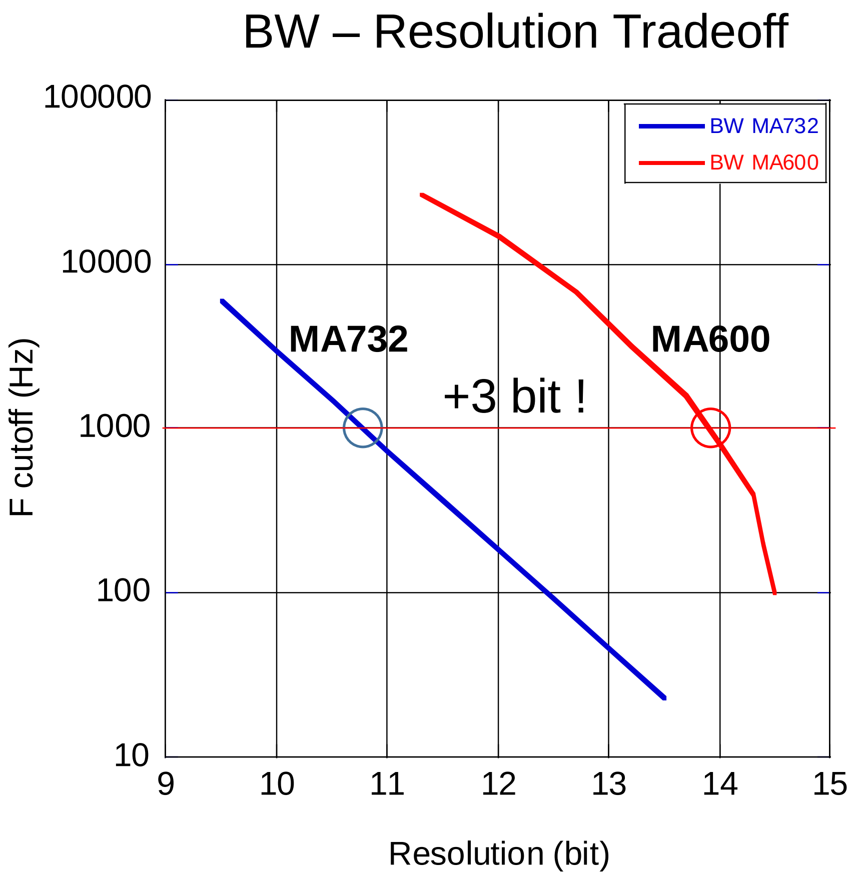
MA732 (Hall based)



MA600 (TMR based)

Resolution and Bandwidth

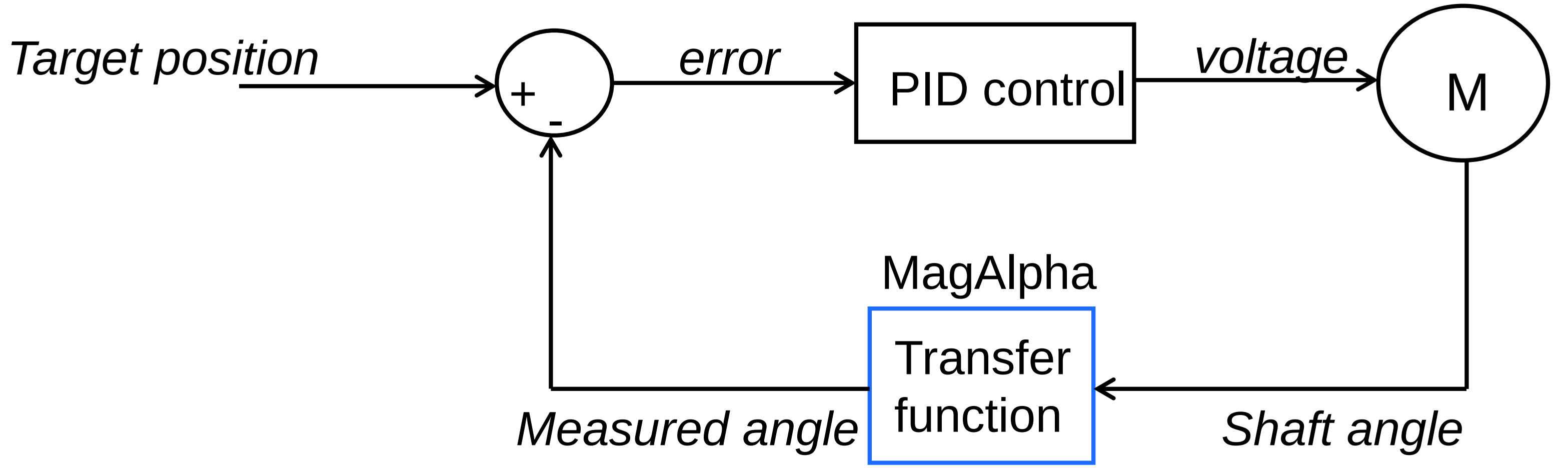




- Higher final resolution trades off bandwidth, resulting in a slower sensor
- Output bandwidth should be indicated in datasheet

How to Choose Bandwidth

Bandwidth determines system dynamic response



MA732:

$$H(s) = \frac{1 + 2\tau s}{(1 + \tau s)^2}$$

MA600:

$$H_{FE} = \frac{1}{(1+\tau_{FE}\ s)^2}$$

$$H_{filter} = \frac{1+(2+\delta)\tau}{(1+\tau\ s)^2}$$

$$H = H_{FE}\ H_{filter}$$

Thumb rule: for dynamic response stability, the MA bandwidth should be 5-10x times than the PID bandwidth

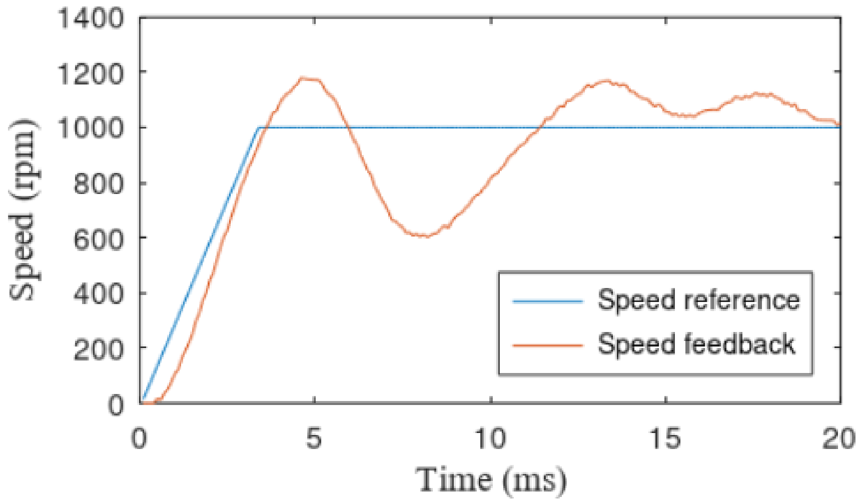
$$f_{cutoff} > 5 f_{PID}$$

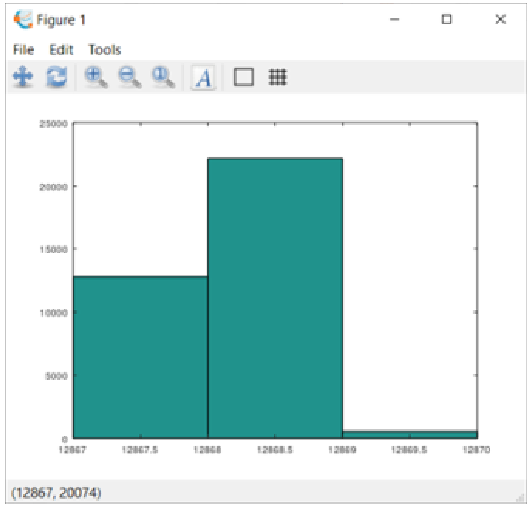
Even more important for multiple nested loops.

