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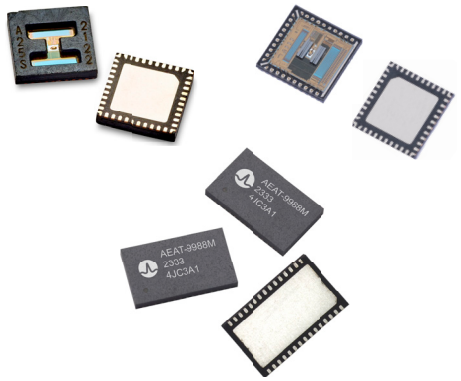
White Paper

How Hollow-Shaft Absolute Encoders Enable Greater Integration of Compact and Lightweight Robots, AGVs, and AMRs



Abstract

As industrial automation rapidly evolves, the demand for more compact, efficient, and intelligent robotic systems is rising—driven by applications like autonomous mobile robots (AMRs), automated guided vehicles (AGVs), and collaborative robots (cobots). A key enabler of this shift is the adoption of large hollow-shaft motors, which allow for the integration of cabling, sensors, and actuators within the motor's axis.

To fully leverage these motors, designers must overcome significant challenges in space constraints, motion accuracy, and system reliability. This white paper explores how high-performance absolute encoders—both optical and magnetic—support the design of compact, lightweight, and high-precision robotic systems. With solutions such as Broadcom's energy-harvesting multi-turn (EHMT) technology, engineers can simplify integration, eliminate maintenance, and drive the next generation of flexible automation.

Introduction

The use of robots and autonomous vehicles on manufacturing floors has driven the need for continuous technological improvement in the motion-control and feedback systems. Encoders are essential to achieving compact, high-precision, and lightweight robotic designs—critical factors in modern automation.

One of the key trends is the use of hollow-shaft motors in multi-axis industrial, collaborative, and mobile robots. Hollow-shaft motors allow the integration of cables, sensors, and mechanical elements (for example, direct-drive torque transmissions, pneumatic or hydraulic tubing) through the shaft, minimizing overall size and weight.

Absolute encoders play a key role in enabling the adoption of hollow-shaft motors. By having the right selection of encoders, obstacles commonly faced by design engineers in terms of space constraints, precision control, durability, and space optimization can be overcome.

Broadcom offers a selection of optical and magnetic encoders that addresses the requirements of hollow shafts in robotic solutions.

Applications

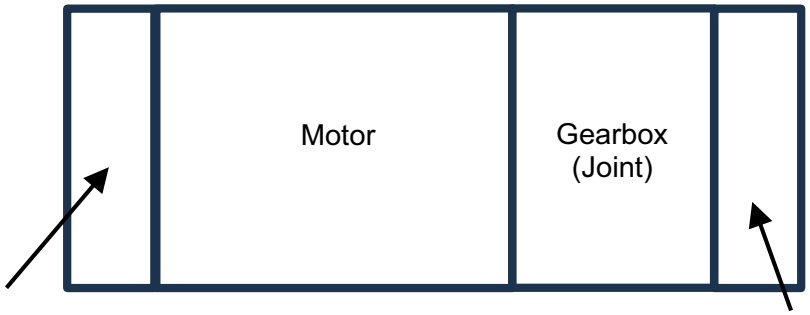
- Industrial multi-axis robots
- Collaborative robots
- Hollow-shaft motors
- Automated guided vehicles
- Autonomous mobile robots
- Medical equipment
- Exoskeletons

Role of Encoders in Closed-Loop Systems

In closed-loop control systems, encoder feedback is essential for maintaining precise control over motion, position, and speed. Encoders serve as sensors that convert mechanical motion into electrical signals, which are then interpreted by the controller to monitor system output in real time. In a robotic motor, this is typically referred to as the input encoder.

An output encoder, on the other hand, measures the actual joint position for feedback and control. There are real performance advantages from measuring the actual joint position instead of the motor-shaft position. Discrepancies can arise between the actual position, speed, or torque of the joint output shaft and those of the motor shaft. The major contributors to these discrepancies are gear backlash, elastic deformation, and transmission errors. Similarly, in AGVs and AMRs, the output encoder monitors the wheel rotation to monitor vital odometry information.

Figure 1: Input and Output Encoders in a Robotic Arm Motor Joint or in AGVs and AMRs



Input Encoder
(Motor Shaft Encoder)

Output Encoder
(Joint or Wheel Position Sensor)

Key Challenges in Hollow-Shaft Motor and Encoder Integration

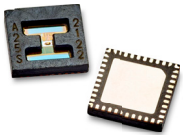
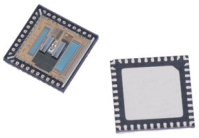
Robotic engineers face some common challenges when trying to integrate hollow-shaft motors and encoders:

