Understanding Position Sensor Resolution and Bandwidth in Servo Control Loops

Webinar will begin at 11am PT | 2pm ET | 8pm Europe

MPS

rev 20180504

Understanding Position Sensor Resolution and Bandwidth in Servo Control Loops

September 2022

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Agenda

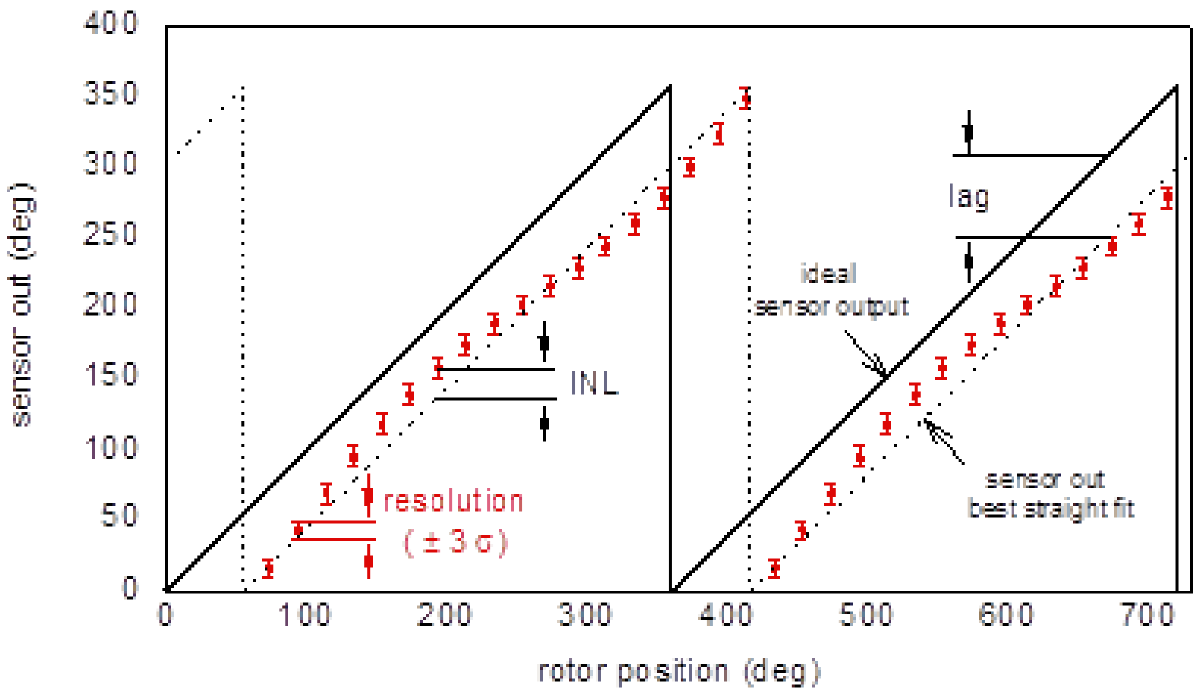
- Advantages of magnetic angle sensing
- Systematic error sources
- Random error sources
- How to understand the true resolution a sensor IC provides
- Best ways to determine a magnetic sensor’s real resolution
- How dynamic bandwidth can affect your control system
- QA

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 *causes* lag



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

Systematic Error Sources (Applied Example)

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2. Magnetic misalignment with sensor
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   - Example with a 30k RPM Motor:
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Total Systematic Error = INL + Magnetic + Latency

- INL: usually provided in datasheet
- Magnetic Error: 0.3º typical, end-of-shaft
- Latency Error: latency x motor speed

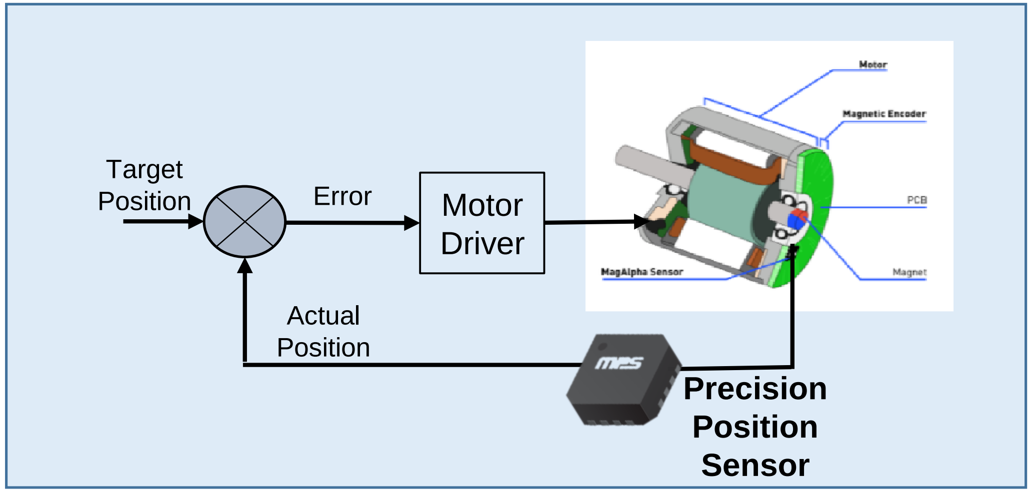
Total Systematic Error	Error Type	Comp A (Factory cal)	MA600 (Factory Cal)	MA600 (In-System Cal)
INL	Static	1º	0.5º	0.1º
Magnetic	Static	0.3º	0.3º	0º
Latency	Dynamic	1.8º	0º	0º
Total Error		**3.1º**	**0.8º**	**0.1º**

Summary:

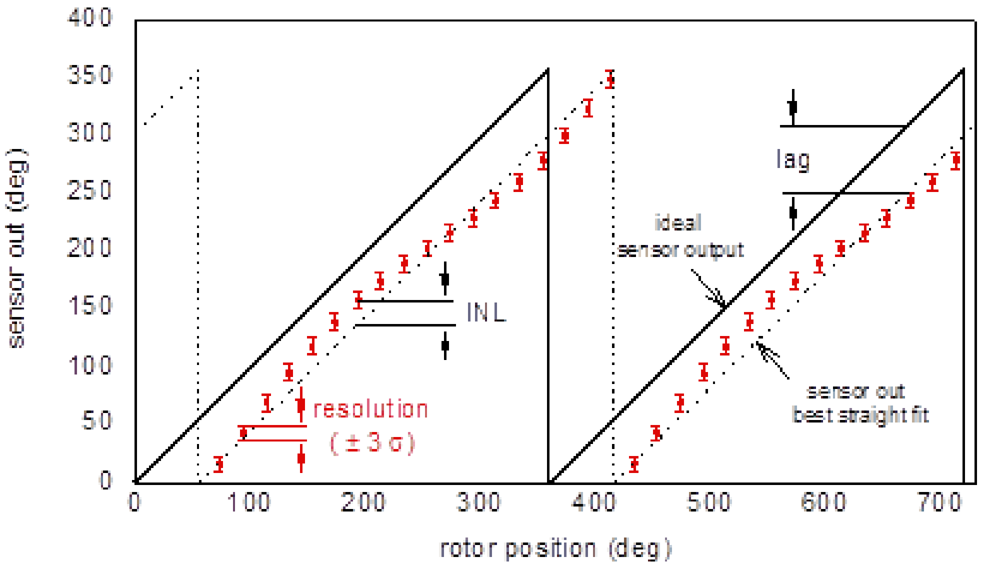
- Latency cannot be calibrated out and can be a large error source. Higher speed = higher error.