Resolution / Bandwidth Tradeoff

FW=10

f_{cutoff}=310Hz

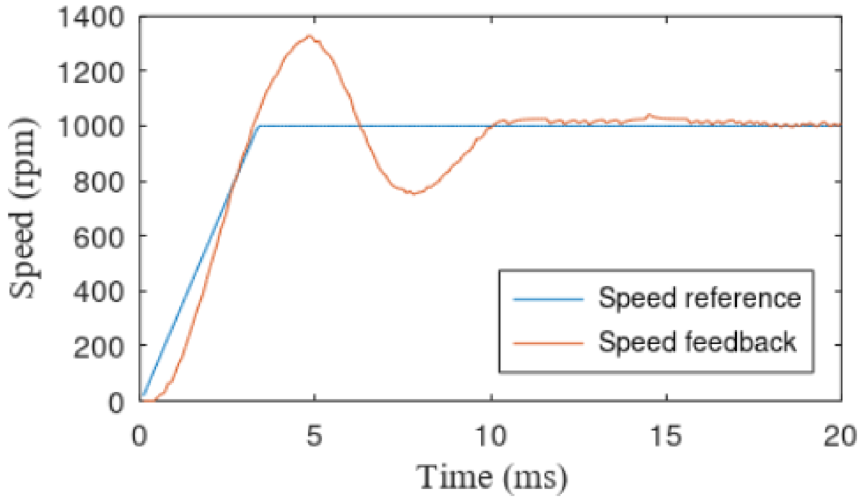


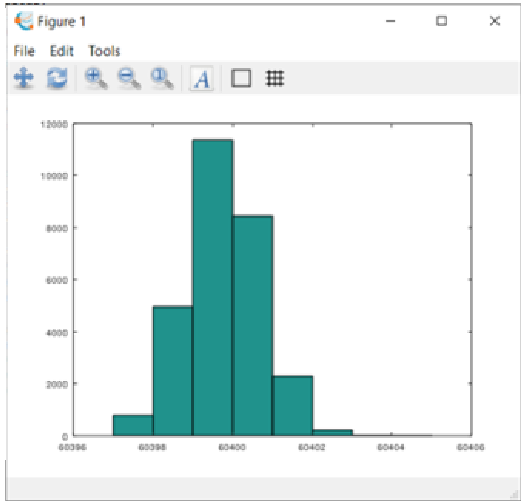


Resolution=14.6 bit

FW=7

f_{cutoff}=2.7kHz

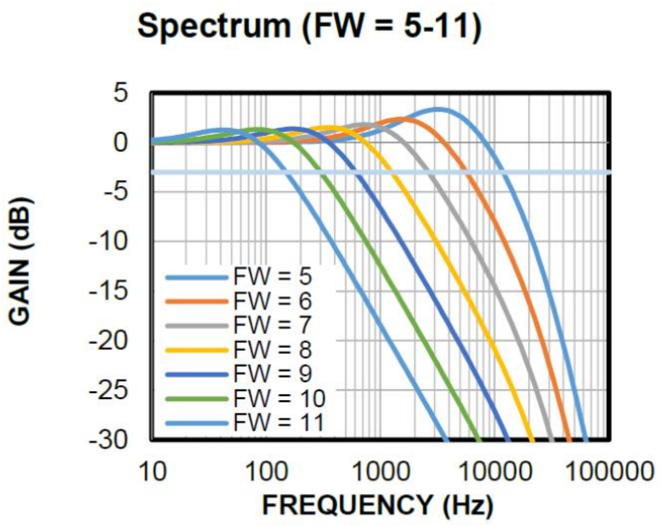




Resolution=13.5 bit

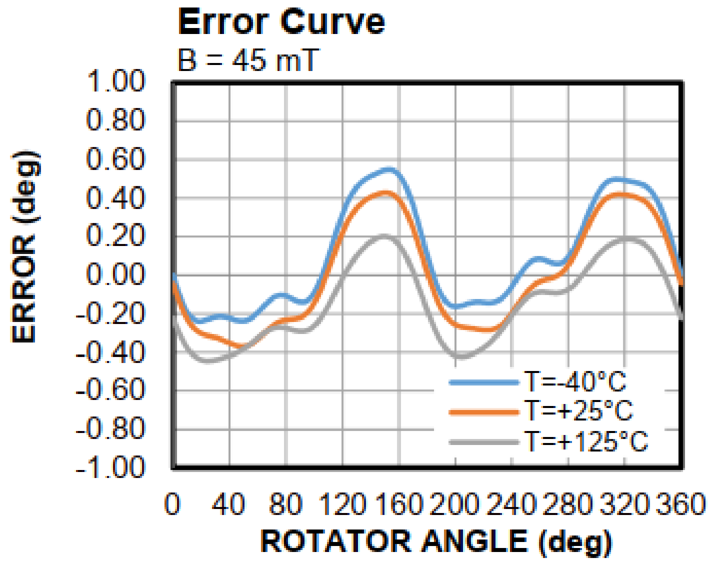
MA600 – Programmable Resolution & BW

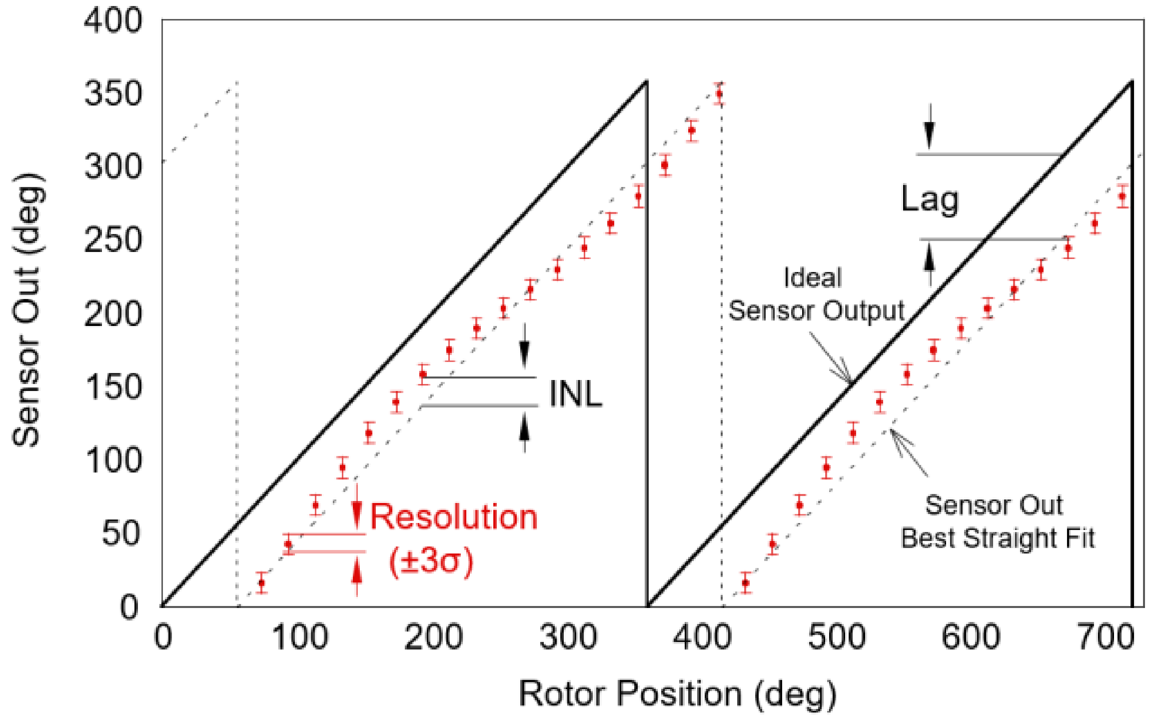
Parameter	Symbol	Condition	Min	Typ	Max	Units
Absolute Output – Serial						
Resolution (7) (±3σ deviation of noise)			12		15	bit
RMS Noise (7)			0.002		0.015	deg
Refresh Rate	$F_{refresh}$		780	800	820	kHz
Data Output Length				16		bit
Response Time						
Power-up Time (7)		FW = 0			250	µs
Latency (7)		FW = 5-11		0	1	µs
Filter Cutoff Frequency	F_{cutoff}	FW = 0		17		kHz



FW (3:0)	τ (µs)	Resolution (bits)	Latency (µs)	f_{CUTOFF} (kHz)
0	0	12.3	32	17
5 (default)	40	12.5	0	12
6	80	13	0	5.8
7	160	13.5	0	2.7
8	320	14	0	1.3
9	640	14.3	0	0.63
10	1280	14.6	0	0.31
11	2560	14.8	0	0.15
12	5120	15.0	0	0.075

INL





$$INL = \frac{\max(err(a)) - \min(err(a))}{2}$$

INL of MPS parts:
MA7XX: 1-1.2° max
MA600：0.5° max (<0.1° after user calibration)

