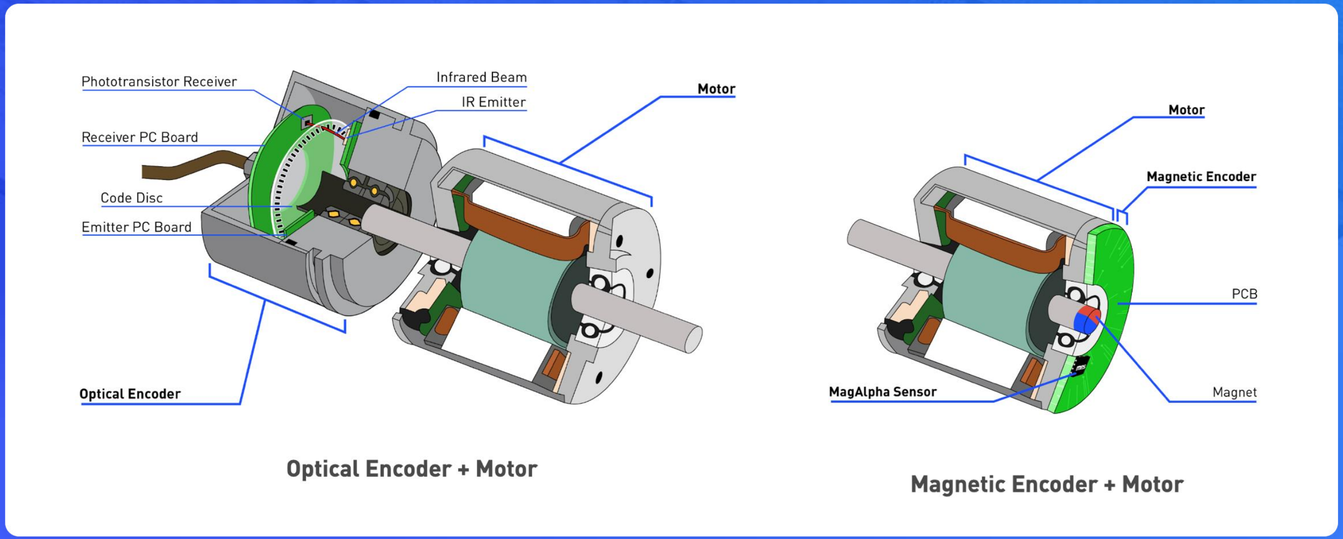
Replacing Optical Encoders with Magnetic Position Sensors

April 2023



Agenda

- Types of Optical Encoders
- Comparison to Magnetic Position Sensors
- Typical Motor Applications
- Choosing a Magnetic Sensor
- Target Magnet Decisions
- Simulation for Magnetics/Mechanicals
- Q&A

Types of Optical Encoders

8 tracks = 8 bits: requires 8 LED / receiver pairs

Cost scales with resolution

Digi-Key Sampling of Optical Encoders

Heavy Duty Hollowshaft Encoder

Key Features

- Phased Array Sensor for Reliable Signal Output
- Rugged Design Withstands up to 400G Shock and 20G Vibration
- Unbreakable Code Disc up to 5000 PPR
- Heavy Duty Design Rated for IP67
- Customizable Mounting Options including Torque Arm with Optional Grounding Strap

Digi-Key Price: $979

Features

- Two channel quadrature output with optional index pulse
- Quick and easy assembly
- No signal adjustment required
- External mounting ears available
- Low cost
- Resolutions up to 1024 counts per revolution
- Small size –40°C to 100°C operating temperature
- TTL compatible
- Single 5 V supply

Digi-Key Price: $56

TMCS-40 is a low-cost and small-size optical incremental encoder for use with stepper motors and 3-phase PMSM/BLDC motors. It comes with high resolution optical code wheels with a resolution of 10.000 lines (40.000 counts).

Digi-Key Price: $114

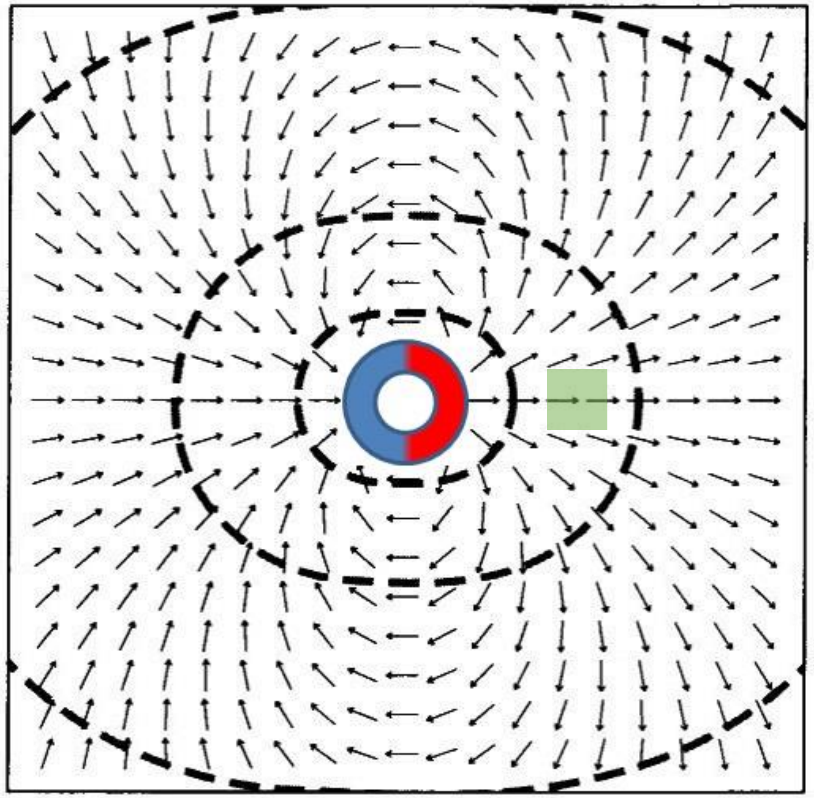
- Compact Ø20mm size package
- 3 million cycles rotational life (1 million cycles with detent)
- 24 PPR resolution
- Wide operating temperature range (-10°C to +85°C)
- 5.0 VDC and 3.3 VDC power options
- Integrated Schmitt trigger and pull-up resistor