Random Error Sources

1. Noise
    - Resolution captures impact from noise
    - Noise can be reduced by filtering, but this reduces sensor bandwidth
    - Sensor bandwidth impacts loop stability
    - Consider Resolution AND Bandwidth
    - When sensor BW is too low, it can look like angle error

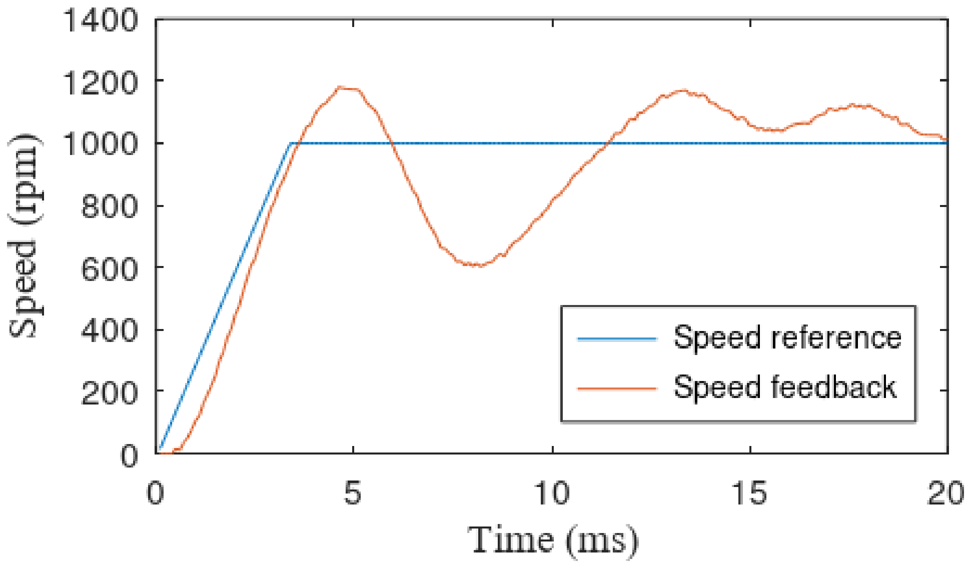


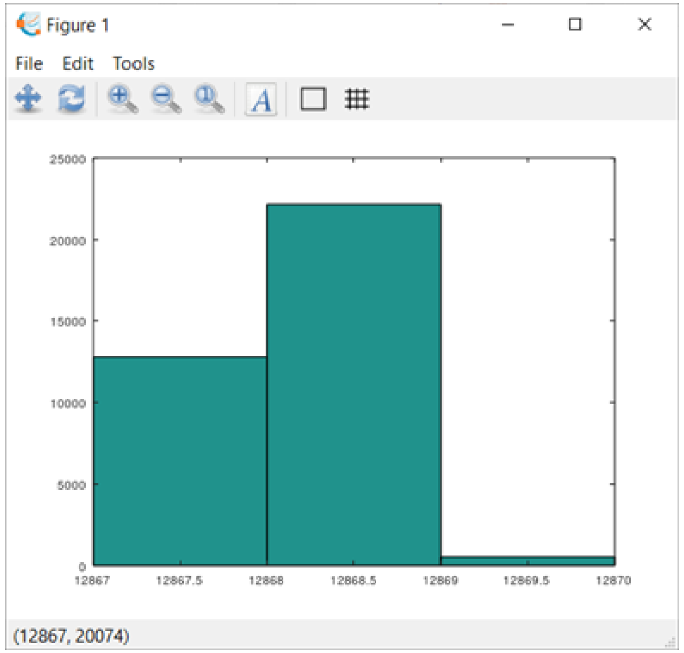
- Challenges:
    1. Determination of the real resolution of a sensor
    2. Understanding the relationship between resolution & BW