What INL influence:

1. Position error
2. In servo motor control, low frequency vibration

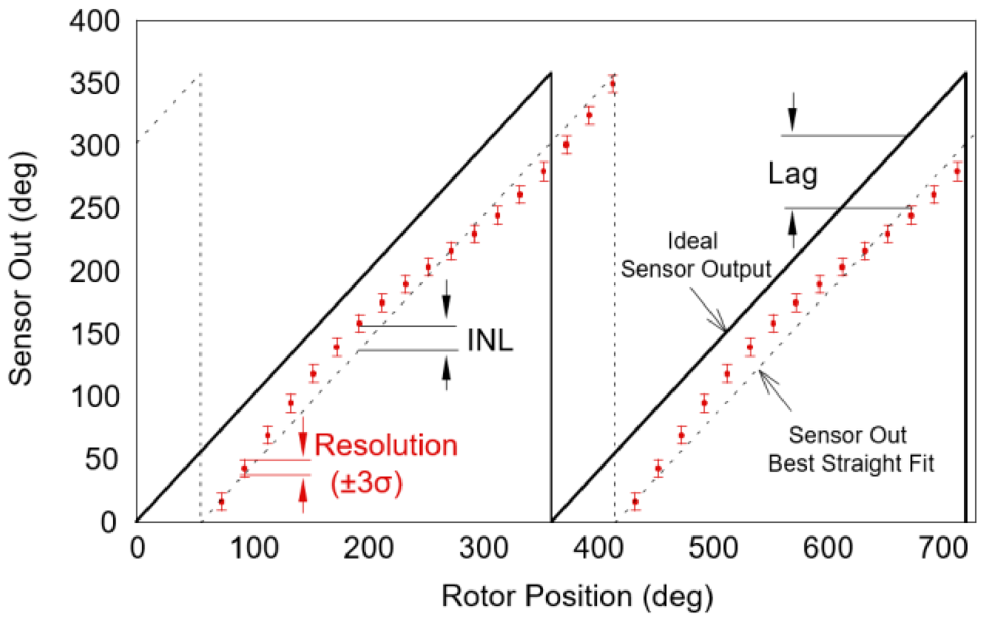
Latency

Systematic Error Sources

1. Integral Non-Linearity (INL)

2. Magnetic Misalignment with Sensor

3. Latency – Impacts Angle Error at Speed
   - Example with a 30k RPM Motor:
   - To calculate latency error:
     1. Convert motor rpm to deg/sec = RPM x 6
     2. Latency x rpm in deg/sec



Latency Error	Comp A	MA600
Latency	10µs	0µs
@30k RPM	**1.8°**	**0°**

<- Latency <u>is not easy to</u> be calibrated out and can be a large error source. Higher speed = higher error.

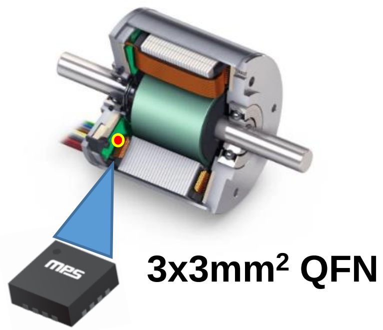
MA600 – Low INL, High Bandwidth Position Sensor

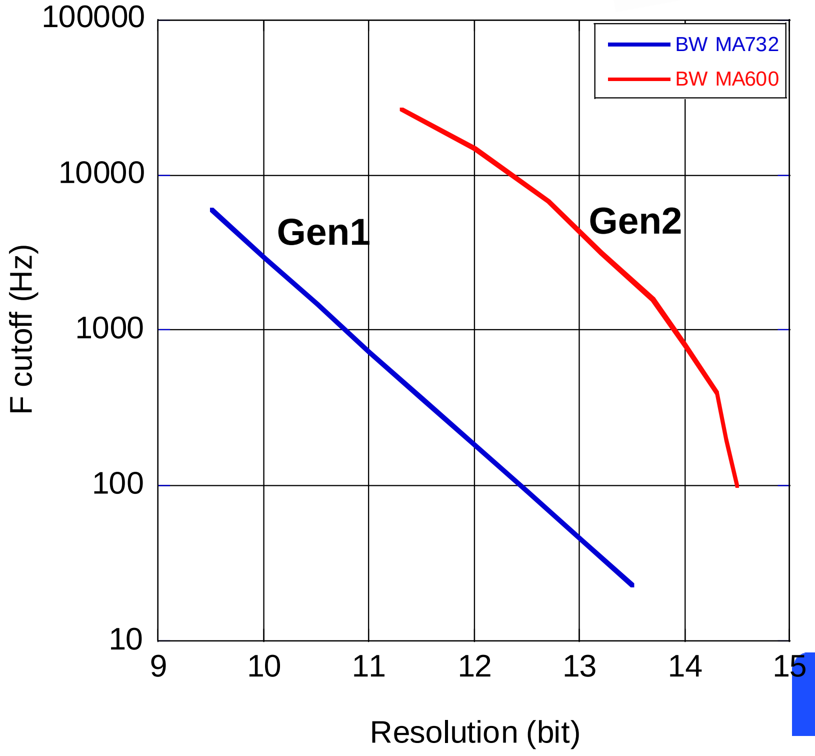
Key Specifications

- **High Accuracy: 0.5° INL**
  - In-system calibration: 0.1° INL
  - Includes on-chip look-up table
- **High Bandwidth & Resolution: Up to 15-Bit (±3σ)**
  - No Internal Hysteresis
- **No Latency**
  - Minimizes error at speed
- **Flexible Operation to Fit Many Applications:**
  - Reliable operation down to 20mT
  - Works in Side-Shaft or End of Shaft