Digi-Key Price: $21

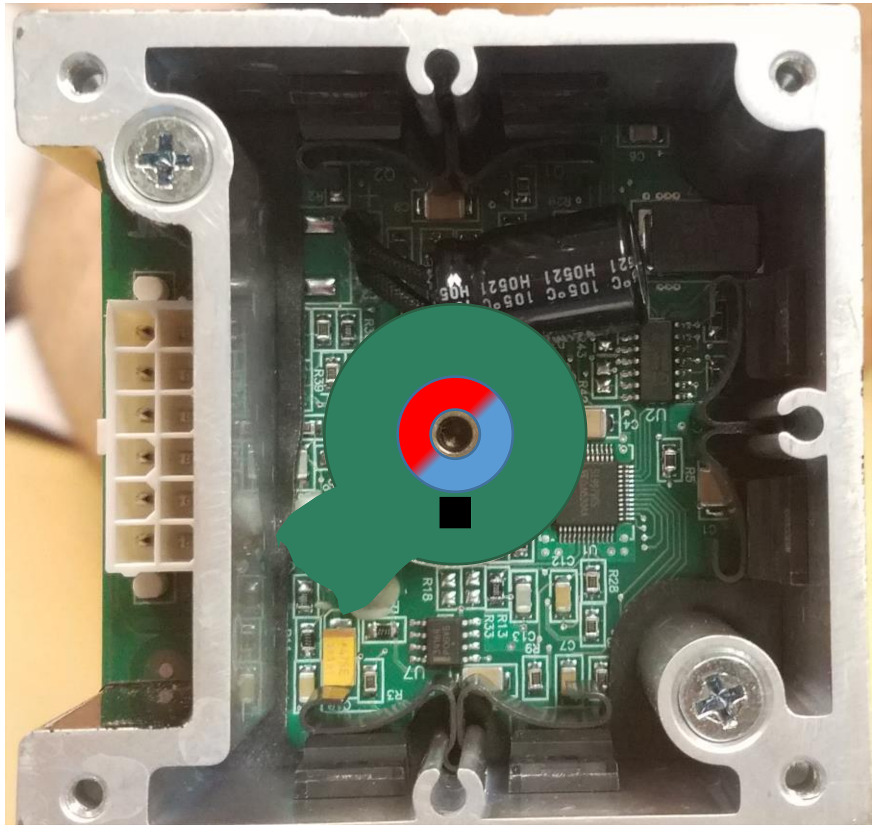
Comparison to Magnetic Position Sensors

	Optical	Magnetic
Resolution (bits)	25+	15 to 16
Accuracy (max INL)	N/A	0.6 / <0.1
Size (mm)	30x30 to 100x100	3x3/ 2x2
Cost	$6 to $100+	$1 to 2 (sensor + magnet)
Flexibility	None	Yes
Output	Incremental or Absolute	Absolute Angle +

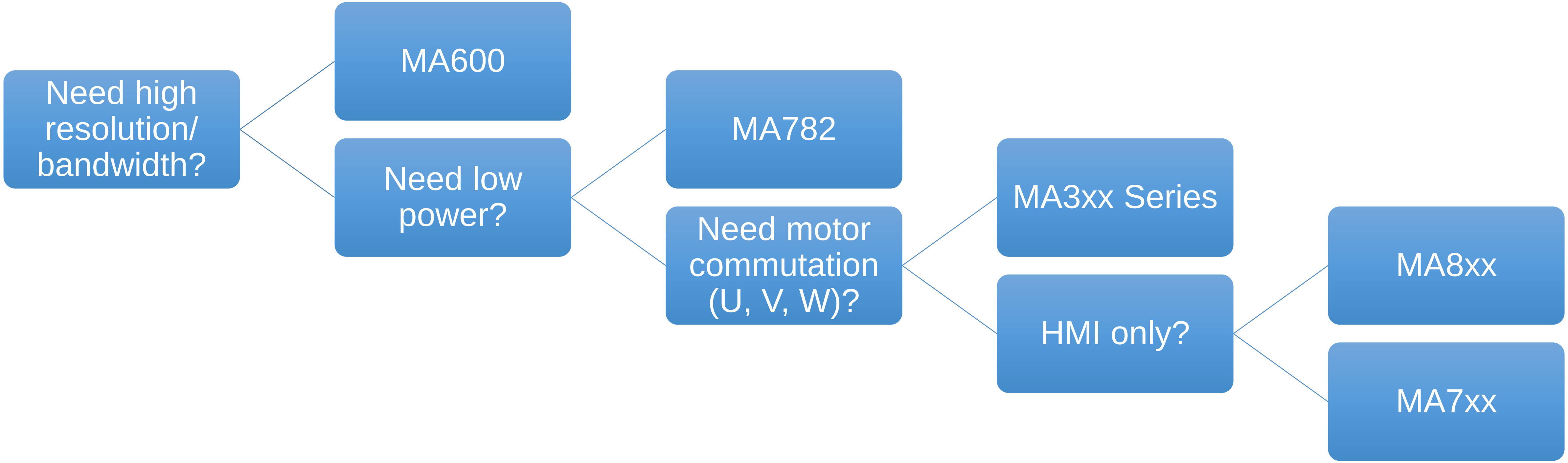
Operation Principles



Typical Motor Applications



Sensor Decision Tree

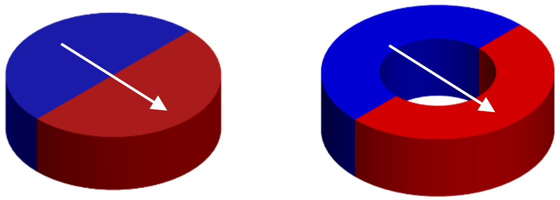


Magnets

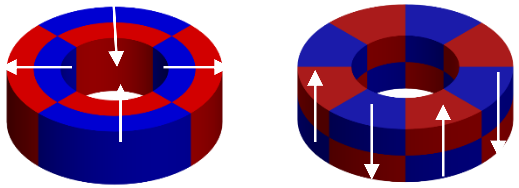
Materials/Geometries

Magnet Design Tradeoffs

- Single Dipole (Diametral)
  - Easy to Simulate
  - True Absolute Position
  - Inexpensive
  - Only Option for On-Axis (Off-Axis Is Possible)



- Multipole (Radial or Axial)
  - Double the Pole Pairs, Gain 1 Bit!
  - Side-Shaft (Off-Axis) Only
  - Airgap Must Be Tight for High PP Counts
  - Check Supplier Magnetization
  - Cannot Achieve True Absolute Output