Resolution / Bandwidth Tradeoff

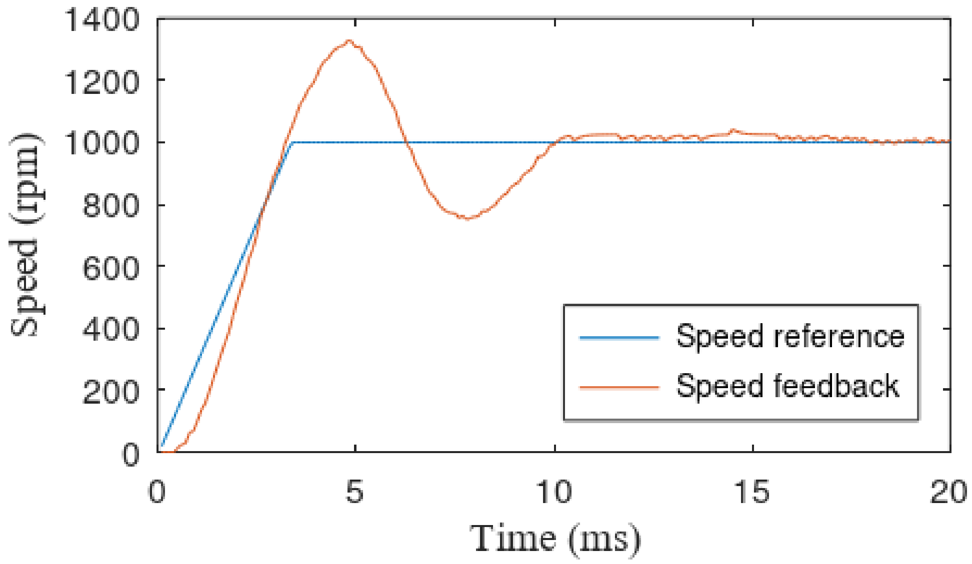
F_{cutoff} = 310 Hz

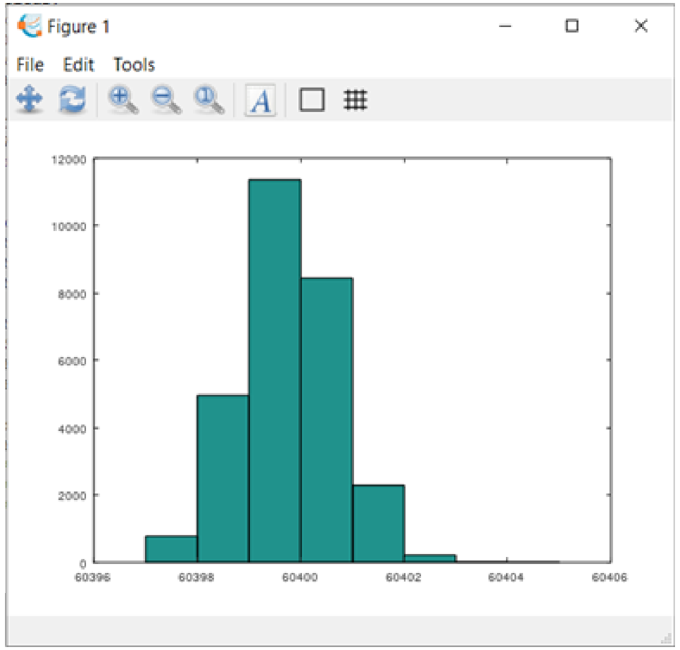




14.3 bits

F_{cutoff} = 2.8 kHz



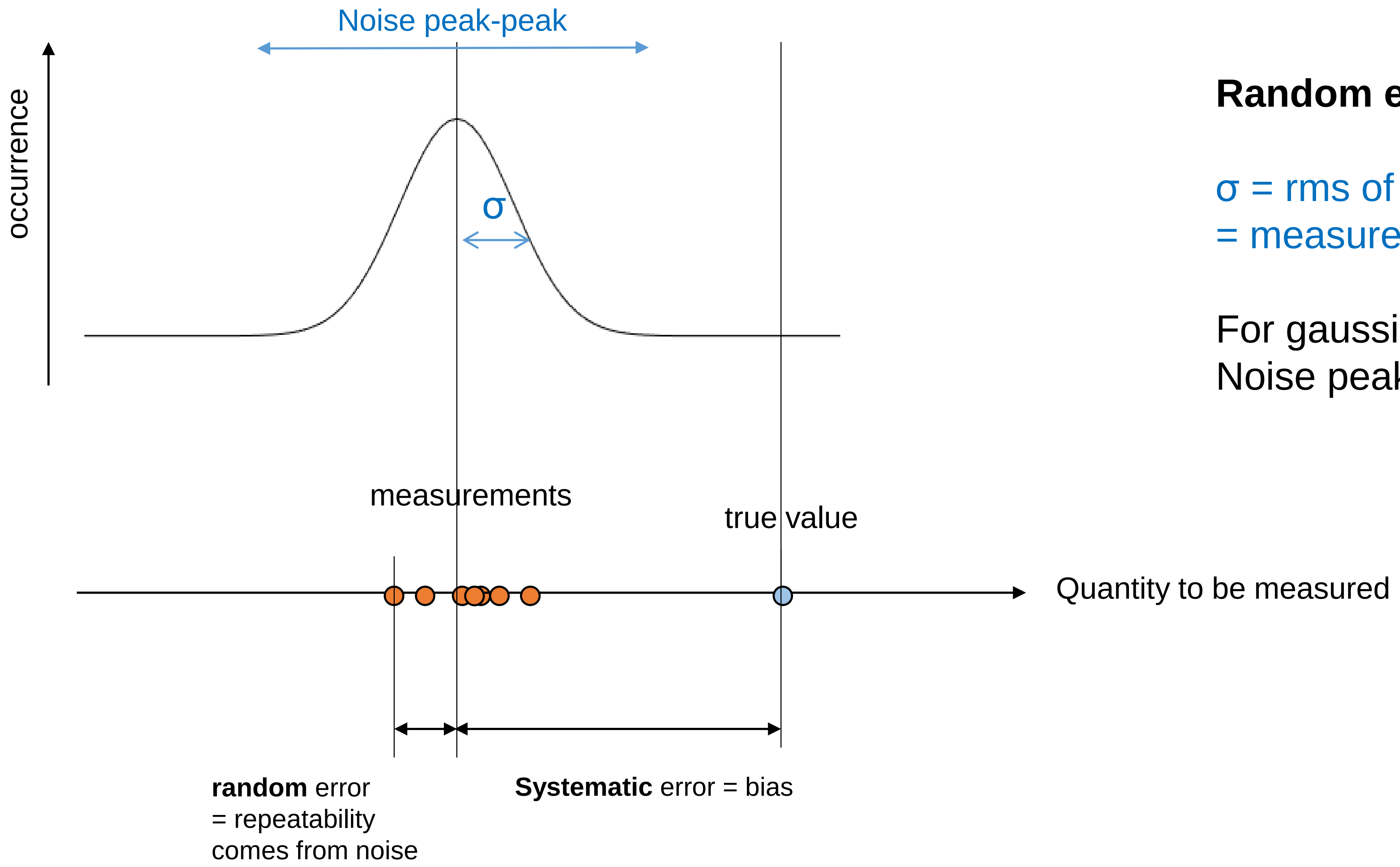


13.2 bits

What is Resolution?

Metrology: Measurement Error

Measurement error:

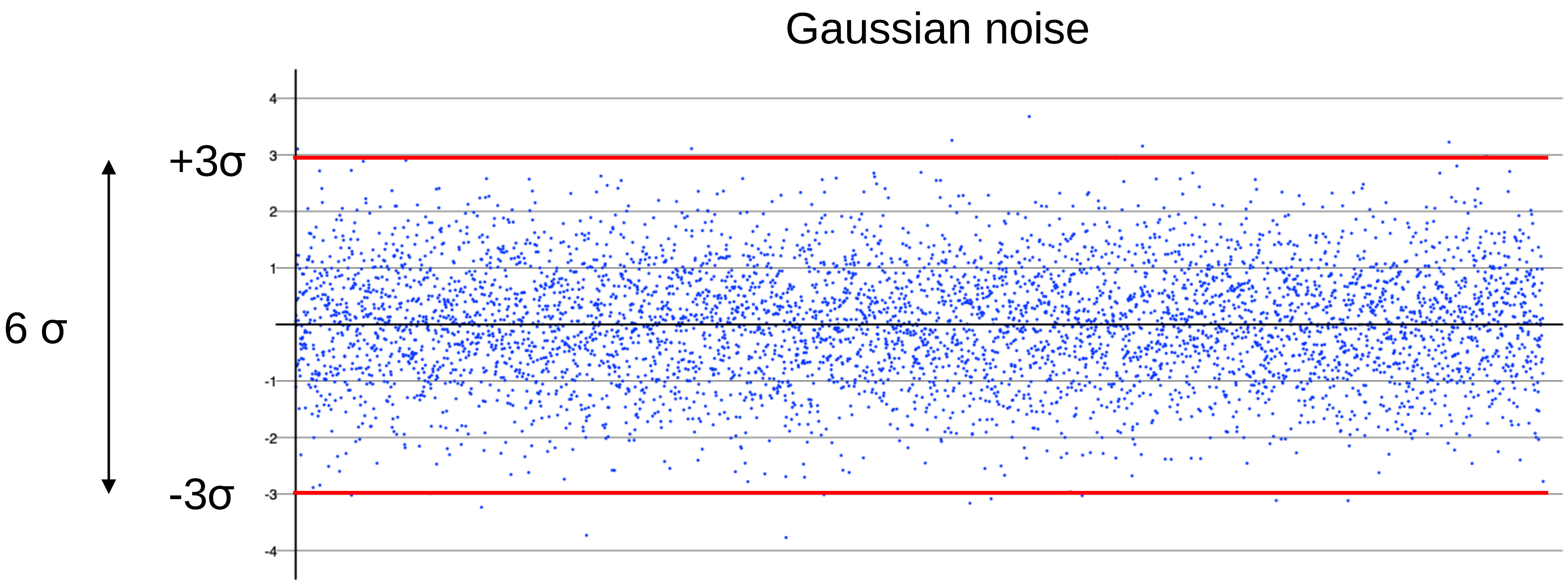


Random error:

σ = rms of measurements
= measurement precision

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

Random Error - Why 6σ?

