

**FOR LINEAR MOTION SYSTEM DESIGNERS**  
When to Consider an Integrated Linear Encoder

## Introduction

Precision in motion systems isn't a given – it has to be diligently engineered into every aspect of the design, from component selection to final assembly and verification. Even the most precise linear guides, ball screws, pulleys, and drive components contain inherent manufacturing tolerances. Add in the compliance that exists between mating parts – even in the stiffest drivetrains – and these cumulative effects ultimately limit the system's ability to accurately position the load. This is why real-time position feedback from an encoder is a key component of high-precision motion systems.

For decades, this feedback came from a rotary encoder mounted on or integrated into the motor. Even linear motion systems relied on the motor's rotational position to extrapolate the linear position of the load. But measuring position at the motor, rather than at the load, means all the tolerance stack-ups and compliance in the system are completely missed. The theoretical, or target, linear position might be meaningfully different from the actual linear position, making it impossible to determine the load's true position and compensate for errors that occur "downstream" of the motor.

As positioning accuracy requirements have increased – especially in semiconductor, medical, and machining applications – relying on a rotary encoder for linear positioning is no longer sufficient. This is why end users and OEMs have begun incorporating linear encoders into their high-precision motion systems. Position feedback from the linear encoder works together with feedback from the rotary encoder, improving the system's ability to track the actual position of the load and send corrective commands to adjust control loop parameters.

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## Encoder Technology Basics

High-resolution encoders are typically categorized by their measuring technology – magnetic, inductive, or optical. The choice often depends on the system’s required accuracy, resolution, and environmental considerations. Here, we give a brief overview of the three encoder measuring technologies, along with their key strengths and weaknesses:

Magnetic	Inductive	Optical
<p>Magnetic encoders use a magnetically coded scale in conjunction with a read head containing a sensing element. As the read head travels over the scale, it detects the magnetic poles on the scale. Once seen as less precise than optical versions, magnetic linear encoders are now available with resolutions down to 1 micron, making them suitable for a wide variety of applications.</p> <p>Mounting a magnetic encoder is relatively easy (particularly when compared with optical encoders), though it does require time and skill to mount the scale and align the read head. Magnetic encoders can withstand harsh environments and liquid contamination, but magnetic particles can interfere with their performance. Temperature fluctuations can also be problematic, as thermal expansion of the scale can degrade accuracy. In general, magnetic encoders are lower-cost solutions for general motion applications.</p>	<p>Inductive encoders use a scale with ferromagnetic gratings and a read head containing a transmitter coil (which generates a magnetic field) and receiver coils. As the read head passes over the scale, the gratings cause the voltages induced in the receiver coils to vary. These changing voltages indicate the sensor’s position.</p> <p>Inductive encoders can achieve high resolution, typically falling between magnetic and optical technologies. However, they can be significantly more expensive than magnetic encoders, with prices closer to optical encoders. A particular strength of inductive encoders is that they’re insensitive to dirt, dust, liquids, EMI, and vibration.</p> <p>This makes them a good solution for applications that have challenging environments but don’t need the accuracy and resolution of optical technologies.</p>	<p>Optical encoders consist of a glass or steel scale marked with periodic graduations, in conjunction with a read head containing a photodetector. Using either the reflection or diffraction of light and the fine-pitch graduations on the scale, optical encoders can achieve sub-micron resolution. However, their reliance on light makes them sensitive to contamination, so optical scales are often contained in a protective housing.</p> <p>Mounting precision is critical for optical encoders since the gap between the scale and the photodetector needs to be maintained at a very small distance – typically 0.5 mm or less.</p> <p>But this compactness, together with their unrivaled high-resolution capabilities, makes optical encoders the primary choice for high-precision applications.</p>

## The Problem with Traditional Linear Encoders

Linear encoders have become essential for meeting the high-accuracy requirements of motion systems in a wide range of industries, but the additional precision often comes at a cost. First, there's the up-front cost of the components, plus the cost of managing an additional vendor, and the costs associated with stocking, shipping, and handling the various components.

There are also costs directly related to the assembly process, which includes preparing the surface, mounting the encoder scale and read head, aligning the components,

and integrating them into the control system. This typically involves several hours of assembly time per encoder and requires technicians with the skills and expertise to properly install, set up, verify, and troubleshoot the system.

The assembly process also increases the risk of performance issues. Mounting errors, incorrect alignment, and Abbé errors (errors that arise due to the distance between the encoder read head and the actual position being measured), can all affect the precision – and even the basic operability – of the encoder.

