BROADCOM®

White Paper

Encoder Technologies

Select the Right Encoder for Motion Control Systems

Introduction

Motion control systems are used in many areas including robotics, factory automation, medical equipment, automated guided vehicle (AGV) and autonomous mobile robot (AMR) systems, and light detection and ranging (LiDAR) systems. These systems depend on accurate position feedback to control movement properly.

Encoders provide this feedback by converting motion into electrical signals. The controller then uses this information to adjust movement and maintain accuracy.

The challenge is that there are many encoder technologies available, and each one behaves differently. Choosing the wrong encoder can lead to poor accuracy, unstable signals, or reliability issues.

This white paper explains the available encoder technologies, how they compare, and how to choose the right one based on application needs.

Encoder Selection is Not Straightforward

Selecting an encoder is not just about picking the option with the highest accuracy—different applications have different priorities. For example, a precision stage in semiconductor equipment needs an encoder with very high accuracy, while an AGV moving in a warehouse needs a robust encoder that can handle vibration and dust.

When selecting an encoder, engineers must often balance factors including resolution, environment, mechanical tolerance, and cost. There is no single encoder that is best for all cases.

Overview of Encoder Technologies

There are several encoder technologies used in motion control systems today, each suitable for different environments and applications:

- Optical encoders use light and a patterned scale to detect motion. They provide very high resolution and accuracy, which makes them suitable for precision applications. However, they are more sensitive to dust and require better alignment.
- Magnetic encoders use magnetic fields to detect position. They are more robust and can operate in harsh environments with dust, oil, and vibration. Their resolution is usually lower than high-end optical encoders, but they are easier to integrate.
- Capacitive encoders detect changes in capacitance. They offer a balance between performance and robustness, with better tolerance for contamination than optical systems.
- Inductive encoders use electromagnetic principles to detect motion. They are very robust and work well in harsh environments, but they can be more complex to design into a system.

Encoder Technology Comparison

This table gives a general view; actual performance depends on design, but this information can guide early decisions.

Parameter	Optical	Magnetic	Capacitive	Inductive
Resolution	Very high	Medium	Medium to high	Inductive
Accuracy	High	Medium	Medium	Medium
Environment Tolerance	Low to medium	High	Medium	Very high
Relative Cost	Medium to high	Low to medium	Medium	Medium

How to Choose the Right Encoder

Choosing an encoder is about matching the technology to the application needs. In most cases, the decision is a trade-off between accuracy, environment, and system complexity:

- If the system needs very high accuracy and fine position control, optical encoders are usually the better choice. This is common in precision equipment and some robotic systems.
- If the system operates in a harsh environment with dust, vibration, or oil, magnetic or inductive encoders are usually more suitable because they are more robust.
- If the design needs easier mechanical integration and can accept moderate accuracy, magnetic encoders are often a practical option.
- If the goal is to balance performance and robustness, capacitive encoders can be considered.

Encoder Selection by Application

This table shows typical choices; actual selection depends on system design.

Application	Preferred Technology	Reason
Robotics	Optical/Magnetic	High accuracy and better durability
Factory Automation (Clean)	Optical	Stable and precise
Factory Automation (Harsh)	Magnetic/Inductive	Handles environment better
AGV/AMR	Magnetic	Vibration and shock resistance
LiDAR	Optical	Accurate angle measurement

Application Examples

Autonomous Mobile Robots and Automated Guided Vehicles

Autonomous mobile robots (AMR) and automated guided vehicles (AGV) rely on encoder feedback to control wheel movement and navigation. These systems often operate on uneven surfaces and run for long periods. Because of this, robustness and reliability are important. Magnetic encoders are commonly used since they can handle vibration and contamination. In cases where higher positioning accuracy is required, optical encoders may also be used.

LiDAR

LiDAR systems use rotating or scanning mechanisms to map the environment. Encoders are used to track the exact position of the rotating part so that distance and angle measurements are accurate. In this case, resolution and signal stability are important, which is why optical encoders are commonly used.

Robotic Systems

Robotic systems require accurate motion feedback, but the choice of encoder depends on the environment. High-precision robots, such as those used in semiconductor or medical applications, often use optical encoders. Industrial robots that operate in harsher environments may use magnetic or inductive encoders for better reliability.