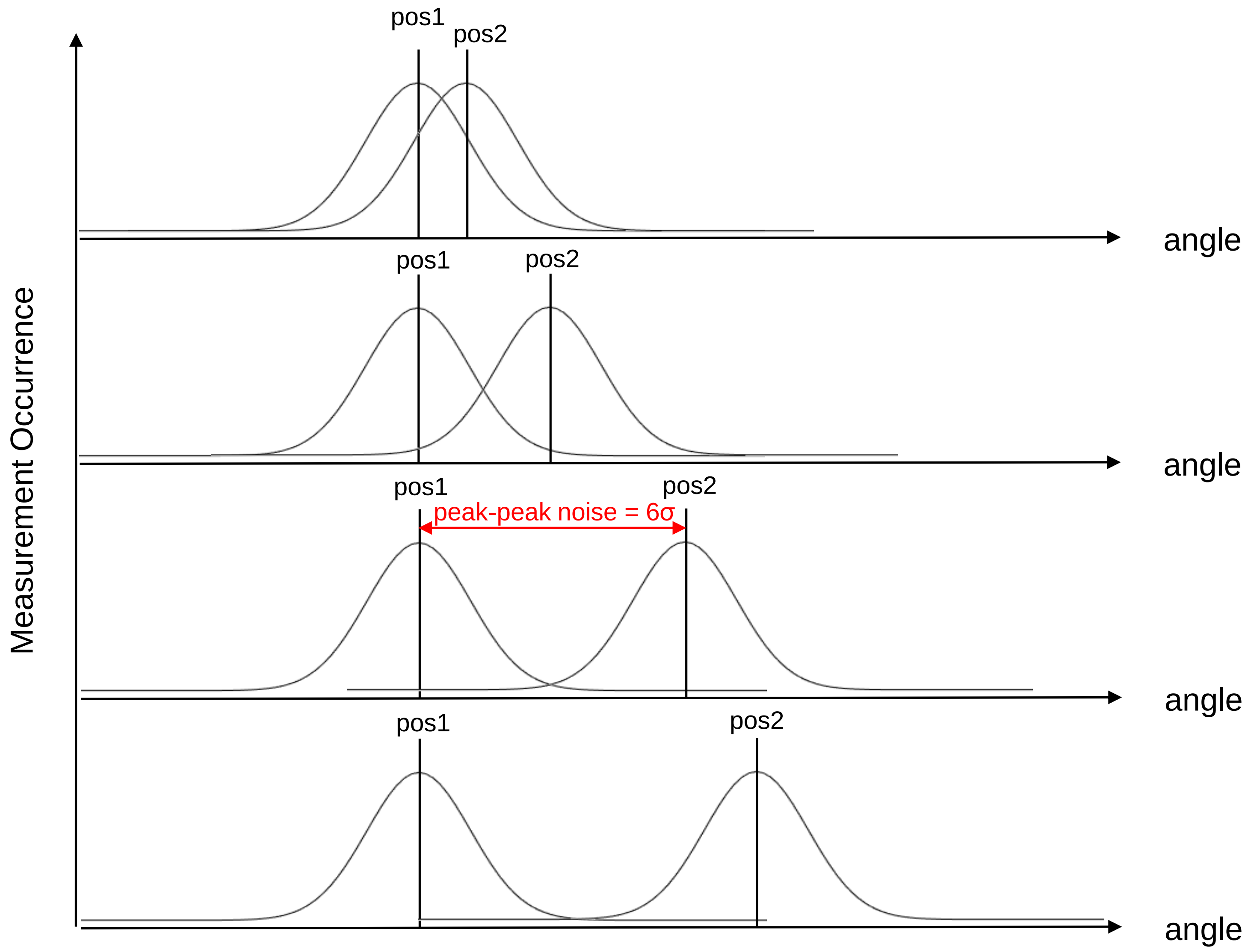


Peak-peak noise: 99.73%

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

Definition of Resolution

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



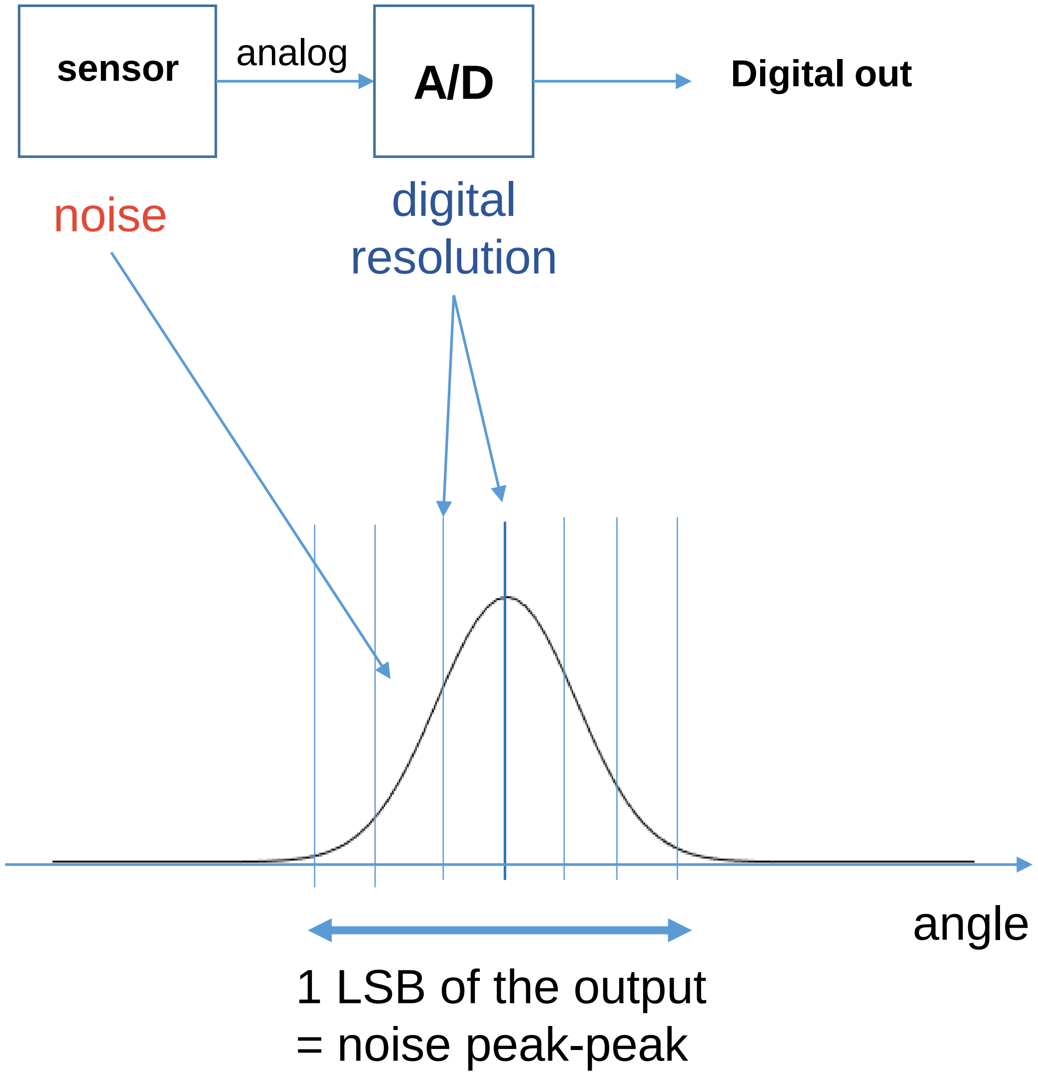
$|\text{pos2} - \text{pos1}| < \text{resolution}$