Applications

- Robotics
- Multi-Turn Encoders
- FOC Motor Control
- Speed Sensors





MagAlpha™ Main parameters for hall-based sensor and TMR based sensor

1. Resolution: hall sensor (8-13.5bit), TMR sensor (9-15bit), with same bandwidth, the TMR sensor has almost 3bit higher resolution.
2. Bandwidth: hall sensor(23Hz-6kHz); TMR sensor (150-21kHz)
3. INL: hall sensor < 1° ， TMR sensor < 0.5°
4. Latency: MA732 9us; MA600 0us
5. User calibration function integrated in MA600
6. Angle temp drift: hall sensor (0.015/℃），TMR sensor (0.002/℃)

MA732

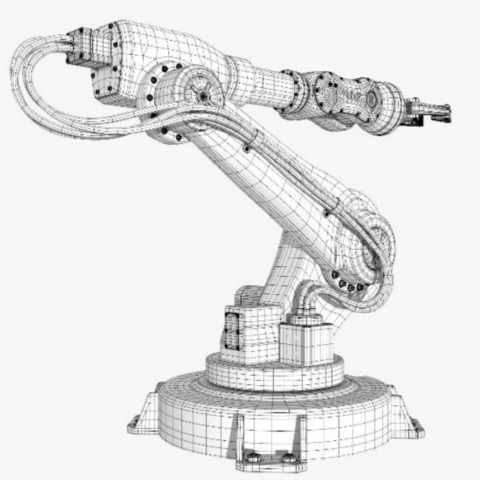
Table 17: Filter Window

FW(7:0)	Time Const. τ (µs)	Effective Resolution at 45mT (bit)	f_{cutoff} (Hz)	Power-Up Time (ms)
51	64	9.5	6000	0.5
68	128	10	3000	1.1
85	256	10.5	1500	2.5
102	512	11	740	5.5
119 (default)	1024	11.5	370	12
136	2048	12	185	26
153	4096	12.5	93	57
170	8192	13	46	123
187	16384	13.5	23	264

MA600

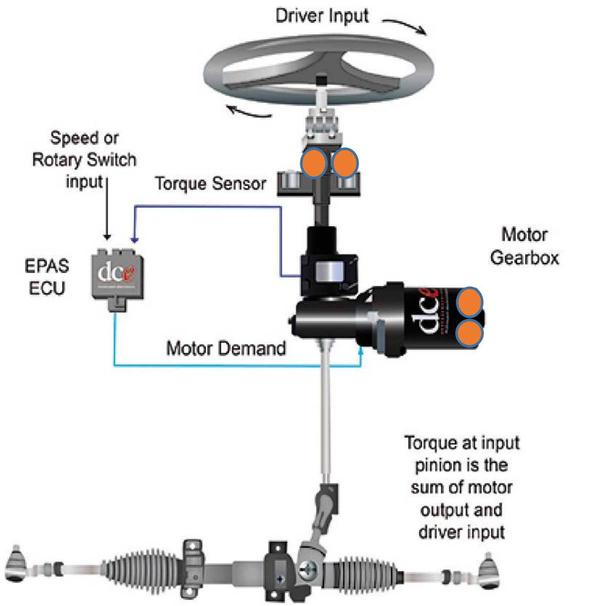
FW (3:0)	τ (µs)	Resolution (bits)	Latency (µs)	f_{CUTOFF} (12) (kHz)
0	0	12.3	32	17
1-4	Not recommended			
5 (default)	40	12.5	0	12
6	80	13	0	5.8
7	160	13.5	0	2.7
8	320	14	0	1.3
9	640	14.3	0	0.63
10	1280	14.6	0	0.31
11	2560	14.8	0	0.15

MA600 Applications



Factory Automation
(Precision Robotics)

