White Paper

# Magnetic Encoders

## Built for Your Application: Customizable Magnetic Encoder Options


## Abstract

Magnetic encoders, which are used for precise positioning and speed measurement, often face challenges from signal errors and noise. These challenges can be addressed through methods like autocalibration, noise reduction, and harmonic suppression, ultimately improving their accuracy.

In closed-loop motion control systems using magnetic encoders, latency refers to the delay between the encoder's feedback and the controller's response. This latency is crucial to ensure stable operation, especially at high speeds.

The Broadcom® AEAT-9955 magnetic encoder includes custom configuration options that allow the encoder behavior to be adjusted to suit a variety of applications.


## Introduction

As industries strive for higher output frequencies and cost-effective solutions, encoder technology must evolve to meet these challenges. The Broadcom AEAT-9955 series of high-performance magnetic encoders includes innovative solutions designed to meet these challenges.

This series features high-accuracy magnetic encoders with a state-of-the-art multi-axis Hall sensing. These encoders are suitable for shaft-end, side-shaft, axial, and radial applications.

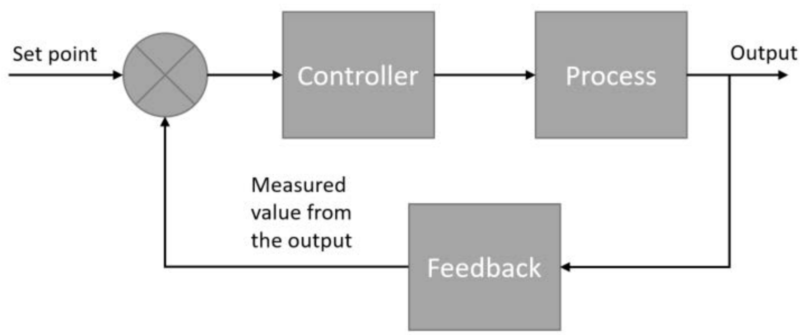
The AEAT-9955 series is automotive-grade compliant to Grade 0 AEC-Q100 automotive reliability standards, operating up to 125°C. With automatic calibration, the AEAT-9955 series delivers high-accuracy outputs after a quick and simple setup process.

## Applications

- Robotics
- Brushless DC motors and stepper motors
- Industrial automation
- Industrial sewing machines and textile equipment
- Light detection and ranging (LiDAR)

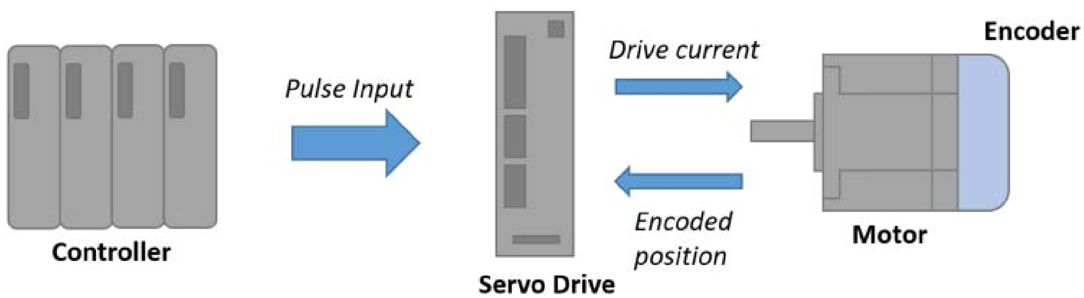
# Encoder in a Closed-Loop System

In closed-loop control systems, encoder feedback is essential for maintaining precise control over motion, position, or 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. This feedback enables dynamic adjustments that help meet desired performance goals.




A closed-loop system is formed by three components: controller, process, and feedback:

- **Controller** regulates the system output by comparing the actual output with the desired output, in order to adjust the system accordingly to minimize errors.
- **Process** is a component in a machine or system that converts energy (electrical, pneumatic, or hydraulic) into mechanical motion or force.
- **Feedback** is typically a feedback device that measures the system output and converts it to a numeric value, such as position count.
  - Tracking error = set point – measured output value



# Key Criteria for Effective Encoder Feedback

Encoders provide continuous updates on position, velocity, or rotation to the controller, allowing for real-time comparisons with the reference input. The controller uses this information to generate corrective actions, minimizing errors and improving the system's stability and accuracy. Common applications include robotics, CNC machinery, and servo motors.

**Accuracy** is the degree to which the encoder's signal represents the true position or speed.

High accuracy ensures that the system can maintain precise control over motion or positioning. In applications such as robotics or manufacturing, even slight inaccuracies can lead to defective products or operational errors.