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

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

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

Definition of Resolution in AD Conversion

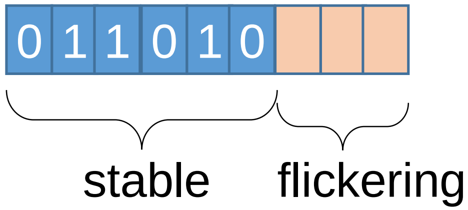


assuming that the digital steps are finer than the noise

Resolution in bit

$$\log_2 \frac{full\ scale}{noise_{pk\ \_\ pk}}$$

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

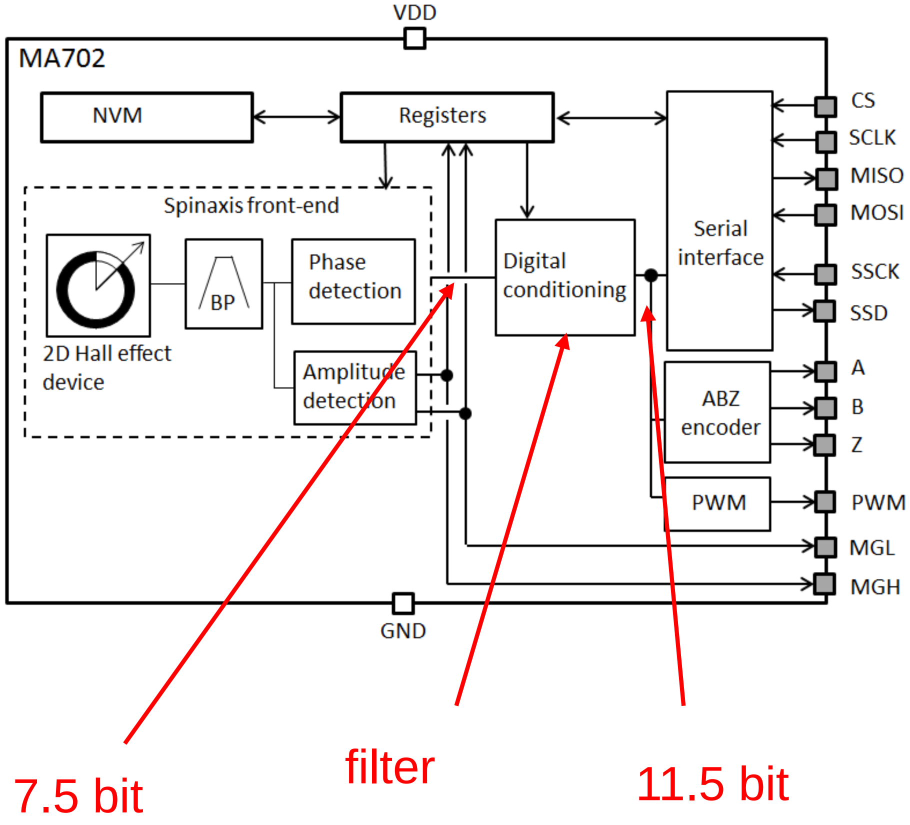


For an **angle sensor** $full\ scale = 360°$ therefore,

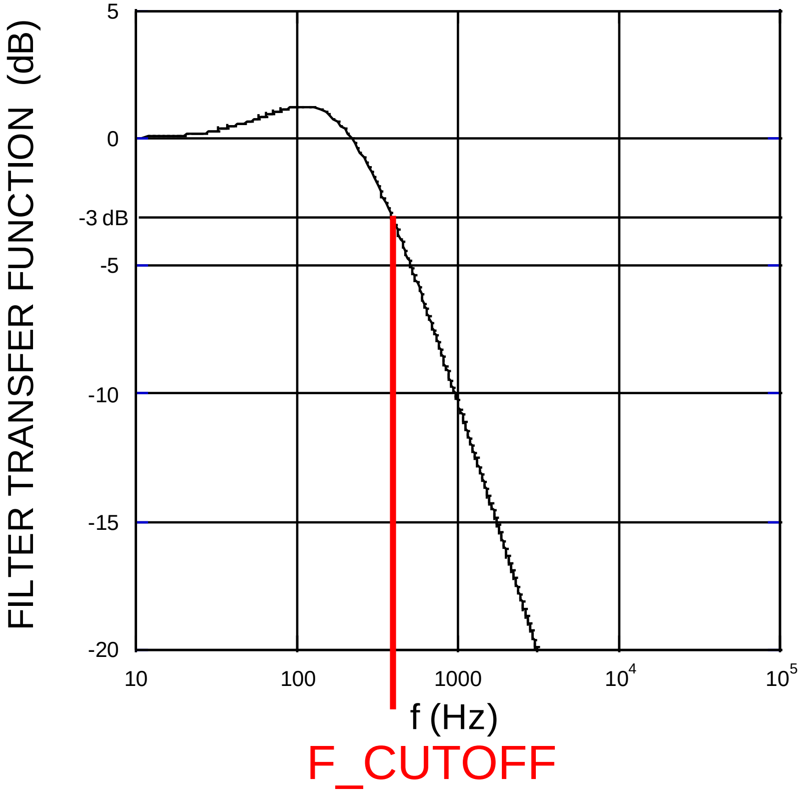
$$Resolution\ in\ bits = \log_2 \frac{360°}{6\sigma}$$

