BROADCOM®

White Paper

Magnetic Encoders

Enabling Functional Safety with the AEAT-9955/9966: High-Precision Magnetic Encoders for Critical Systems

Abstract

A functional safety encoder is critical in motor applications. It ensures proper control of operations by providing reliable position and speed information for control and monitoring purposes. A fail-safe system prevents costly damage to both humans and property during system operation. In this document, we will briefly show how to use Broadcom® AEAT-9955 and AEAT-9966 magnetic encoders to design a functional safety system.

Introduction

The AEAT-9955 and AEAT-9966 are high-performance magnetic encoders designed to meet the stringent safety standards of functional safety systems (SIL3/ASIL-D in compliance with IEC 61508/ISO26262-8). This paper demonstrates how these devices can provide robust, redundant position sensing for automotive and industrial applications:

- The safety goal is to flag an error when it detects a sudden change in angle greater than 5.6 mechanical degrees.
- The encoder supports two independent output interfaces operating simultaneously.
- Diagnostic features include overvoltage and undervoltage detection, magnet strength monitoring, memory CRC error checks, track error (DSP processing error) detection, and encoder-ready indication.
- Diagnostic analysis is performed during startup and operation.

The AEAT-9955 is a single-turn (ST) encoder, which provides unique position feedback within a revolution. The AEAT-9966 is a dual-die version of the AEAT-9955 in a single package, which is a cost-effective option to achieve a functional safety system. Both devices feature multiple integrated Hall sensor architectures to provide high flexibility for system mounting using the following configurations: shaft-end/side-shaft/axial/radial. The AEAT-9955 and AEAT-9966 are automotive grade in compliance with IATF-16949 and qualified to Grade 1 AEC-Q100 automotive reliability up to 125ºC.

Applications

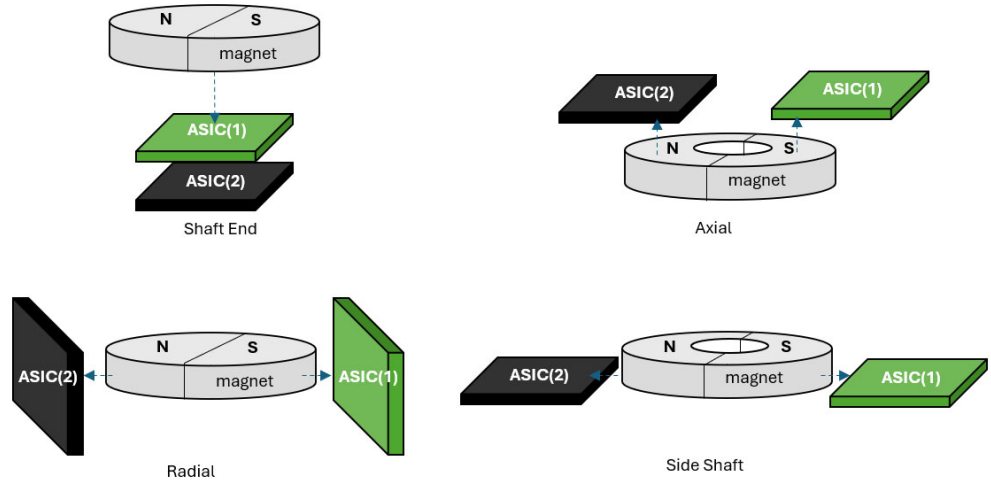
- Robotics
- Medical applications
- Brushless DC motors and stepper motors
- Resolver and potentiometer replacement
- Industrial automation
- Industrial sewing machines and textiles equipment
- Light detection and ranging (LiDAR)
- Vending machines
- Liquid level monitoring

Using the AEAT-9955/9966 for a Functional Safety Encoder System

The AEAT-9955 can be used for a functional safety encoder system by using two physically independent AEAT-9955 ASIC, channel 1 (CH1) and channel 2 (CH2), that generate ST positions independent of each other to achieve redundancy. Both devices are equipped with multiple Hall sensor architectures to allow high flexibility for the user to arrange the system at either the shaft end, axial, radial, or side shaft configurations as shown below.