Magnet Materials

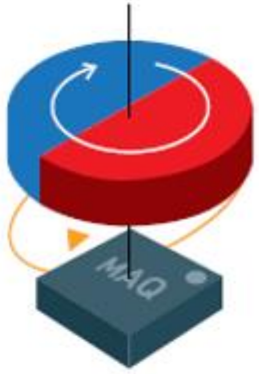
	Br (mT)	Working Temp (°C)	Comments
Neodymium **Sintered** **Bonded**	**1200 to 1400** **470 to 620**	**80 to 150** **130**	• Very high resistance to demagnetization • Susceptible to corrosion; needs coating • Most common target magnet
SmCo **Sintered** **Bonded**	**820 to 1050** **400 to 700**	**250 to 300** **400 to 700**	• High resistance to demagnetization • Medium/high temperature resistance
AlNiCo **Sintered** **Cast**	**650 to 1050** **600 to 1350**	**810*** **450 to 550**	• Low resistance to demagnetization • High production cost • **Rarely used for target magnet**
Ferrite **Ceramic** **Molded**	**200 to 450** **140 to 290**	**450*** **50**	• Molded ferrite can be flexible, easy to cut • Very inexpensive • May need a relatively large magnet due to low Br

Mechanical Considerations

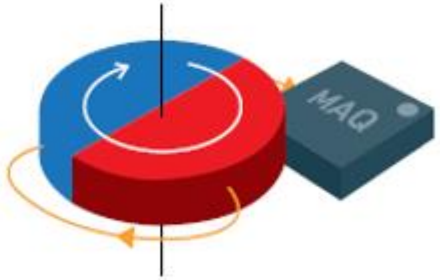
Attachment to Shaft:
- Epoxy
- Press Fit
- Magnet Coupling
- Magnetic Assembly

PCB/Sensor Placement:
- On-Axis/End of Shaft
- Off-Axis/Side-Shaft
- Off-Axis Orthogonal