Resolution and Bandwidth

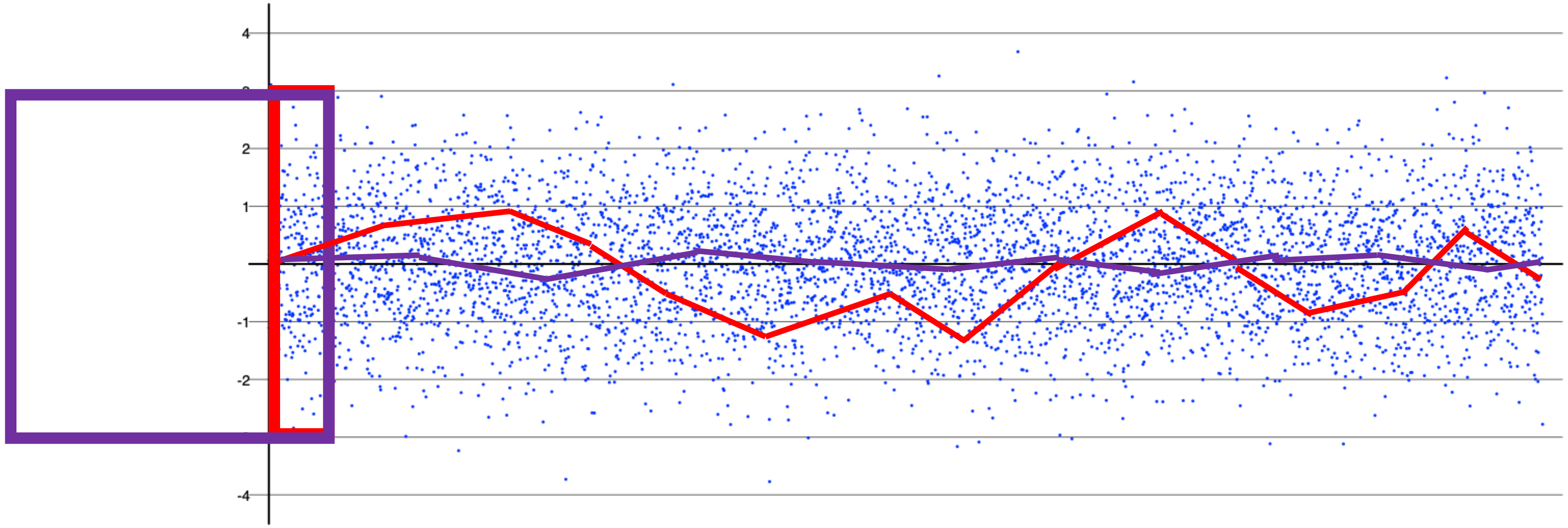
- Output bandwidth should be indicated in datasheet
- Higher final resolution trades off bandwidth, resulting in a slower sensor