Factory Automation

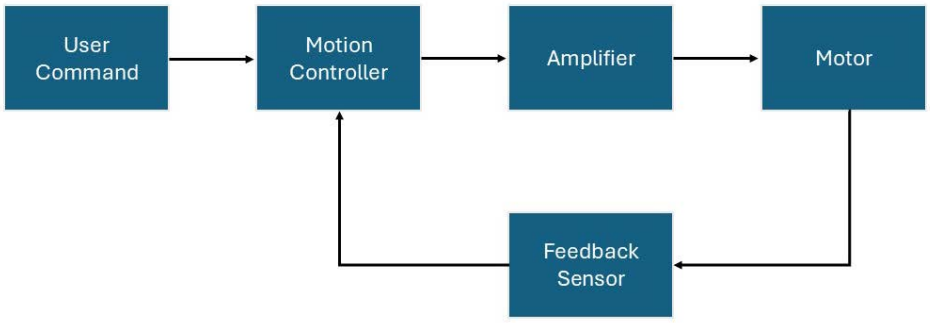
Factory automation includes a wide range of systems. In clean environments, optical encoders are used for their accuracy. In harsher environments such as motor control or conveyor systems, magnetic or inductive encoders are more common because they are more robust. This shows that even within the same category, different encoder technologies are used depending on the conditions.

Motion Control System Overview

In a typical motion control system, the encoder works together with the motor and controller: the motor creates movement, the encoder measures position, and the controller adjusts the motor based on the feedback.

This feedback loop is what allows the system to maintain accurate and stable motion. Because of this, the performance of the encoder directly affects the overall system performance.

Figure 1: Motion Control System Feedback Loop



Role of Broadcom MCPD Encoder Solutions

Broadcom is a leading supplier of motion control optical and magnetic encoders including incremental and absolute encoders for motion feedback and positioning systems.

These incremental encoders and absolute encoders meet the stringent requirements of precise positioning and velocity sensing in a wide range of applications including industrial machines, robotic arms, lifts, elevators, light detection and ranging (LiDAR) systems, automated guided vehicle (AGV) systems, solar panel tracking, medical devices, factory automation, and semiconductor equipment.

Broadcom is the main supplier of absolute encoders based on the proprietary energy-harvesting multi-turn counter. The state-of-the-art solution has supported the digitization of industrial machineries worldwide, though the integration into servo motors from major OEM makers.

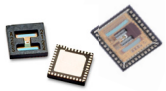
What Broadcom MCPD Offers

To help users select the right encoder based on applications needs, a comparison of key solutions is shown below.

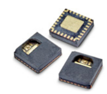
Start by identifying what your system needs in terms of positioning, environment, and cost. Broadcom MCPD solutions can be grouped into three main categories:

- Absolute encoders: Best when position must be known immediately at power-up. Suitable for servo motors and systems where homing is not possible or not desired.
- Incremental reflective encoders: A good fit for compact and cost-sensitive designs. Common in robotics, factory automation, and smaller motor systems where relative position tracking is sufficient.
- Absolute magnetic encoder ICs: Designed for harsh environments with dust, oil, or vibration. Suitable for industrial systems, AGVs, and applications where optical solutions may not be reliable.

Absolute Encoder Quick Selection Guide

Parameter	AR18	AR25/AR25DP	AR55	QS35	AR49	AS20-M42M	AS33-M42M	AS38-H39E
Product Image								
Type	Optical reflective	Optical reflective	Optical reflective	Optical transmissive	Optical reflective	Magnetic	Magnetic	Optical transmissive
Operating Voltage	3.3V and 5V	3.3V and 5V	3.3V and 5V	5V	5V	5V	5V or 7 to 12V	5V
Operating Temperature	–40°C to 115°C	–40°C to 125°C	–40°C to 125°C	–40°C to 105°C/ 115°C	–40°C to 115°C	–40°C to 115°C	–40°C to 115°C	–20°C to 105°C
Package Size in mm (W × L × H) or (OD × H)	9.1 × 10.9 × 1.5	6 × 6 × 1.05 6 × 6 × 0.7 (DP)	6 × 6 × 0.7	35 × 21	35 × 17.5	20 × 22.5	33 × 20	38 × 40
Applications	■ Robotic automation ■ Factory automation and drones ■ Medical devices ■ Miniature motors, servo motors, linear actuators	■ Robotic automation ■ Factory automation and drones ■ Medical devices ■ Miniature motors, servo motors, and linear actuators ■ Through-shaft motors, gear motors, and speed reducers	■ Housed encoder makers ■ Linear motor applications ■ Robotics automation Hollow-shaft servo motors ■ Factory automation ■ Medical devices	■ Servo motors ■ SCARA or multi-axis robots ■ Factory automation ■ Linear positioning systems ■ CNC machine tools ■ Medical devices	■ AC/DC servo motor feedback ■ SCARA or multi-axis robots ■ Medical devices ■ Robotics ■ CNC machine tools ■ Factory automation	■ Miniature servo motors and drives ■ Linear actuators ■ Medical devices ■ Robotics ■ Automated guided vehicles (AGVs) ■ Factory automation	■ Small motors and linear actuators ■ Robotics automation ■ Drones and automated guided vehicles (AGVs) ■ DC and AC servo motors	■ Robotics ■ Factory automation ■ Linear positioning systems ■ CNC machine tools ■ Medical devices