Robotics and Fluid Control

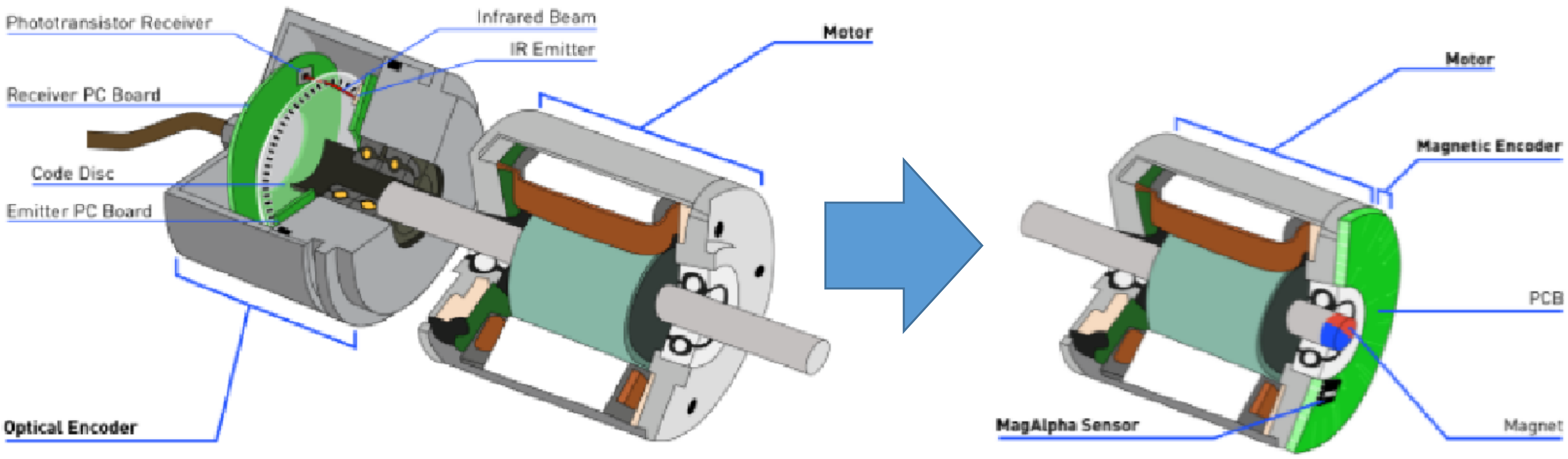


Electronic Power Steering

Building Automation & Control

Reduce Cost with Magnetic Encoders

Optical Encoder → Magnetic Encoder



Optical Encoder + Motor

Magnetic Encoder + Motor

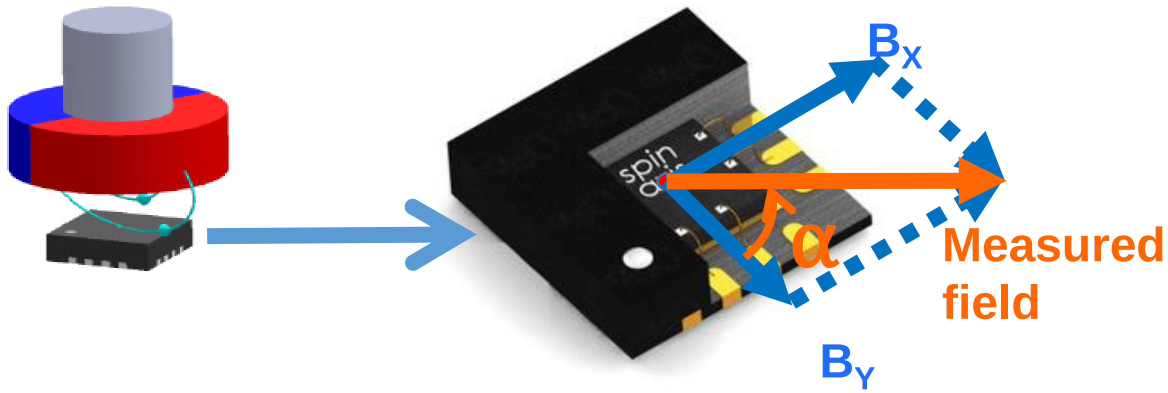
Customer Benefits

Reduce Cost 5-10x

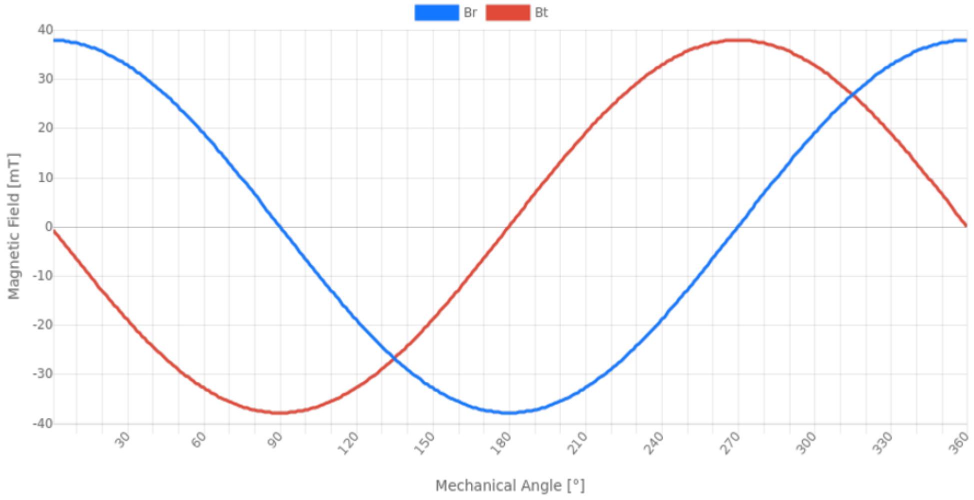
Immune to Dust and Debris

Operates in Harsh Environments Without Costly Enclosures

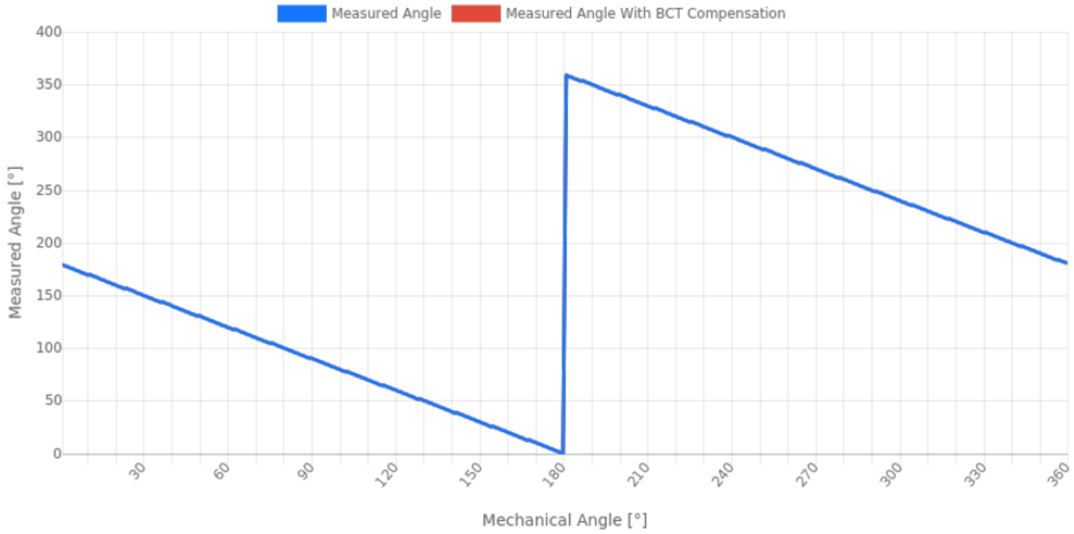
End of Shaft Design Note



- Appropriate magnetic filed: 20mT-80mT is preferred for MA600
- Mechanical setup and installation should be as accurate as possible
- No magnetizable materials close to magnet