Filter transfer function shown in the datasheet

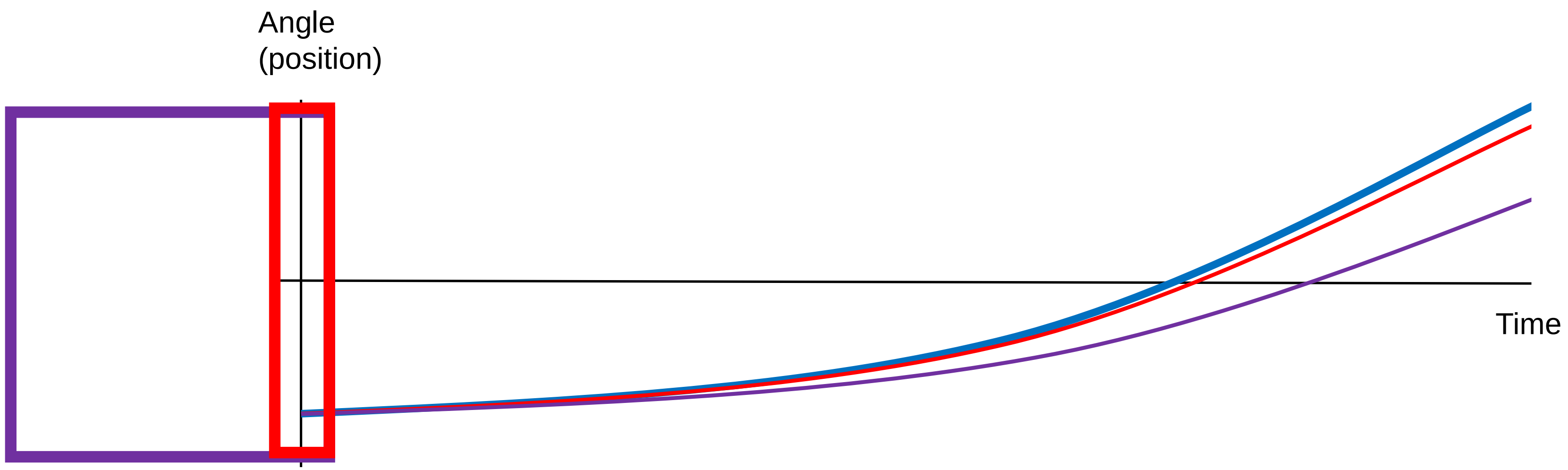


Filter Window Tradeoff



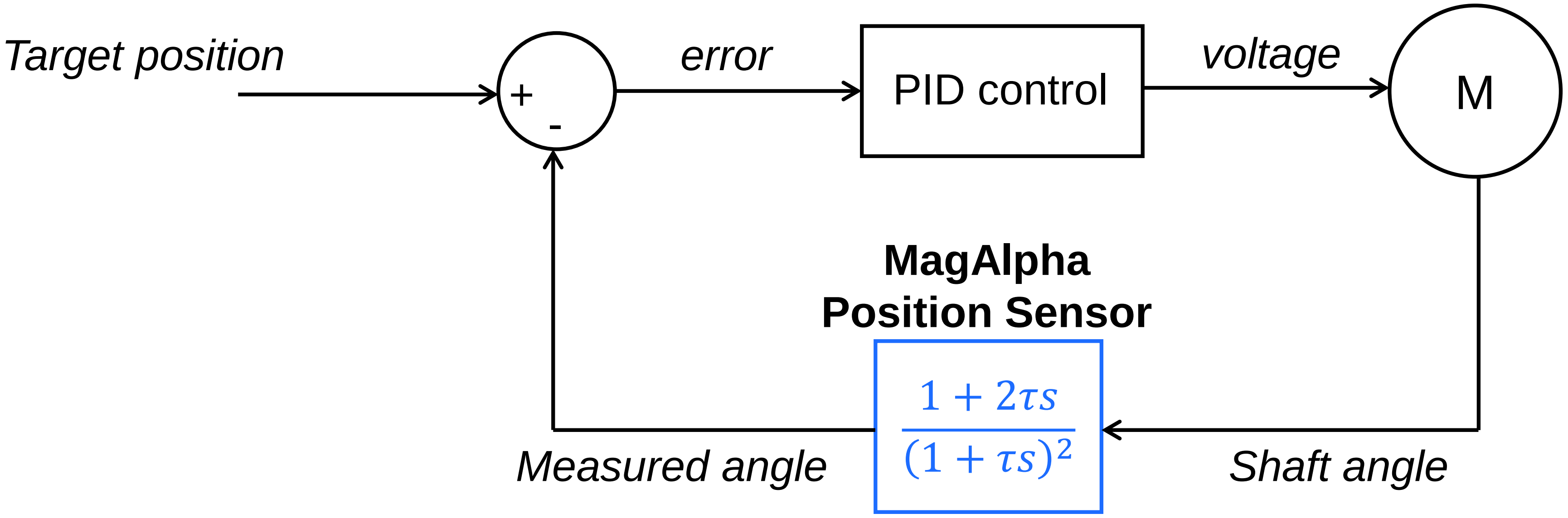
Small Filter Window
Large Filter Window

Filter Window Tradeoff



Small Filter Window
Large Filter Window

Why Bandwidth Matters

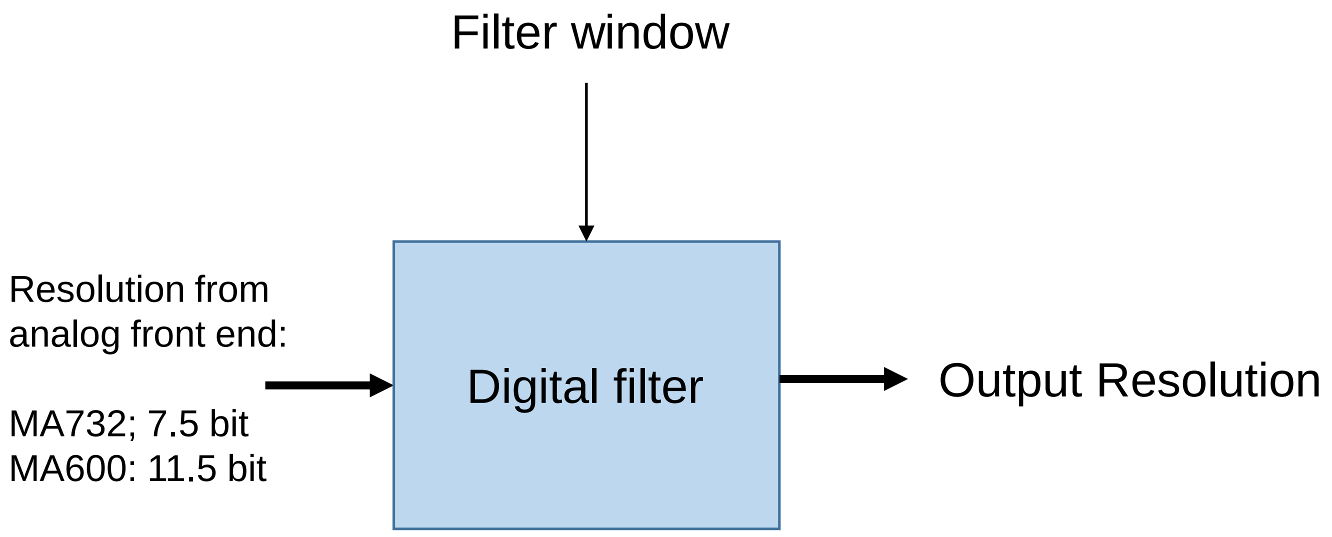


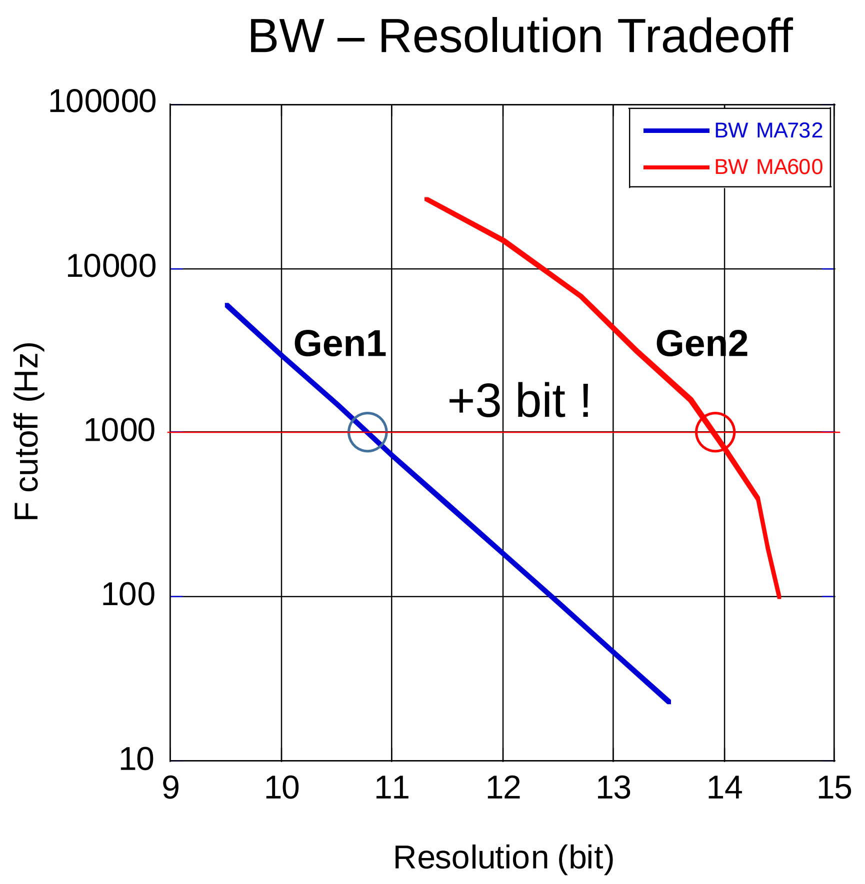
General Guideline: for stability, the sensor time constant should be **10x smaller (i.e., 10x >BW)** than the PID time constant:

$$\tau < 10\frac{k_p}{k_i}$$

Even more important for multiple nested loops such as field oriented control.

More About Sensor Resolution Bandwidth





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 $log_2 \frac{360°}{6\sigma}$, where 6σ = 6 x 0.05°**

Actual Resolution is 10.2 bits, not 15 bits

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]		15		bits
		Medium Mode[10]		14		bits
		Fast Mode[10]		14		bits
Output stage Noise		Clamped Output		0.05		%VDD
Noise pk-pk[14]		VG = 9, Slow mode, Filter=5		0.03	0.06	Deg
		VG = 9, Fast mode, Filter=0		0.1	0.2	Deg

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

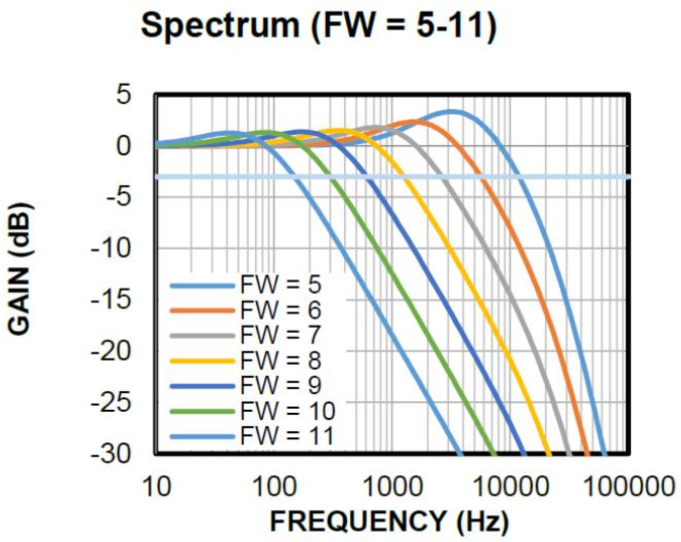
  Actual Resolution is 13.6 bits, not 15 bits (slow mode)

- **Fast mode is, of course, even lower resolution: $log_2 \frac{360°}{6\sigma}$ pk-pk noise = 0.1°**