If either of the CH1 or CH2 ASIC break, or if the data becomes erroneous, the other channel is still operational. Therefore, the failure or error can be detected. In the event that both CH1 and CH2 fail simultaneously, then the encoder becomes inoperable, leading to the loss of detectable safety function. As it is unlikely that both CH1 and CH2 would fail in the same manner and the ST position from them would be different, the simultaneous failure of both CH1 and CH2 can be detected by cross-checking ST positions between them to see if it is within the expected limit (5.6°).

Figure 1: AEAT-9955 Four-Mode Alignment with Built-In CH1/CH2 Redundancy



The AEAT-9966 (dual die) can be used for a functional safety encoder system is using two physically independent die, each equivalent to a single AEAT-9955 ASIC, to form CH1 and CH2, to achieve a similar safety level as described above.

Figure 2: AEAT-9966 (Dual Die) Four-Mode Alignment with Built-In CH1/CH2 Redundancy

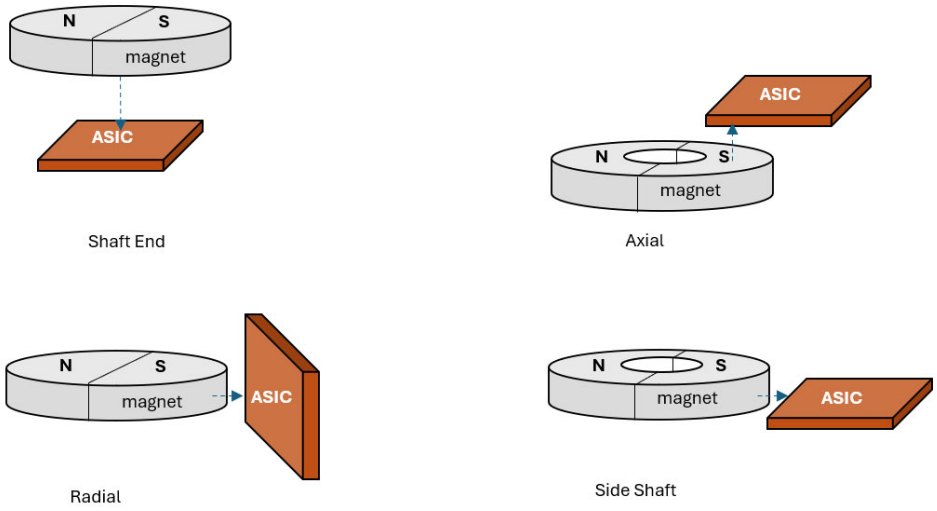
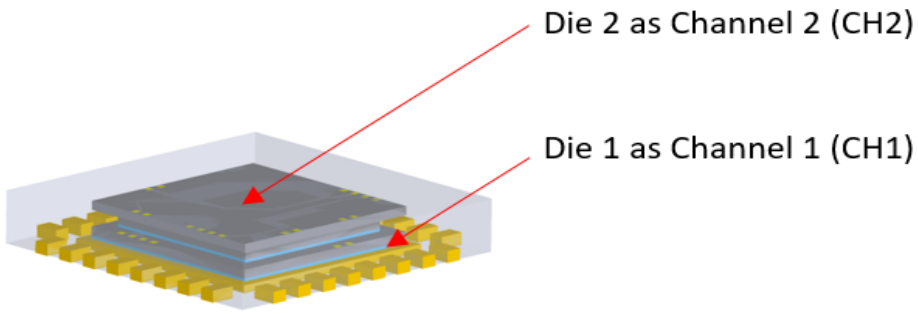


Figure 3: AEAT-9966 (Dual Die) Distribution of Two Separate Die within a Single Package as CH1 and CH2



The AEAT-9955 and AEAT-9966 generate safety data that is transmitted to the user via either SSI3, SSI2, or SPI4 protocols. The AEAT-9955 and AEAT-9966 send 32-bit to 50-bit data (depending on user configuration) over the protocol interface. The data content is as follows:

Table 1: Safety-Related Data (SSI3/SSI2/SPI4)