Several factors influence accuracy:

- Encoder resolution (counts per revolution)
- Mechanical alignment
- Signal noise and interpolation errors

**Latency** is the delay between the actual movement and when the encoder feedback is processed by the control system.

When an encoder has latency, it becomes harder to accurately track the position of a moving object in real time. This is because the system is essentially working with outdated position information, which can lead to errors in control loops and other applications. This can result in jitter, overshoot, or even instability in the system.

Low latency is crucial for high-speed applications where real-time response is required.

High latency can lead to control loop instability or sluggish system behavior.

Causes of latency include the following:

- Signal processing time
- Communication delays
- Sampling rate of the control system

# What Causes Latency?

Latency in a magnetic encoder refers to the delay between the actual physical position of the motor shaft and the time the encoder reports this position to the control system. This delay can arise from multiple sources:

- Signal processing time within the encoder
- Communication delays (SPI, $I^2C$, or other digital protocols)
- Filtering algorithms when the encoder uses internal smoothing or averaging techniques to reduce noise

During motor acceleration, position and velocity change rapidly. In this scenario, any latency introduces a mismatch between the actual shaft position and the measured position reported to the controller. This can cause several issues:

- **Speed estimation errors:** Most controllers derive speed by differentiating position feedback. Latency causes outdated position readings, leading to underestimation or overestimation of speed which is especially noticeable during sharp changes in acceleration or deceleration.
- **Phase lag in control loops:** The delay introduces phase lag in the feedback loop, which reduces the phase margin. This degrades system stability and can lead to oscillations or overshoot, particularly in high-performance applications requiring tight control (servo motors, robotics).
- **Degraded torque control:** In vector control (FOC) systems, accurate rotor position is essential for properly aligning stator currents. Latency distorts this alignment, reducing torque efficiency and potentially increasing thermal stress on the motor.
- **Poor synchronization in multi-axis systems:** In coordinated motion control (CNC or robotic arms), synchronization between axes is critical. Latency-induced discrepancies between encoders can cause misalignment, reducing accuracy and introducing mechanical stress.

# Custom Configurations

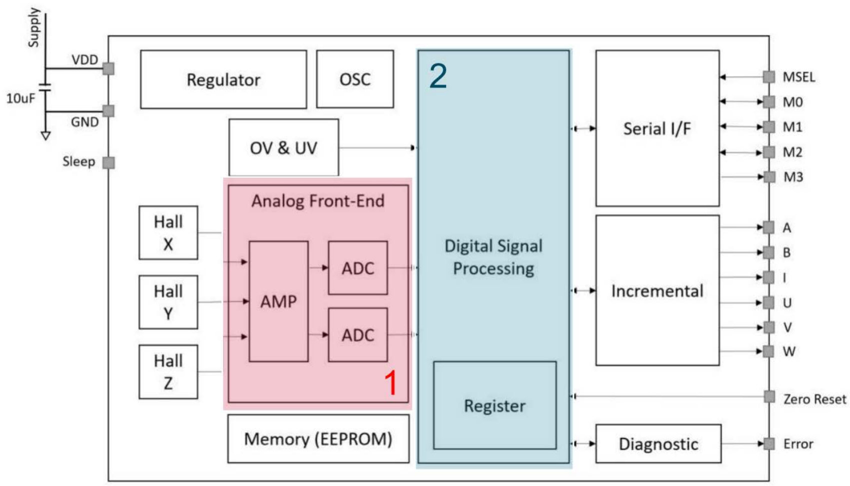
The AEAT-9955 uses integrated Hall sensor elements with complex analog and digital signal processing to produce high-resolution output with precision. A prediction algorithm is used to compensate for latency due to processing time. The algorithm calculates sensing velocity, resulting in zero latency.

*Constant velocity* is key for the prediction algorithm to accurately calculate this position. If the velocity is changing due to acceleration, then over-prediction or under-prediction will occur.

The AEAT-9955 features various configurations that allow end users to configure the chip for optimum performance based on specific requirements.