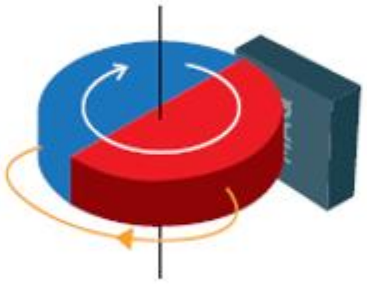
End of shaft



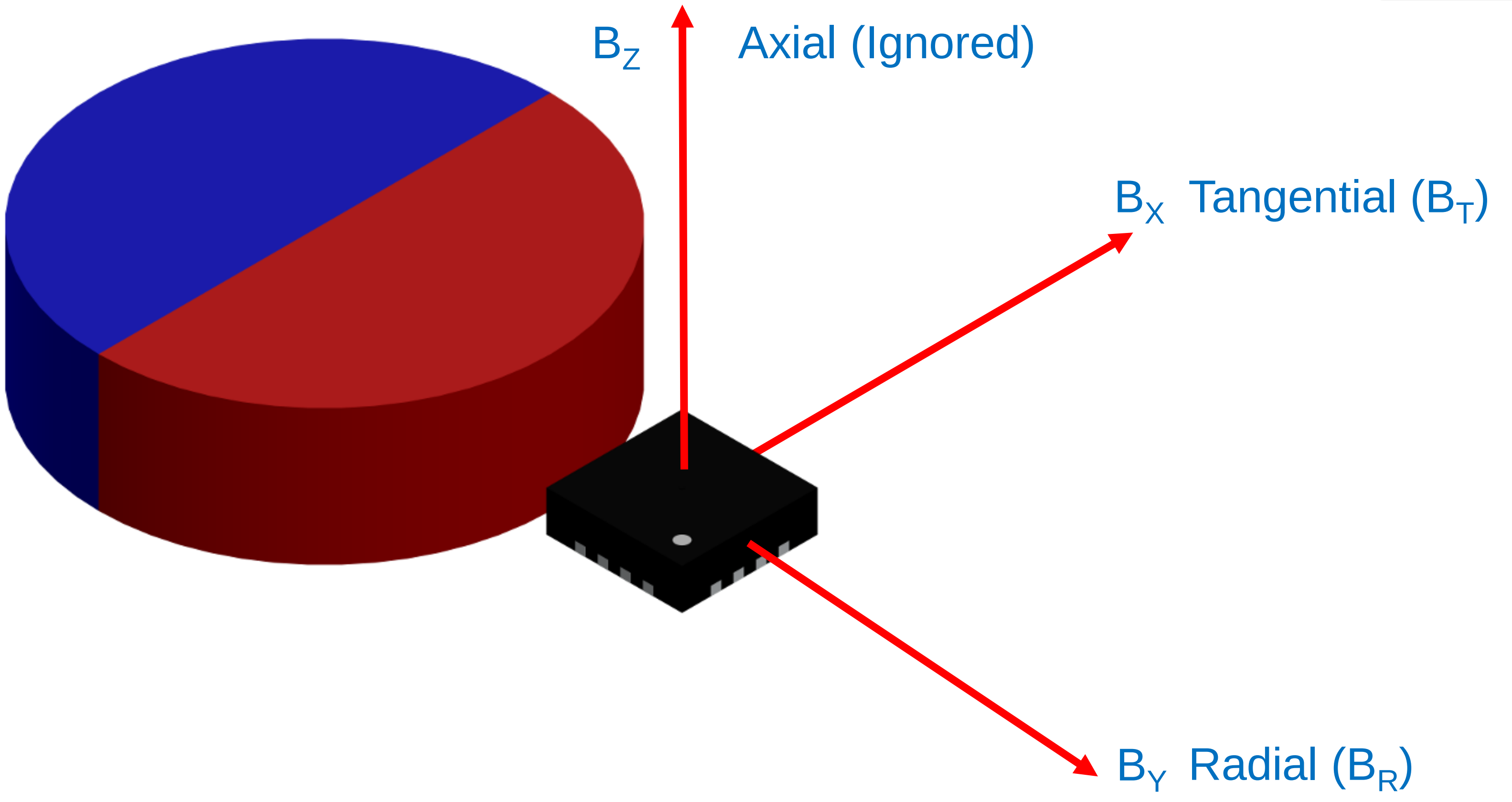
Side of shaft

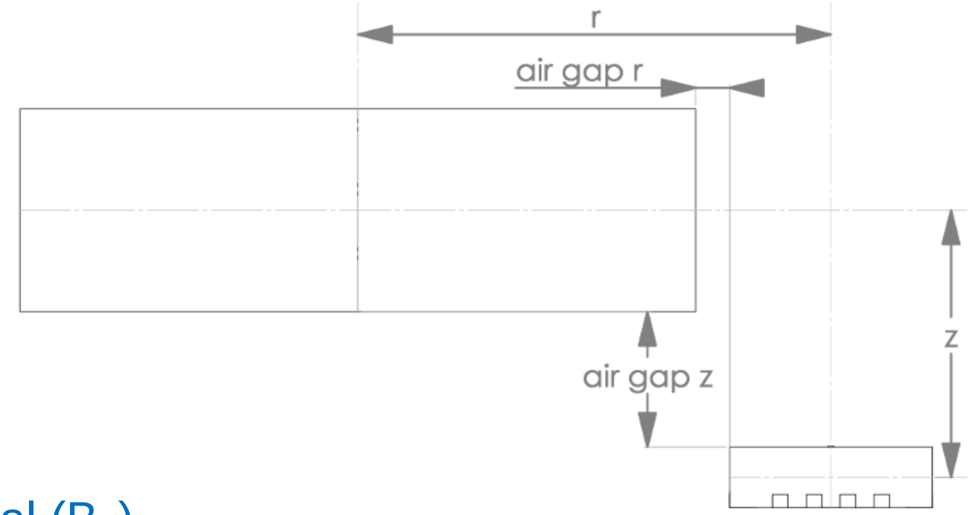


Side of shaft orthogonal



Coordinate System Conventions



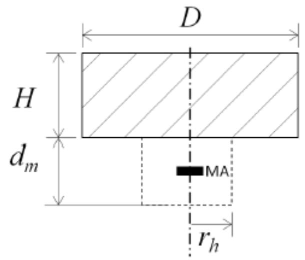


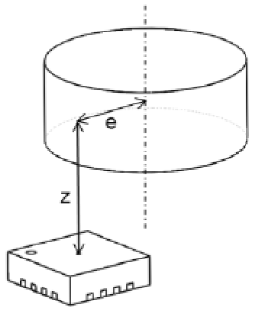
Tools

Simulation/Lab Set-Up

Application Notes

Appendix A: Sensor Position for a Cylinder without a Hole





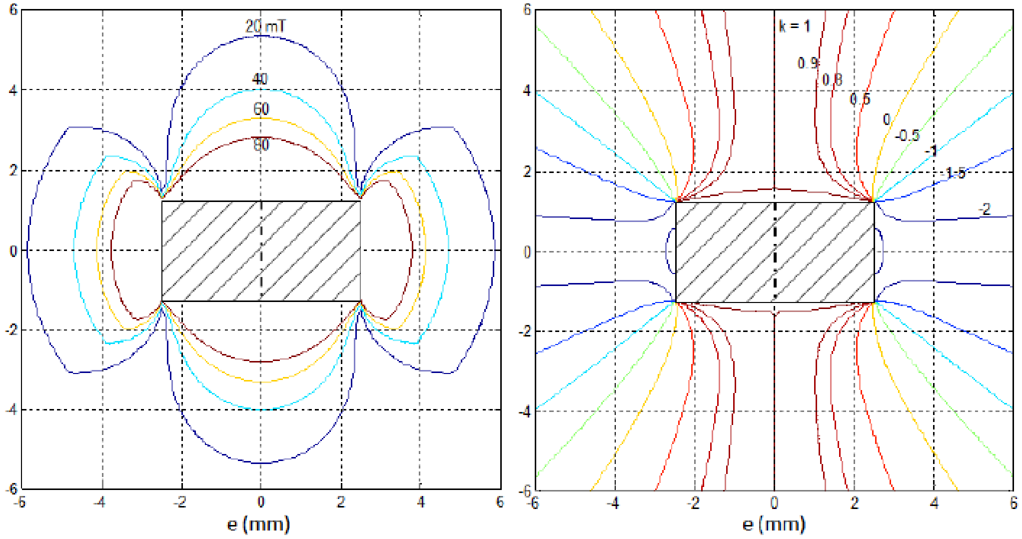
Use Table 1a and Table 1b to determine the height and radius of the cylinder.

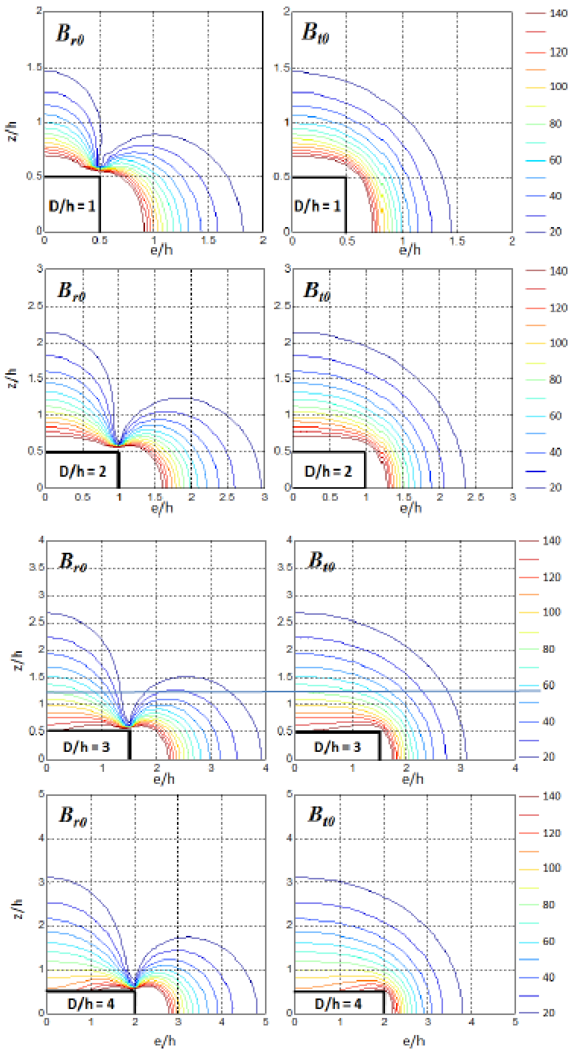
Table 1a: Specifications to Determine the Height of the Cylinder

d_m (mm)		D (mm)							
		3	4	5	6	7	8	9	10
H (mm)	2.0	2.1	2.6	3.1	3.5	3.8	4.1	4.3	4.6
	2.5	2.2	2.8	3.3	3.7	4.1	4.5	4.8	5.1
	3.0	2.3	2.9	3.5	4.0	4.4	4.8	5.2	5.5
	3.5	2.4	3.0	3.6	4.1	4.6	5.0	5.5	5.9
	4.0	2.4	3.1	3.7	4.3	4.8	5.3	5.7	6.1
	4.5	2.5	3.2	3.8	4.4	4.9	5.4	5.9	6.4
	5.0	2.5	3.2	3.9	4.5	5.1	5.6	6.1	6.6