  Actual resolution = 11.8 bits

MA600 – Resolution and Bandwidth Defined

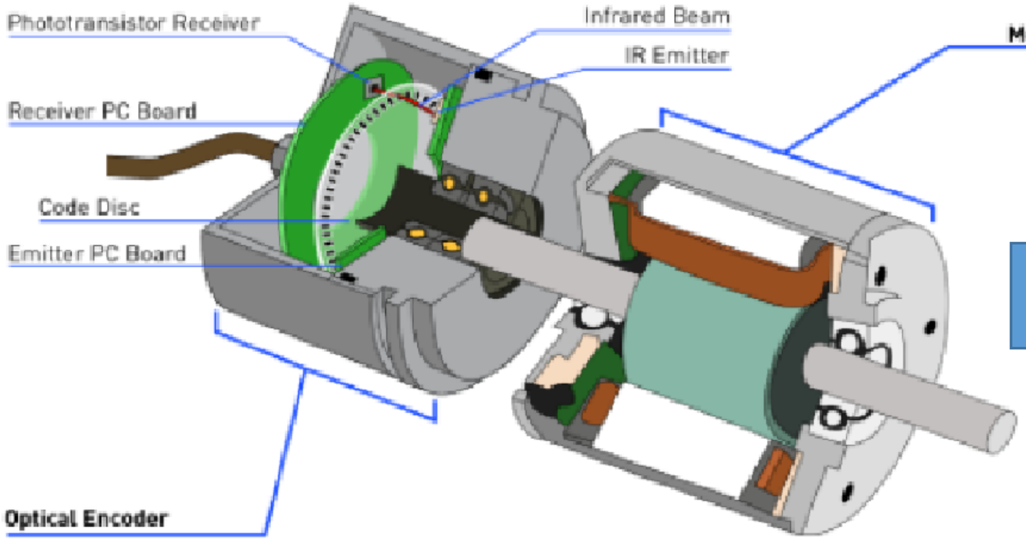
Parameter	Symbol	Condition	Min	Typ	Max	Units
Absolute Output – Serial						
Resolution (7) (±3σ deviation of noise)			11.5		14.5	bit
RMS Noise (7)			0.002		0.02	deg
Refresh Rate	$F_{refresh}$		780	800	820	kHz
Data Output Length				16		bit
Response Time						
Power-up Time (7)		FW = 0			250	µs
Latency (7)		FW = 5-11		0	1	µs
Filter Cutoff Frequency	F_{cutoff}	FW = 0		21		kHz



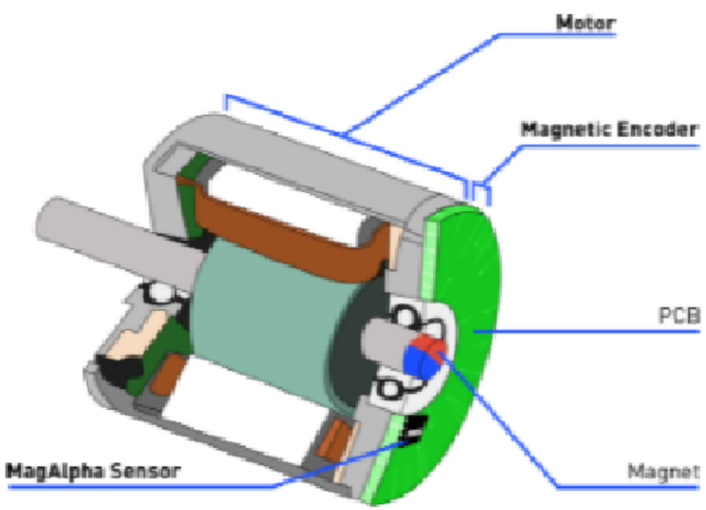
FW (3:0)	τ (µs)	Resolution (bits)	Latency (µs)	f_{CUTOFF} (kHz)
0	0	11.5	32	21
5 (default)	40	12.0	0	13.1
6	80	12.5	0	6.0
7	160	13.2	0	2.8
8	320	13.6	0	1.3
9	640	14.0	0	0.63
10	1280	14.3	0	0.31
11	2560	14.4	0	0.15

Reduce Cost with Magnetic Encoders

Optical Encoder → Magnetic Encoder



Optical Encoder + Motor



Magnetic Encoder + Motor

Customer Benefits

Reduce Cost 5-10x

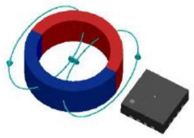
Immune to Dust and Debris

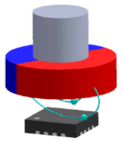
Operates in Harsh Environments Without Costly Enclosures

MA600 – Higher Bandwidth, Higher Resolution in Magnetic Angle Sensing

Key Specifications

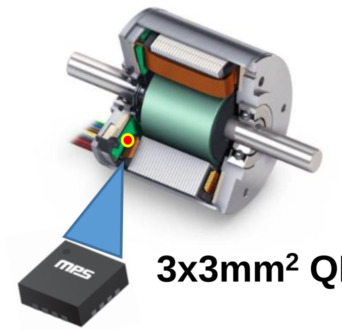
- **High Accuracy: 0.5° INL**
  - In-system calibration: 0.1° INL
  - Includes on-chip look-up table
- **High Bandwidth & Resolution: Up to 14.5-Bit (±3σ)**
  - No Internal Hysteresis
- **No Latency**
  - Minimizes error at speed
- **Flexible Operation to Fit Many Applications:**
  - Reliable operation down to 20mT
  - Works in Side-Shaft or End of Shaft



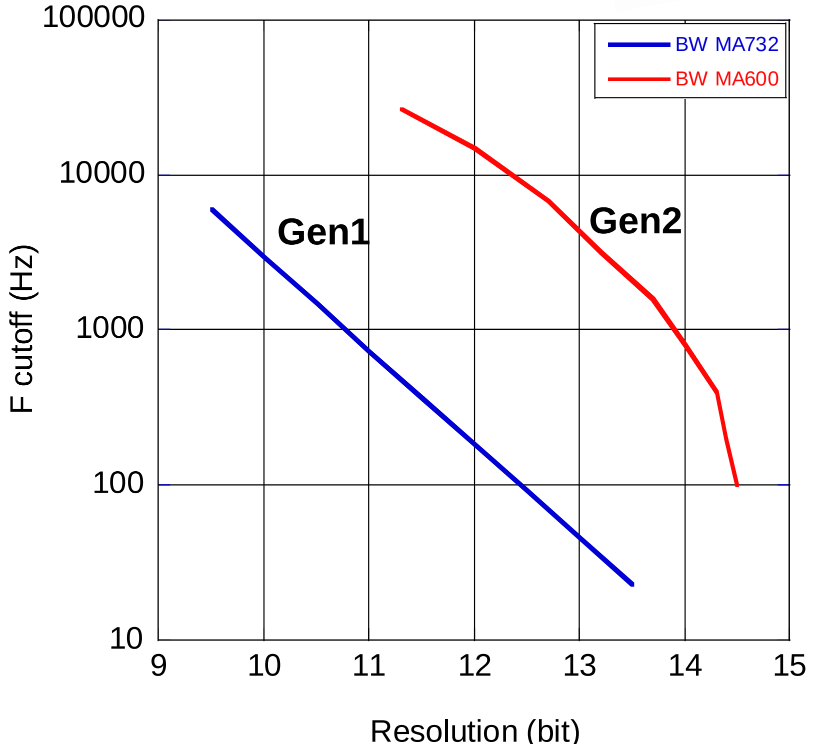


Applications

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



3x3mm^2 QFN



Thank You
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