The AEAT-9955 filtering is divided into two sections:

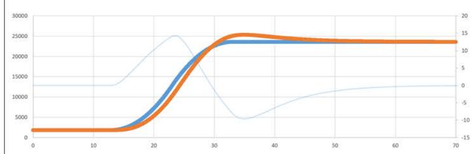
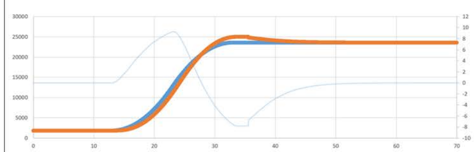
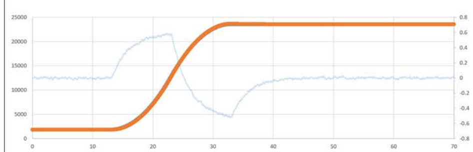
1. The analog low-pass filter stabilizes the angle signals from the Hall sensor.
2. The digital moving average samples and reduces the random noise.




| More Filtering | Less Filtering |
|---|---|
| Smoother signal | More noise visible |
| Higher latency (delay) | Faster response |
| Good for slow movements | Good for fast dynamics |

The digital filtering has more flexibility in the configuration and has a direct relation to the output performance. In the following example, different averaging settings translate into different time constants (T). The speed profile is set to accelerate and decelerate at the same rate across all cases.

- The higher time constant at 6.6 ms causes a huge latency during acceleration, hence the high accuracy error.
- The lower time constant at 1.3 ms matches the acceleration rate and has a much lower accuracy error.

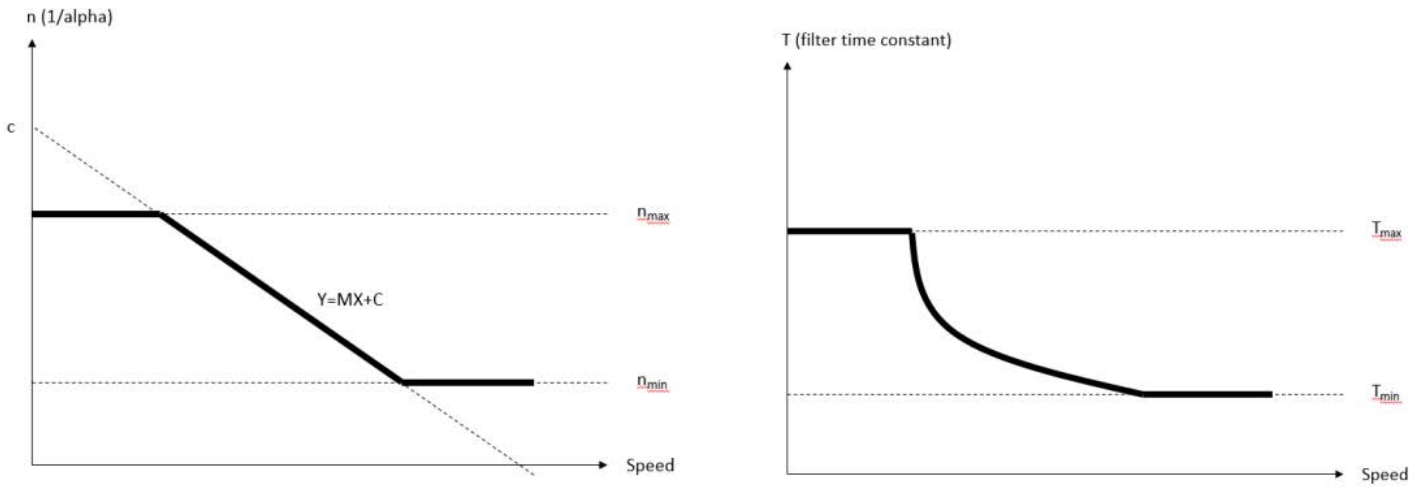
| Speed profile | Configuration | Accuracy Error | Response Curve |
|---|---|---|---|
| 0 -> 2000RPM -> 0<br><br>Acc: 200000RPM/s | Abs.Hys : 0.08°<br>Averaging : 8x<br>Time Constant 6.6ms | ±11.9° |  |
| 0 -> 2000RPM -> 0<br><br>Acc: 200000RPM/s | Abs.Hys : 0.08°<br>Averaging : 8x<br>Time Constant 3.3ms | ±8.55° |  |
| 0 -> 2000RPM -> 0<br><br>Acc: 200000RPM/s | Abs.Hys : Off<br>Averaging : 8x<br>Time Constant 1.3ms | ±0.55° |  |

The moving average can be split into two options:

1. A static filter, where a constant filter is applied regardless of the speed.
2. A dynamic filter, where a different filter is used at high speed and low speed.

   The dynamic filter applies a higher time constant (T) at lower speeds and a lower time constant at higher speeds. This filter is configurable at registers page 3/6/9/12, address 0x09 to 0x0A (Level 2a memory). Users can adjust the dynamic filter by setting four parameters to determine the value of *n*, where T is inversely proportional to n, as shown in the following figure.