Table 1b: Specifications to Determine the Radius of the Cylinder

r_h (mm)		D (mm)							
		3	4	5	6	7	8	9	10
H (mm)	2.0	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6
	2.5	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6
	3.0	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
	3.5	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
	4.0	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
	4.5	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
	5.0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6





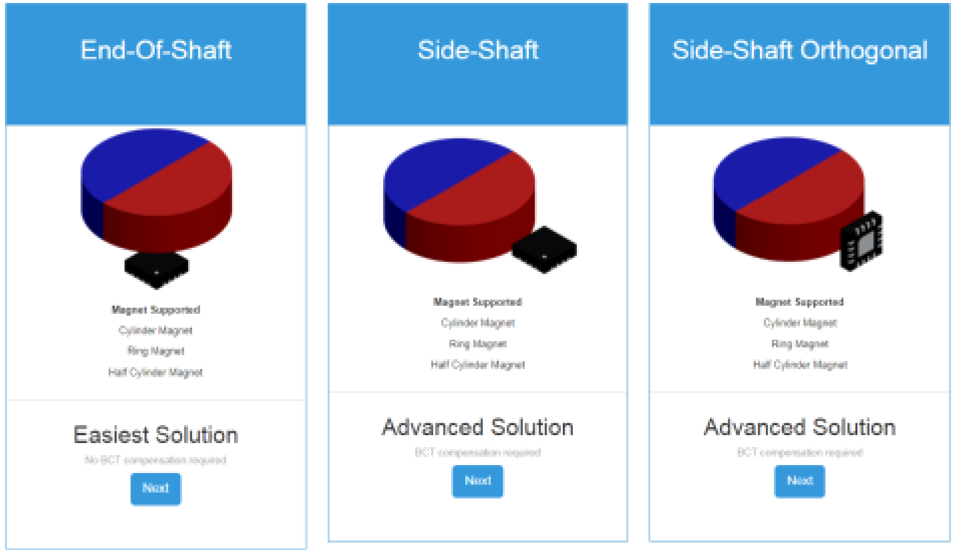
MPS Online Simulation

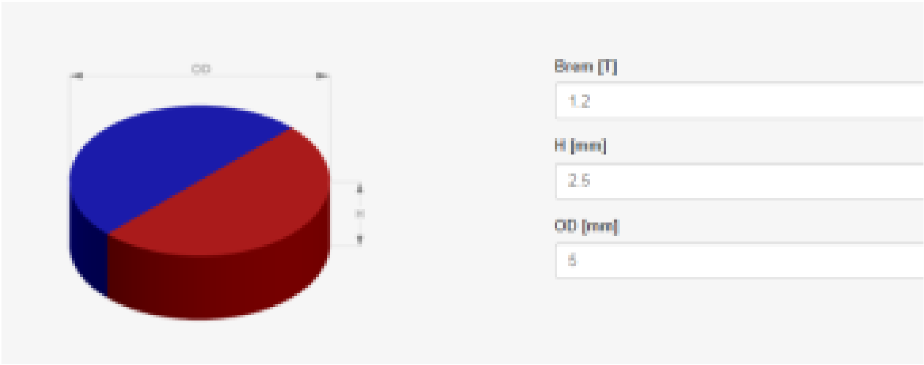
Simulates for all magnet and sensor topologies

Finds optimum mechanical positioning for a particular magnet material and dimension