- **Space constraints** – Only a finite amount of space is available for a particular arm or joint. Compact integration is thus very difficult when hollow-shaft designs must accommodate the routing of internal cabling for control, feedback, and sensor data communication. Moreover, other mechanical components, such as pneumatic or hydraulic tubing and transmission drive shafts, may also be required to pass through the same hollow shaft.
- **Multi-turn counting** – Traditionally, there is a lack of multi-turn tracking options with hollow-shaft encoders. The most common solution today of using a battery-backup multi-turn requires maintenance over the lifetime of the usage. Broadcom's proprietary energy-harvesting multi-turn solution based on the Wiegand wire solves this problem, improving reliability in multi-turn applications.
- **Accuracy** – Due to gear backlash, joint elasticity, and thermal expansion effects, high-precision encoders might be needed to achieve an effective and accurate feedback system.
- **Cost and complexity** – A high degree of customization is required to design compact hollow-shaft motors and encoders. Moreover, a precise alignment and assembly process might be required, which translates into increased production costs. Sourcing of suitable encoders that meet the expected technical and commercial viability can be challenging.
- **Robustness** – Encoder construction and signal integrity must be robust in terms of immunity to electromagnetic interference (EMI) and mechanical and environmental impacts (contamination, shock and vibration, thermal fluctuations).

Hollow-Shaft Encoder Selection

Broadcom hollow-shaft encoders are well positioned to address the unique requirements of fixed and mobile robots. For high-performance solutions, optical encoders are recommended. For solutions that require high resistance to contamination, magnetic encoders are the alternatives. In general, the resolution and accuracy performance of magnetic encoders is lower when compared to the optical encoders.

Table 1: Hollow-Shaft Optical Absolute Encoders

Specification	AR25	AR55
Product Image		
Optical Technology	Reflective	
Resolution (Binary)	15 to 25 bits	1 to 32 bits
Operating Voltage	3.3V ±0.3V and 5V ±0.5V	
Operating Temperature	–40°C to 125°C	
Size (W × L × H) or (OD × H)	6 mm × 6 mm × 1.05 mm	6 mm × 6 mm × 0.7 mm
ABIUVW	Yes	
Shaft Type	Blind/through hollow	Through hollow/linear
Protocol	SSI, SPI 4-Wire, ESL, RS485, BiSS-C	
Multi-Axis	Daisy chain (7 clients in bus or line mode)	
Multi-Turn Integration	Yes: energy harvesting (EHMT) or battery-backed-up (BBMT)	
Shaft Inner Diameter (ID)	Up to 30 mm	45 mm to 2.66 meters
Product Outer Diameter (OD)	30 mm to 60 mm	63 mm to 2.68 meters
Linear Length	N/A	Up to 8.33 meters
Calibration Kit	Yes	
Angular Accuracy Error [a]	±30 Arc-seconds	

a. Calibrated accuracy: After being electronically corrected. Better accuracy can be obtained depending on the calibration system and mechanical mounting tolerances.

Figure 2: Examples of Large-Diameter Matching Code Wheels for the AR55 Series Encoders

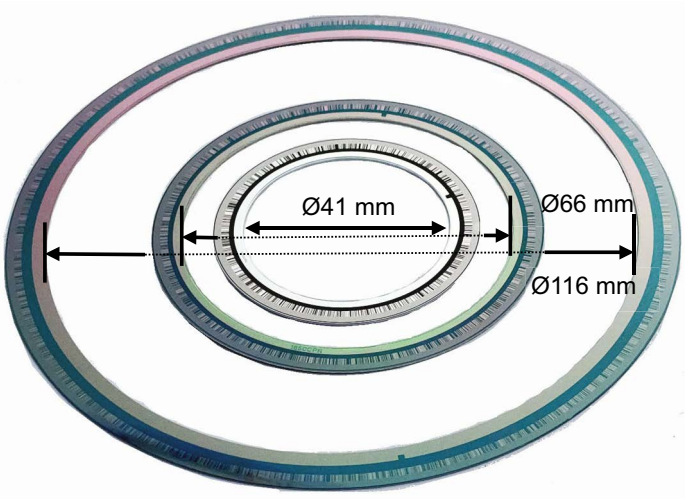
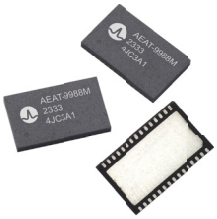
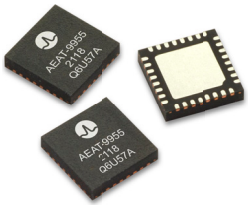
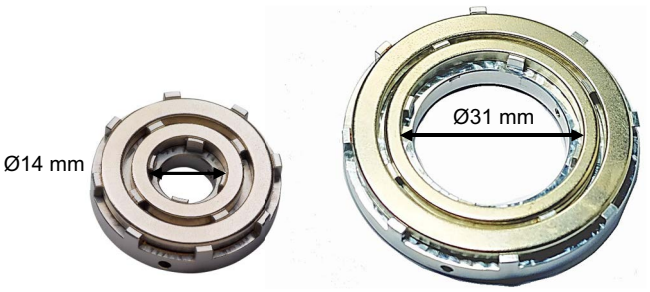