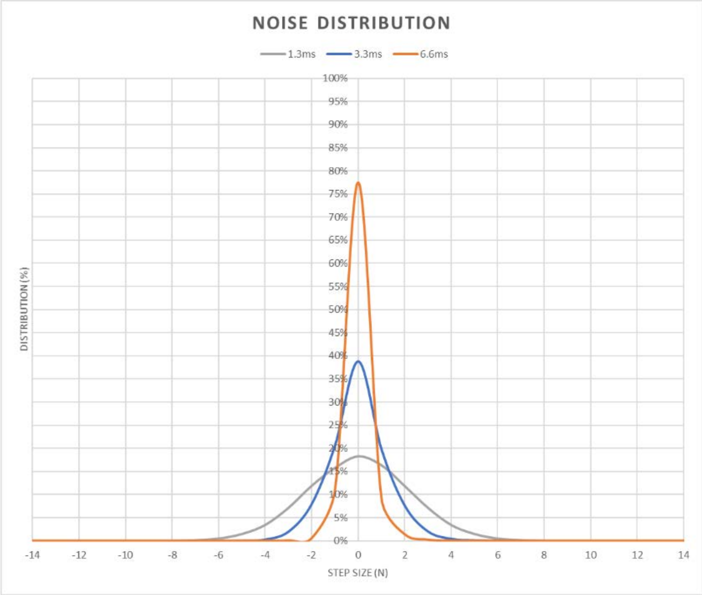
   - df_m1: Dynamic filter slope (M) of n
   - df_c: Dynamic filter Y-intercept of n
   - df_nmax: Dynamic filter maximum limit for n
   - df_nmin: Dynamic filter minimum limit for n




By default, the dynamic filter is enabled, with a maximum filter time constant ($T_{max}$) of 1.5 ms when the speed is <300 rpm and a minimum time constant ($T_{min}$) of 1.3 ms when the speed is >500 rpm.

The mitigation of latency affects the noise stability, which needs to be balanced in order to achieve optimum performance. The table below summarize the relation between the time constant (T) and the effective noise (ENOB).

| Averaging Filter | | Effective Resolution (ENOB) |
|---|---|---|
| **N Value** | **Time Constant (ms)** | |
| 0 | 1.3 to 1.5 (default) | 13.71 |
| 1 | 0.24 | 12.62 |
| 2 | 0.40 | 13.07 |
| 3 | 0.57 | 13.17 |
| 4 | 0.73 | 13.27 |
| 5 | 1.06 | 13.45 |
| 6 | 1.39 | 13.68 |
| 7 | 1.72 | 13.71 |
| 8 | 2.04 | 13.83 |
| 9 | 2.37 | 14.05 |
| 10 | 2.70 | 14.19 |
| 11 | 3.35 | 14.25 |
| 12 | 4.01 | 14.30 |
| 13 | 4.66 | 14.36 |
| 14 | 5.32 | 14.42 |
| 15 | 6.63 | 14.61 |




# Conclusion

Encoder latency is an often-overlooked but critical parameter in dynamic motor systems. During acceleration, its impact is magnified, potentially leading to instability, control inaccuracies, and degraded performance. Careful system design, encoder selection, and latency compensation strategies are essential to maintain control fidelity in high-performance applications.

The AEAT-9955 series represents a technological advancement in encoder design, offering flexibility over customer configuration and robust performance for both automotive and industrial applications. Broadcom continues to lead the way, delivering innovative solutions for precision motion control.

# Use the 5W 1H Principle to Determine Encoder Selection

**Who to choose:**

Broadcom is a global infrastructure technology leader built on 50 years of innovation, collaboration, and engineering excellence. With roots based in the rich technical heritage of AT&T/Bell Labs, Lucent, and Hewlett-Packard/Agilent, Broadcom focuses on technologies that connect the world. Through the combination of industry leaders LSI, Broadcom Corporation, Brocade, CA Technologies, VMware, and Symantec, the company has the size, scope, and engineering talent to lead the industry into the future.

**Why choose Broadcom:**

Broadcom is one of the leading global encoder makers and has an extensive portfolio of encoder-related intellectual property ranging from optical encoders to magnetic encoders.

**Where to find Broadcom encoder products:**

Access Broadcom encoder product details at: www.broadcom.com/products/motion-control-encoders/.

**What types of encoder to choose:**

- Optical absolute encoders
- Optical incremental encoders
- Optical absolute encoders with incremental output
- Magnetic absolute encoders with Incremental output

**When to choose:**

Choose encoders for new projects or the ongoing manufacture of products that require better performance, safety requirements, a consistent supply chain, and cost savings.

**How to choose:**

Know the design requirements and consult with a Broadcom sales representative for recommendations.

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