Incremental Reflective Encoders Quick Selection Guide

Parameter	AEDR-9820/9820A	AEDR-9830/9830A/9830DP	AEDR-9920	AEDR-9930E/9930E2/ 9930E2L/9930EA	AEDR-9940/9940ER/9940A
Product Image					
Type	Optical reflective				
Operating Voltage	3.3V or 5V				
Operating Temperature	–40°C to 115°C –40°C to 125°C (AEDR-9820A)	–40°C to 115°C –40°C to 125°C (AEDR-9830A)	–40°C to 115°C	–40°C to 115°C –40°C to 125°C (AEDR-9930EA)	–40°C to 115°C –40°C to 125°C (AEDR-9940A)
Package Size in mm (W × L × H) or (OD × H)	4 × 4			5 × 5	4 × 4
Applications	■ Closed-loop stepper motors ■ Small motors ■ Industrial printers ■ Robotics ■ Card readers ■ Pan-tilt-zoom cameras ■ Portable medical equipment ■ Optometric equipment ■ Linear stages	■ Closed-loop stepper motors ■ Small motors ■ Industrial printers ■ Robotics ■ Card readers ■ Pan-tilt-zoom cameras ■ Portable medical equipment ■ Optometric equipment ■ Linear stages	■ Closed-loop stepper motors ■ Small motors ■ Industrial printers ■ Robotics ■ Card readers ■ Pan-tilt-zoom cameras ■ Portable medical equipment ■ Optometric equipment ■ Linear stages ■ LiDAR	■ Closed-loop stepper motors ■ Small motor ■ Industrial printers ■ Robotics ■ Card readers ■ Pan-tilt-zoom cameras ■ Portable medical equipment ■ Optometric equipment ■ Linear stages ■ LiDAR	■ Closed-loop stepper motors ■ Small motors ■ Industrial printers ■ Robotics ■ Card readers ■ Pan-tilt-zoom cameras ■ Portable medical equipment ■ Optometric equipment ■ Linear stages ■ LiDAR

Absolute Magnetic IC Quick Selection Guide

Parameter	AEAT-9988M	AEAT-9966	AEAT-9955	AEAT-9922/9933
Product Image				
Type	Magnetic absolute			
Operating Voltage	3.0V to 5.5V			
Operating Temperature	–40°C to 125°C			
Package Size in mm (W × L × H) or (OD × H)	4.2 × 5	5 × 5	5 × 5	4 × 4
Applications	■ Industrial automation ■ Hollow-shaft servo motors ■ SCARA or multi-axis robots	■ Brushless DC motors and stepper motors ■ Resolver and potentiometer replacement ■ Industrial automation and robotics ■ Industrial sewing machines and textile equipment ■ LiDAR	■ Brushless DC motors and stepper motors ■ Resolver and potentiometer replacement ■ Industrial automation and robotics ■ Industrial sewing machines and textile equipment ■ LiDAR	■ Brushless DC motors and stepper motors ■ Resolver and potentiometer replacement ■ Industrial automation and robotics ■ Industrial sewing machines and textile equipment

Conclusion

Selecting the right encoder requires understanding the trade-offs between different technologies. There is no single solution that fits all applications.

Engineers must consider resolution, environment, mechanical design, and cost when making a decision. Different applications will prioritize different factors, which leads to different encoder choices.

By understanding these trade-offs and using the right technology for the right application, engineers can design motion control systems that are both accurate and reliable.

Broadcom MCPD provides encoder solutions that support key application needs, helping engineers implement effective motion sensing in a wide range of systems.

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