Field Name	Bit Length	Description
Position	8 to 18	Position is an 8-bit to 18-bit absolute position; the user can configure the bit length. The user may configure an individual channel with a different zero position to better differentiate between the two channels.
Status	2	This 2-bit status indicates encoder readiness and the pass/fail status of the force test.
MHI	1	The magnet strength is above the intended limit.
MLO	1	The magnet strength is below the intended limit.
OV	1	The voltage supply is above the intended limit.
UV	1	The voltage supply is below the intended limit
MEM	1	Internal memory configuration corruption (CRC error).
TRK	1	Digital processing tracking failure.
SC	8	The 8-bit SC (sequence count, or life counter) automatically increments with every position transmission. The counting starts from 1 to 255. Users may configure individual channel with different initial SC numbers to better differentiate between two channels.
CRC	8 or 16	Relevant safety data is protected by CRC checksum, which is generated over the position, status, and SC fields. ORION3 allows users to choose an 8-bit CRC (SAE-J8150, polynomial 0x1D) or a 16-bit CRC (CCITT-False, polynomial 0x1021) per AUTOSAR recommendation. The initial CRC value is configurable (0x0000, 5555, AAAA, FFFF). The user may configure individual channels with different initial CRC numbers to further differentiate the CRC calculation of individual channels.

As the user acquires the safety-related data from the AEAT-9955/9966, the user must ensure the following:

1. Crosscheck position data from both channels to make sure that the delta between them is within the expected limit (5.6°).
2. Check each channel status field to make sure that the following are true:
   a. The encoder is ready and has passed the forced test.
   b. No alarm is flagged.
3. Ensure that each channel's first SC upon power-up is as expected.
4. Crosscheck the SC from both channels to make sure that the delta between them matches the expected delta.
5. Ensure that each channel's transmitted CRC is correct.

In addition to safety features, the AEAT-9955/9966 also provide the following features:

- ABI (incremental) output with safe state, programmable resolution (1 to 20,000 CPR), index width/state/count.
- UVW output with safe state and programmable resolution (1 to 32 pole pairs).
- PWM output with error flag and programmable resolution (10 bit to 14 bit).
- Absolute output over 2-wire SSI, 3-wire SSI and 4-wire SPI with programmable resolution (10 bit to 18 bit).
- Dedicated serial and incremental pads to provide absolute output with 6-channel incremental signals (ABI and UVW) at the same time.
- Dedicated zero reset and error pin.
- EEPROM architecture for multi-time user configuration, with an optional memory lock function (user-defined passcode).
- Automatic integral non-linearity angle correction for high accuracy.

NOTE: The AEAT-9955/9966 are designed to be safety compliant, but this does not represent certification of a safety-related encoder system. For certification of a safety-related encoder system, contact Broadcom for further information.

Using 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 our world. Through the combination of industry leaders Broadcom, 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.

Conclusion

The AEAT-9955 and AEAT-9966 are built to meet the stringent safety standards of functional safety systems (SIL3/ASIL-D in compliance with IEC 61508 / ISO26262-8), they allow ease of integration, and they are priced competitively for users implementing a fail-safe system.

Product Summary

Parameter	AEAT-9922	AEAT-9933	AEAT-9955	AEAT-9966	AEAT-9988M
Product Image					
Voltage	3.3V to 5V (±10%)				4.5V to 5V (±10%)
Magnet Track Type	Single Track				Dual Track
Package Size	4 mm × 4 mm		5 mm × 5 mm		8.2 mm × 5 mm
Automotive Ready[a]	X		√		X
Temperature Rating	–40°C to 125°C				
ABI Output	√				
UVW Output	√				
ABI Differential Output	X				√
UVW Differential Output	X				√
PWM Output	√				
RS485 Protocol	X				√
BiSSC Protocol	X				√
SSI2 Protocol	√				
SSI3 Protocol	√				
SPI3 Protocol	√				
SPI4 Protocol	X				√
Standby Mode	X		√		
Resolution (Selectable)	10b to 18b	10b to 14b	10b to 18b		16b to 23b
Accuracy	±0.10				±0.015
Latency (Typical)	80 ns				
Spatial Tolerance	±250 µm				
Calibration Required	√				
Maximum Digital Output (AB) Interpolation (Selectable)	1 to 10,000	1 to 1024	1 to 20,000		1 to 65,536
Maximum Digital Output (UVW) Pole-Pair (Selectable)	1 to 32				
Status Pin	X		√		

a. Manufacturing/Quality Management System compliant to automotive IATF-16949. AEAT-9955, AEAT-9966 (production status) qualified to Grade 1 AEC-Q100 automotive reliability 125°C.

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