Includes tolerance analysis effect on angle error

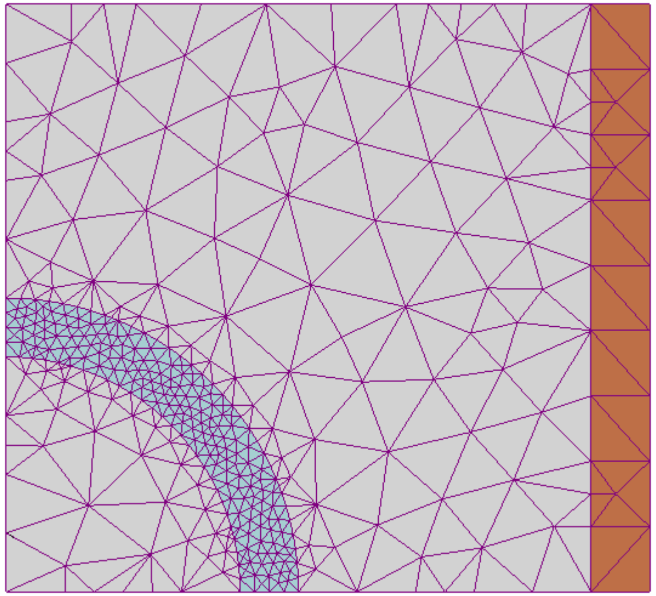
http://sensors.monolithicpower.com/

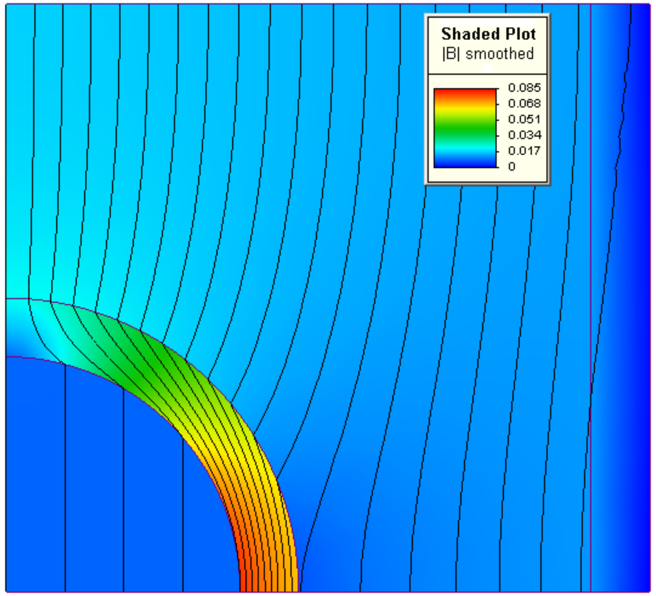




Finite Element

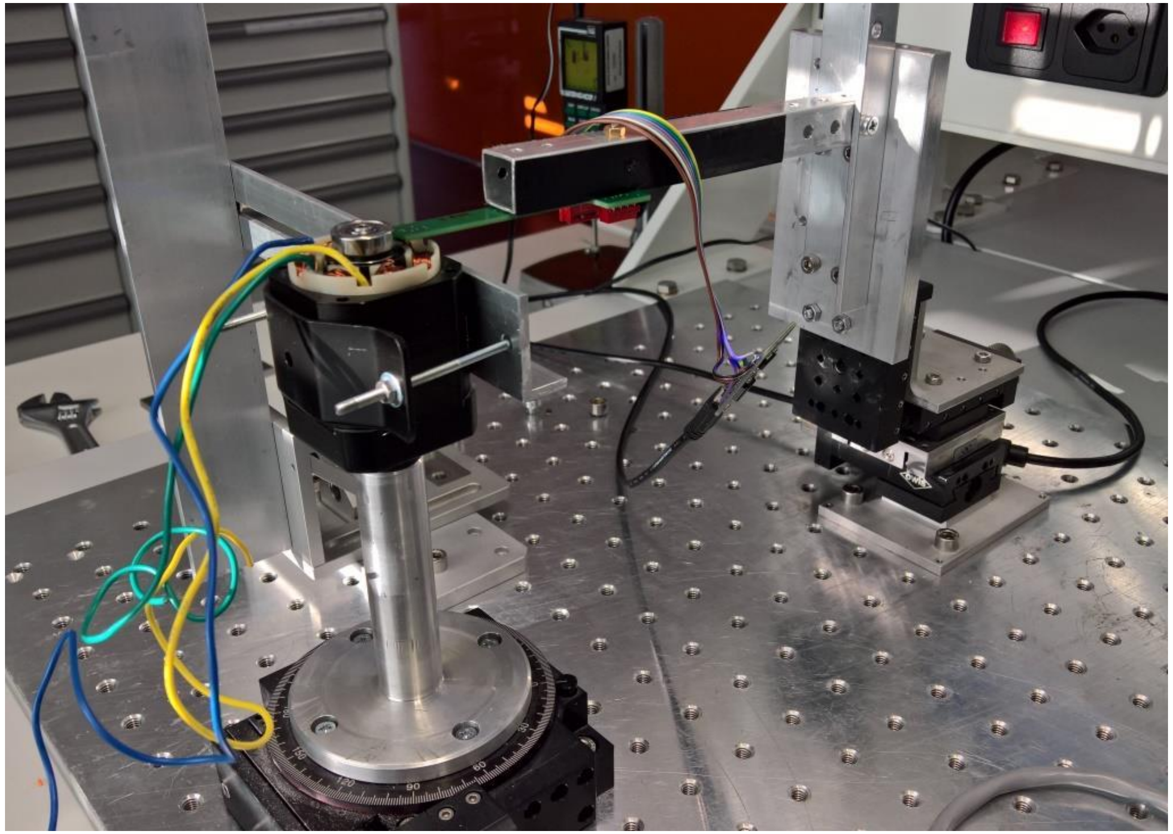
- Used for Simulation when…
  - There is a high-permeability material nearby
  - The target magnet has no symmetry
- Why I Rarely Recommend FEM
  - Software is complex and expensive
  - Results are highly dependent on optimized mesh, proper boundary conditions, and problem definition
  - In the end, we need to verify with real measurements anyway