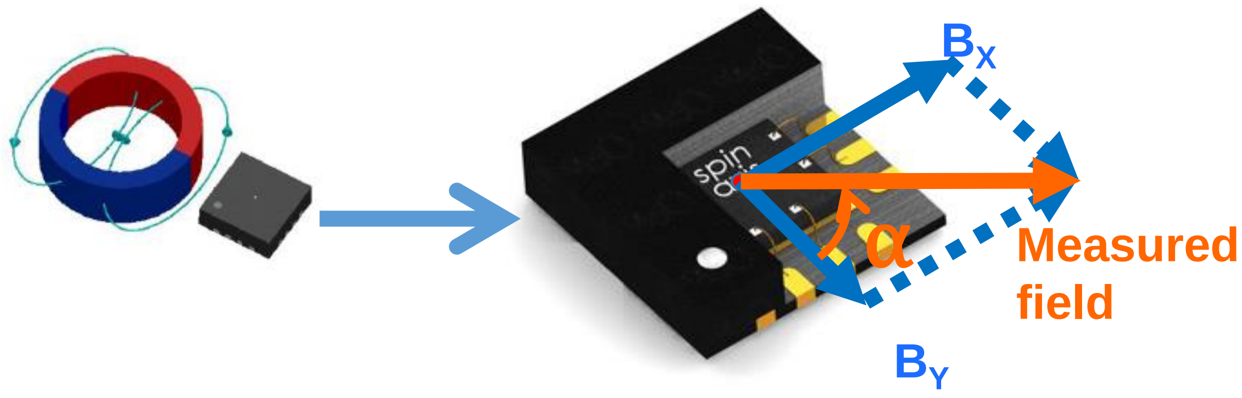


Same B_X and B_Y amplitude

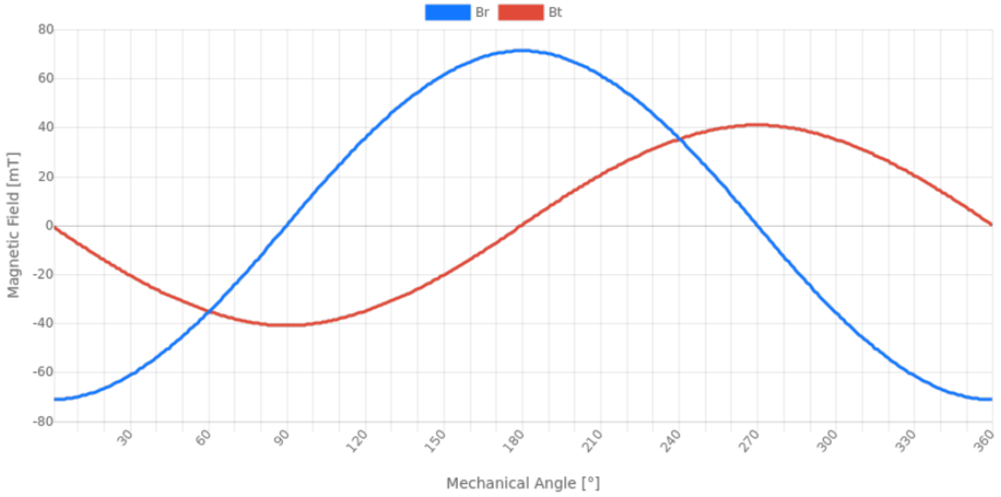


Online simulation tools:
http://sensors.monolithicpower.com/

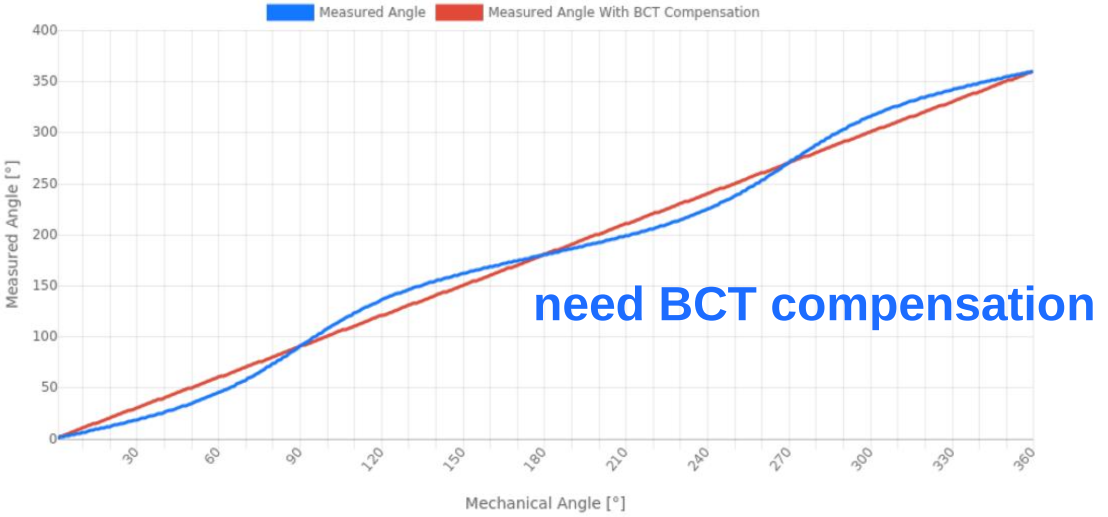
Side of Shaft Design Note



- More requirements for a magnet: shape, material, well magnetized
- Find a suitable position for sensor: appropriate magnetic field strength, less magnetic distortion, need do the simulation first
- Mechanical setup and installation should be as accurate as possible
- No magnetizable materials close to magnet