Table 2: Hollow-Shaft Magnetic Absolute Encoders

Specification	AEAT-9988M	AEAT-9955
Product Image		
Sensor Axis	Off-axis shaft-end	On-axis shaft-end and Off-axis: side-shaft, axial and radial
Current Consumption	48 mA (5V supply) 500 µA (Sleep mode)	24 mA (5V supply) 300 µA (Sleep mode)
Supply Voltage	5V ±0.5V	3.3V ±0.3V and 5V ±0.5V
I/O Voltage	3.3V or 5V	
Communication Interface	RS485, BiSS-C, SPI, SSI, ABZ, UVW, PWM	SPI, SSI, ABZ, UVW, PWM
Magnet Type/Strength	Dual-ring Single-pole (20 mT to 100 mT) and Multi-pole (30 mT to 150 mT)	Ring (30 mT to 150 mT)
Memory	MTP – Multiple time programmable (56-bit passcode protection)	
Operating Temperature	–40°C to 125°C	
Incremental ABZ Resolution	Programmable 1 to 65,535 CPR	Programmable 1 to 20,000 CPR
UVW Resolution	1 to 32 pole-pairs (dedicated output pins)	
Absolute ST Resolution	16 to 23 bits	10 to 18 bits
Absolute ST Integral Non-Linearity Error (INL)	±0.02° (typical)	±0.15° (Off-axis, typical)
Angle INL Calibration	Auto-calibration without reference encoder	
Package Size	DFN-32 8.2 mm × 5 mm	QFN-32 5 mm × 5 mm
Magnet Inner Diameter (ID) [a]	Up to 65 mm	Up to 65 mm
Zero Reset Calibration	Auto-reset on command	Auto-reset on command or dedicated Zero Reset pin
Multi-Turn Output	Yes (battery backup)	No
Programmable I/O Pins	3 I/Os	No
Functional Safety	No	Yes (ISO-26262 ASIL-D/SIL3 ready)
Automotive Grade	No	AEC-Q100 Grade 0

a. The magnet size is limited by the availability of the diametrically polarized single dipole magnet.

Figure 3: Examples of Ring Magnets for the AEAT-9988M Series Encoders



Comparison of Absolute Encoder Types

The following table provides an overview of encoders with different sensing technologies. Broadcom provide solutions based on optical and magnetic technologies.

Table 3: Brief Comparison between Different Encoder Types Based on Sensing Technologies

Type	Typical Resolution	Accuracy	Key Features
Optical	Very High	Very High	Best performance, with metal or glass code wheel, IP-rated protective casing for dust and moisture protection.
Magnetic	High	Medium	Contamination and moisture resistant; tolerates mechanical shock and vibration.
Inductive	High	High	Contamination resistant, precise motion control.
Capacitive	Medium	Medium	Compact, lightweight.

When Multi-Turn Encoders Are Useful

Although multi-turn encoders are not always required for cobots, they can be beneficial for:

- High-precision tasks, especially with high-accuracy optical encoders
- Power efficiency by avoiding position loss during power-off scenarios
- Extended joint rotation without losing position information

Cobot manufacturers typically integrate multi-turn absolute encoders in their higher-end models. Whereas entry-level compact cobots typically use only single-turn encoders or even incremental encoders.

As for AGVs and AMRs, multi-turn encoders are integrated due to following benefits:

- **Motor position tracking** – An accurate odometry (that is, the distance traveled) can be obtained with the multi-turn encoder reading, which provides the exact angular position of the motor shaft, including the rotation counts.
- **Lift platform control** – Tracking of the vertical position of the lift is possible in AGVs or AMRs that include a lifting platform (for example, for pallets or bins). An absolute multi-turn encoder ensures that the AGV/AMR system knows the lift height even after a power-loss event.
- **Power-loss safety and recovery** – The beauty of a multi-turn absolute encoder is that it retains position data (including the rotation count). No homing or recalibration is required after a power failure. AGVs/AMRs can resume operations safely because the absolute position data is retained.

Benefits of Energy-Harvesting Multi-Turn Encoders

Broadcom plays a very important role in the development of energy-harvesting multi-turn (EHMT) encoders, also known as Wiegand encoders. Multiple encoder options are available to suit different application requirements. The following are the key benefits of EHMT encoders:

- **No external power needed** – EHMT eliminates the need for batteries, reducing power consumption and the periodical maintenance costs of battery replacements.
- **Long-term reliability** – Unlike gear-based solutions, there are no moving parts, making them ideal for continuous operation in industrial cobots or AGVs/AMRs.
- **Compact and lightweight** – Integration with space-saving applications enables lightweight cobots used in collaborative environments. Reduce the drive load needed for AGVs/AMRs by high integration of the encoders to the motor systems.
- **Environmentally friendly** – Reduce electronic waste in robotic systems by reducing the use of disposable batteries.

Conclusion

By integrating hollow-shaft encoders in robotic and autonomous vehicles, system designers can solve some of the key challenges in these applications. Broadcom offers the right optical and magnetic hollow-shaft absolute encoders in terms of design features, flexibility, and performance.