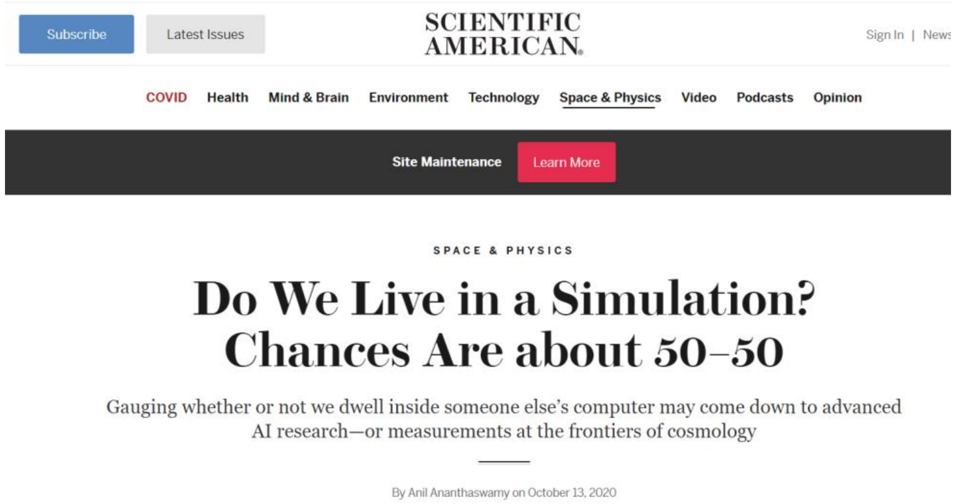


Real Measurements

3D Magnetic Field Scanning Set-Up



"The Universe is the best physics simulator."
- One of my college professors



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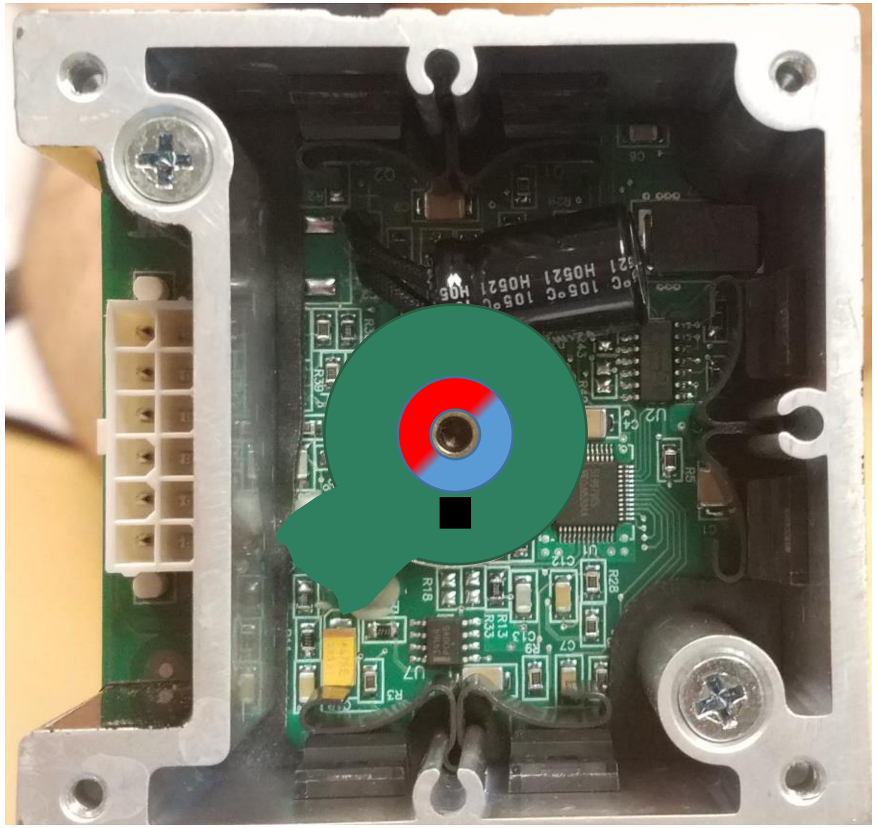
SPACE & PHYSICS

Do We Live in a Simulation? Chances Are about 50–50

Gauging whether or not we dwell inside someone else's computer may come down to advanced AI research—or measurements at the frontiers of cosmology