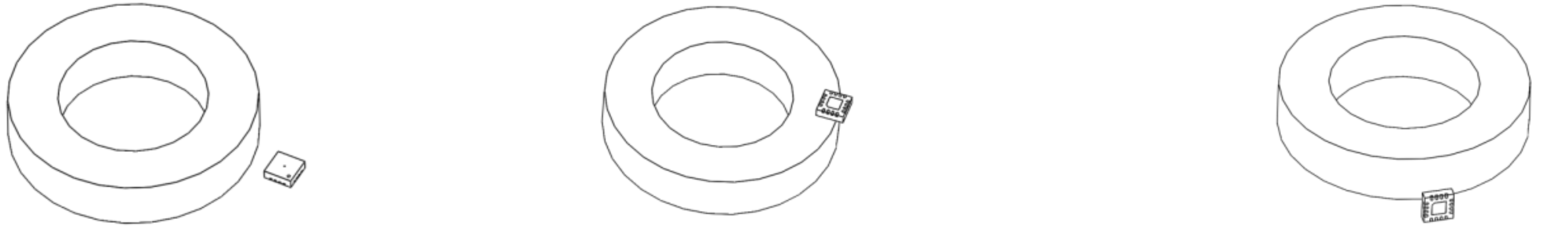
Different B_X and B_Y amplitude



Online simulation tools:
http://sensors.monolithicpower.com/

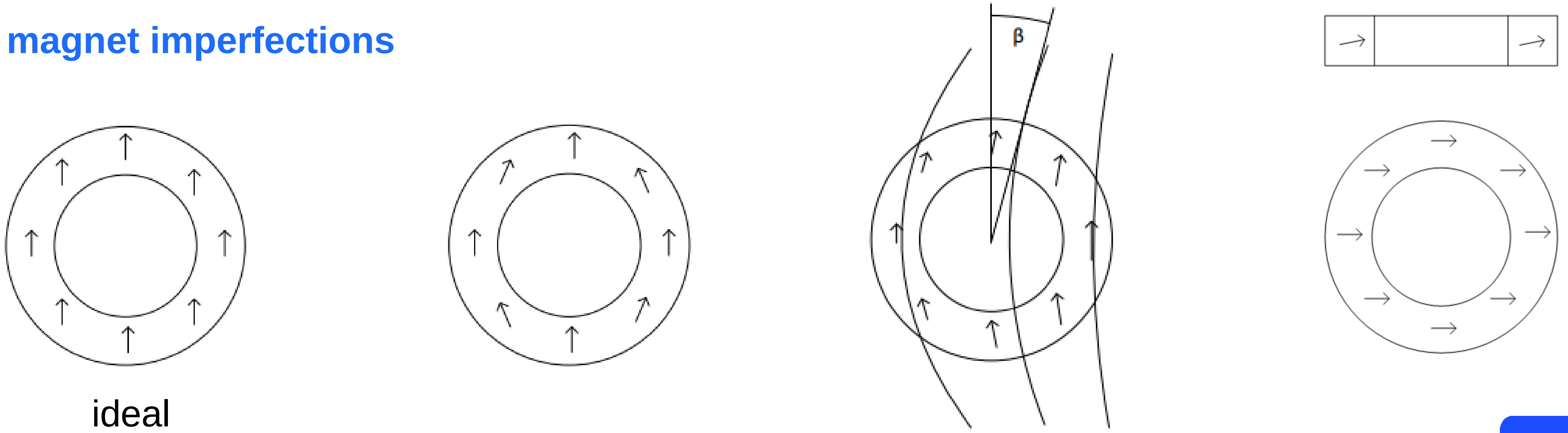
Side of Shaft Design Note

Different side shaft configurations



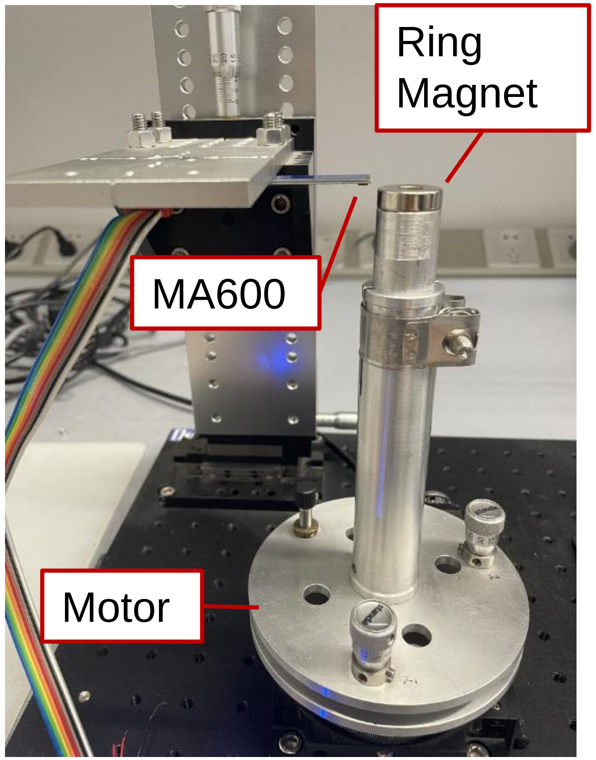
Side | Side Top/Bottom | Side Orthogonal

Common magnet imperfections



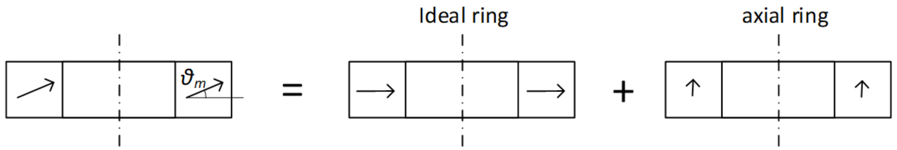
ideal

BCT Compensation (Example)



- Ring magnet
- Diametral magnetization
- OD(outter diameter)=20mm, ID(inner diameter)=8mm, H(height)=6mm
- Material: NdFeB (Brem=1.2T)

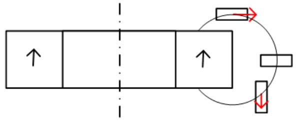
BCT Compensation (Example)

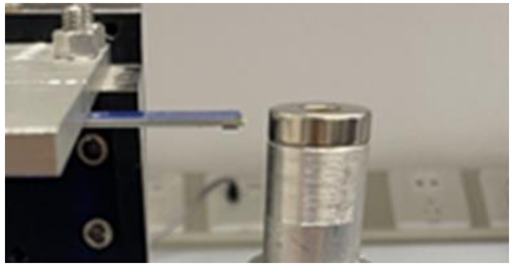


Position 1

Before BCT compensation

After BCT compensation

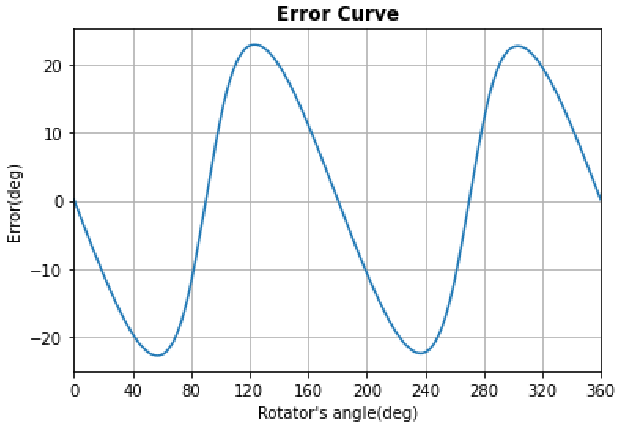


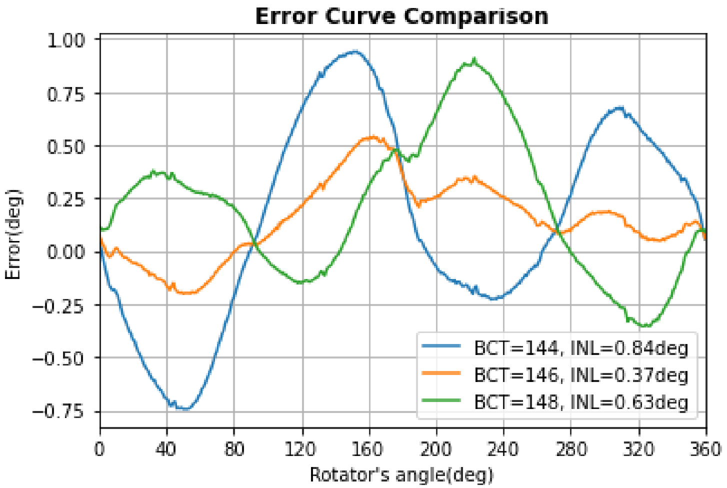


BCT

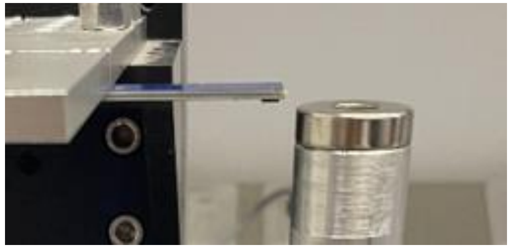
144*

*Optimum value must be found experimentally





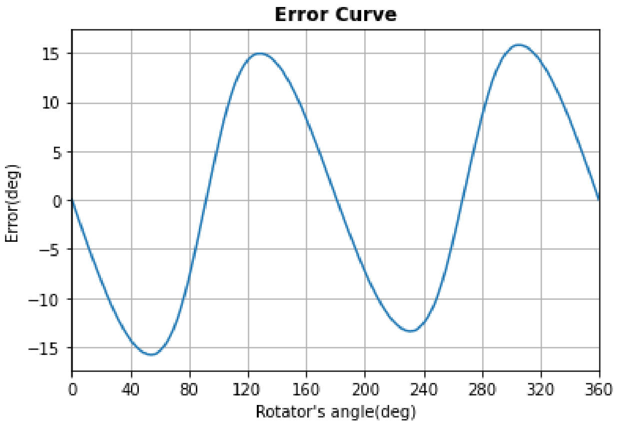
Position 2

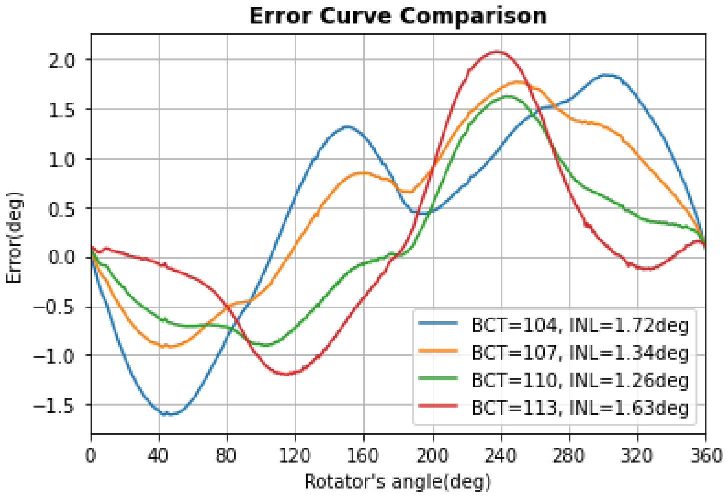


BCT

104*

*Optimum value must be found experimentally





The imperfection of magnet is hard to be compensated by BCT

User Calibration (Example)

1. Adjust the zero position of the motor, make it close to the zero position of sensor
2. Rotate the motor with step of 11.25° , record the sensor output $\mathrm{out}_i(\mathrm{deg})$ when motor turns to 0° , 11.25° , 22.5° …until 348.75° , and get the correction value $\mathrm{corr}_i(\mathrm{deg})$:

$$\mathrm{corr}_i(\mathrm{deg}) = \mathrm{ref}_i(\mathrm{deg}) - \mathrm{out}_i(\mathrm{deg})$$

3. Calculate the corresponding register value $\mathrm{corr}_i(\mathrm{dec})$

   1) If $\mathrm{corr}_i(\mathrm{deg}) \geq 0$

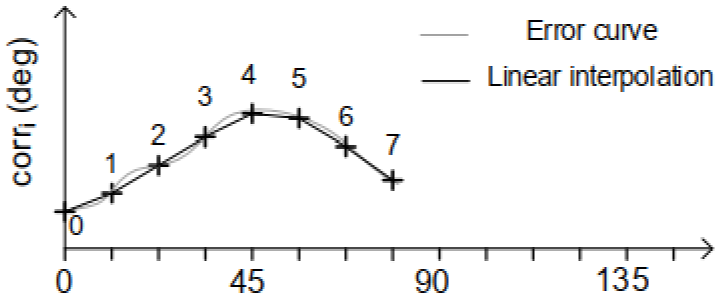
$$\mathrm{corr}_i(\mathrm{dec}) = \frac{\mathrm{corr}_i(\mathrm{deg})}{360} \cdot 128 \cdot 32$$

   2) If $\mathrm{corr}_i(\mathrm{deg}) < 0$

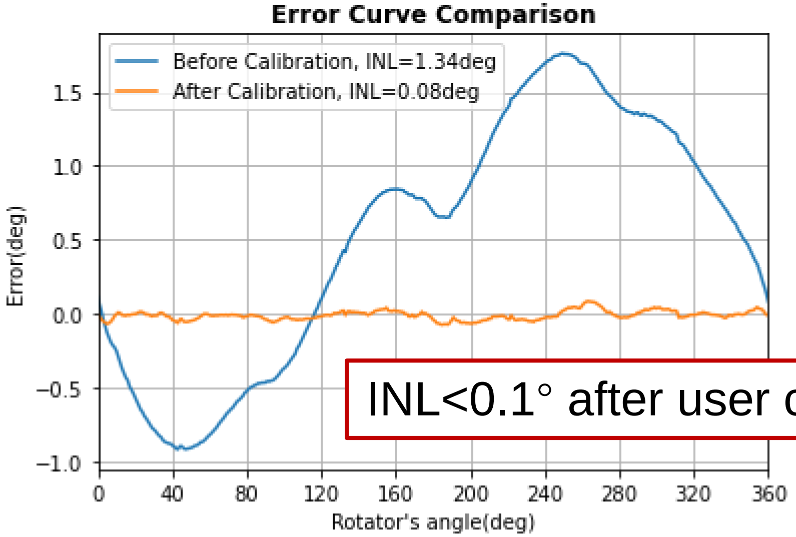
$$\mathrm{corr}_i(\mathrm{dec}) = \frac{\mathrm{corr}_i(\mathrm{deg})}{360} \cdot 128 \cdot 32 + 256$$

   Write the value into Reg32 – Reg63 accordingly

4. Store the Reg32 – Reg63 (Block1) value into NVM

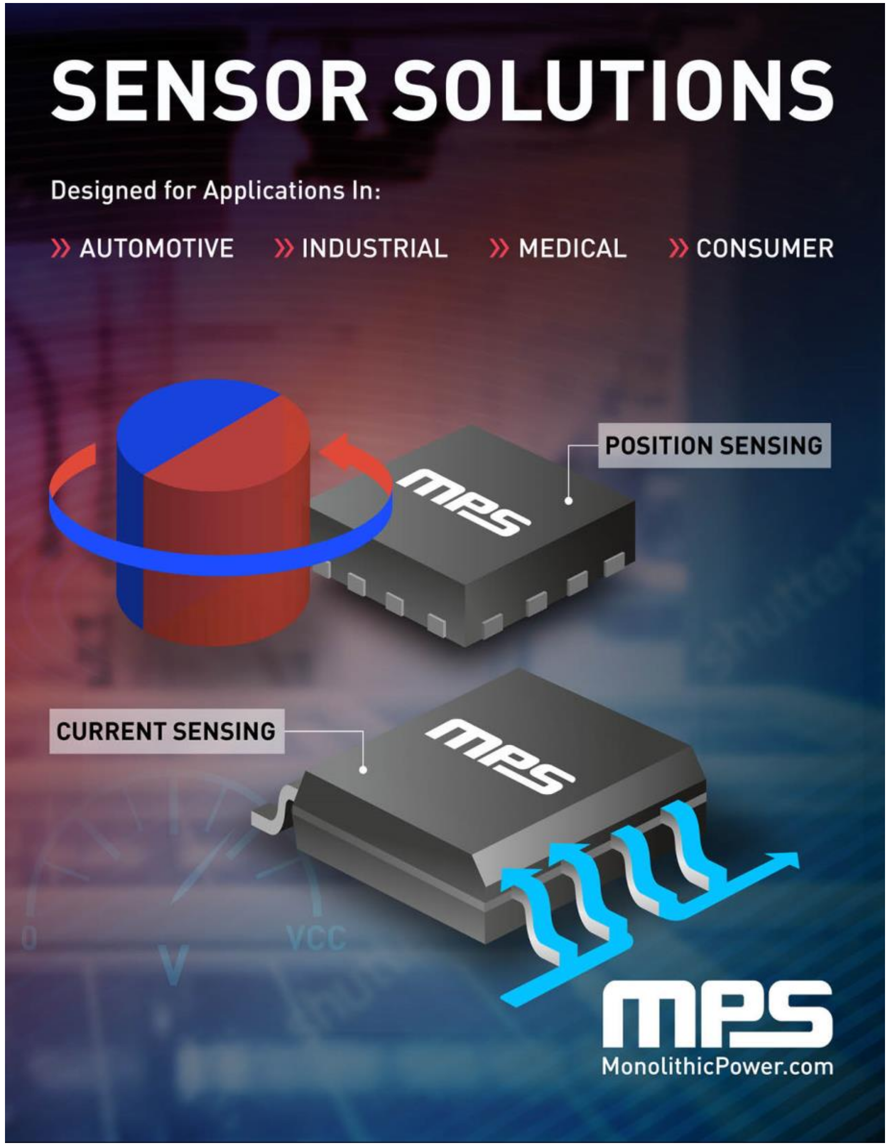


Position 2 -> further calibrated



INL<0.1° after user calibration

Thank You



For more information, contact:
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Check out our Sensor Solutions brochure at **MonolithicPower.com**