By Anil Ananthaswamy on October 13, 2020

Sample Simulation



Magnet Size

- ID = 4mm
- OD = 10mm
- H = 3mm

Sensor Placement

- D_{AXIAL} = -3mm
- D_{RADIAL} = +5mm

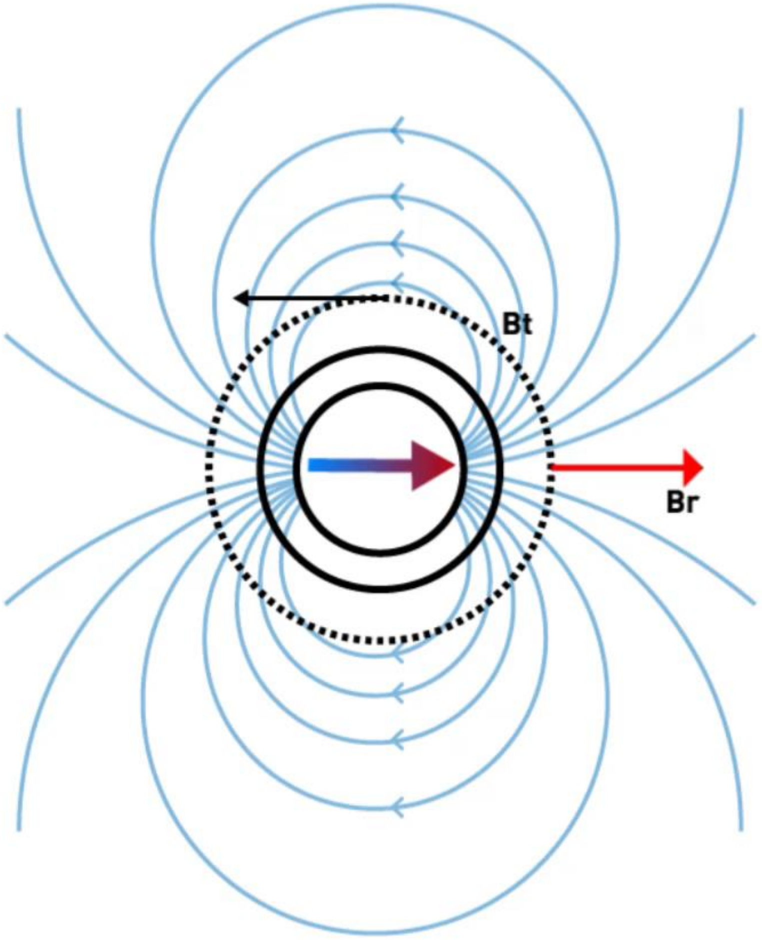
Magnet Material

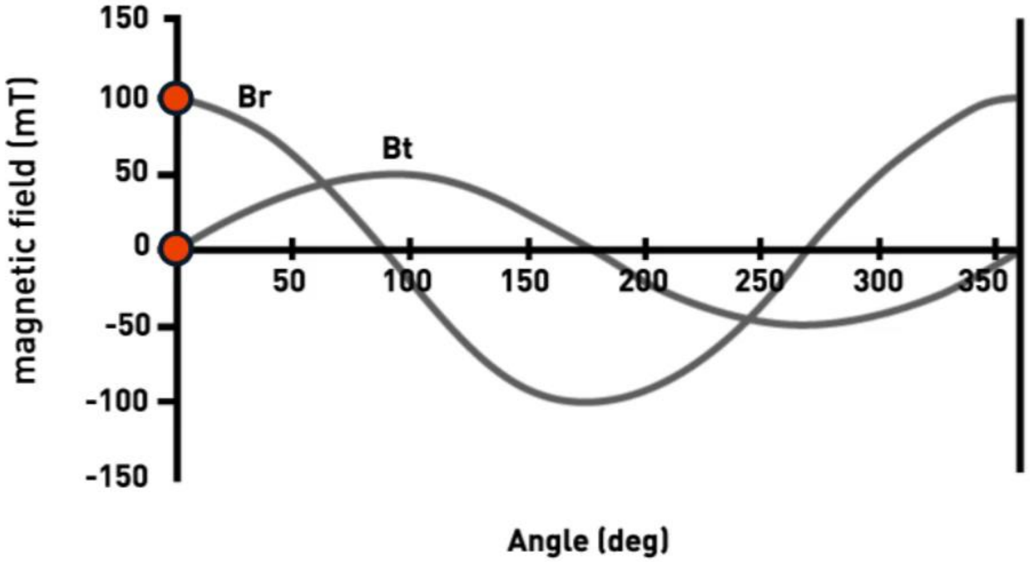
- Sintered Neodymium

Off-Axis Sensing

Side-Shaft Position

Off-axis Compensation





$$k = \frac{\max B_r}{\max B_t} \qquad BCT = 258\left(1 - \frac{1}{k}\right)$$

Choosing a Magnetic Sensor

Part Number	Description	Output Format	Resolution (bits)
MA600	Hi… Resolution, Digital Magnetic Angle Se…	ABZ, PWM, Reduced Wire Mode, SPI, SSI, UVW	15
MA732	14… ncremental & PWM Outputs	ABZ, PWM, SPI, SSI	14
MA735	9-… ABZ and PWM Outputs in an Ultra-Small UTQFN-14 Package	ABZ, PWM	9 to 13
MA736	8-Bit to 12.5-Bit, 3µs Low-Latency, Ultra-Small, Contactless Digital Angle Sensor	SPI	8 to 12.5
MAQ473	9-Bit to 14-Bit, MagAlpha Automotive Angle Sensor with ABZ Incremental and PWM Outputs	ABZ, PWM, SPI, SSL	14
MA734	…gle Sensor	SPI	8 to 12.5
MA780	…rated Wake-Up Angle Detection	SPI	12
MA782	Ultra-Small, Low-Power Angle Sensor with Integrated Wake-Up Angle Detection	SPI	12
MAQ470	12-Bit, Automotive Angle Sensor with ABZ Incremental & PWM Outputs	ABZ, PWM, SPI, SSI	12
MAQ430	12-Bit, Automotive Angle Sensor with ABZ & UVW Incremental Outputs	ABZ, SPI, UVW	12
MA800	8-Bit, Digital, Contactless Angle Sensor with Push Button Function	SPI, SSI	8
MA820	8-Bit Contactless Angle Encoder with ABZ Output and Push Button Function	ABZ, SPI	8
MA704	10-Bit, Digital, Contactless Angle Sensor with ABZ Incremental & PWM Outputs	ABZ, PWM, SPI, SSI	10
MA730	14-Bit, Digital, Contactless Angle Sensor with ABZ Incremental & PWM Outputs	ABZ, PWM, SPI, SSI	14
MA710	12-Bit, Digital, Contactless Angle Sensor with ABZ Incremental & PWM Outputs	ABZ, PWM, SPI, SSI	12
MA702	12-Bit, Digital, Contactless Angle Sensor with ABZ Incremental & PWM Outputs	ABZ, PWM, SPI, SSI	12
MA310	12-Bit, Digital, Contactless Angle Sensor with ABZ & UVW Incremental Outputs	ABZ, SPI, UVW	12
MA302	12-Bit, Digital, Contactless Angle Sensor with ABZ & UVW Incremental Outputs	ABZ, SPI, UVW	12
MA102	Mo… le Pair Emulation	SPI, UVW	8
MA850	8-B… and Push Button Function	PWM, SPI	8
MA330	14-… UVW Incremental Outputs	ABZ, SPI, UVW	14

TMR – Newest, highest resolution

Hall – Programmable resolution / bandwidth. Superset of all MA7xx

Hall – Low power, wake-on-change

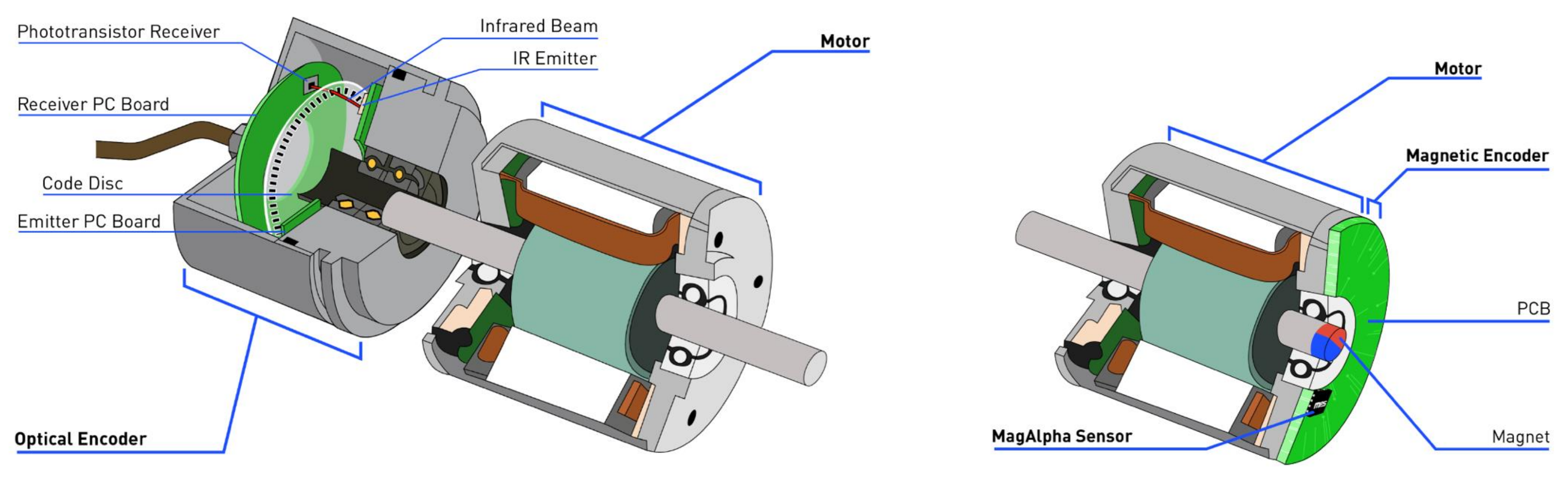
Hall – Programmable resolution / bandwidth. Like MA732 but can block commutate BLDC

Sensor Selection Starting Point

Part Number	Description	Output Format	Resolution (bits)
MA600	TMR – New, high resolution/bandwidth	ABZ, PWM, Reduced Wire Mode, SPI, SSI, UVW	15
MA732	Hall – Programmable resolution/bandwidth	ABZ, PWM, SPI, SSI	14
MA780	Hall – Low power; consider for anything operating from battery	SPI	12
MA330	Hall – Identical to MA732 except the UVW outputs for BLDC commutation	ABZ, SPI, UVW	14
MA800	Hall – Very low cost, slow; ideal for HMI	SPI or ABZ or PWM	8

Reduce Cost with Magnetic Encoders

Optical Encoder → Magnetic Encoder



Optical Encoder + Motor

Magnetic Encoder + Motor

Customer Benefits:

Reduce Cost

Reduce Size

Operates in Harsh Environments without Costly Enclosures

Thank You
ted.smith@monolithicpower.com