The primary limitation of traditional linear encoders is the space they require. Mounting a steel tape or glass scale alongside the guide rail increases the system footprint, which many high-precision applications cannot accommodate. In practice, this often leads to complex workaround solutions involving additional components or brackets, which not only increase system complexity, but can also negatively affect measurement accuracy and stability. Add in the size of a separate read head mounted on the bearing carriage, and the entire system becomes much larger and more complex.

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## Integrated Linear Encoders Eliminate Errors and Reduce Risks

Some machine builders and users have considered these costs and larger footprint requirements to be unavoidable for applications that require a linear encoder.

Others underestimate the assembly time, complexity, and potential performance issues that come with mounting and integrating a linear encoder into a motion system.

Linear guide manufacturers have watched their customers struggle with the mounting, footprint, integration, and troubleshooting issues that linear encoders introduce.

Over the years, various encoder integration concepts have been developed to help reduce these challenges. SCHNEEBERGER has taken the integration concept a step further, with a truly integrated system that doesn't increase the size (length, width, height) of the linear guide or carriage.

Solutions like the MINISCALE PLUS and MINISAM from SCHNEEBERGER are truly plug-and-play systems, requiring no additional mounting, setup, or troubleshooting steps. This integrated approach results in a lower total cost of ownership (TCO)

for the linear guide and measuring system and assembly.

Integrating the linear encoder into the linear guide and carriage also eliminates the direct costs associated with stocking, shipping, and managing additional part numbers.

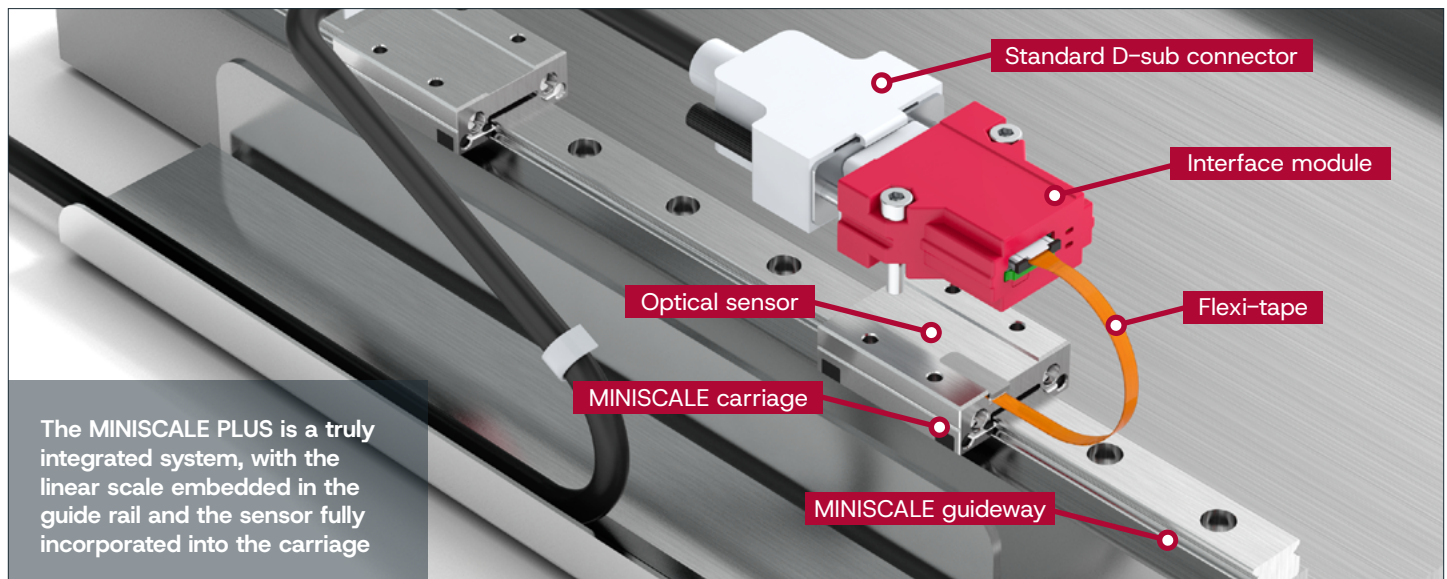
And capturing position directly at the point of motion improves system accuracy and simplifies the system's design, with fewer components and a smaller footprint than the traditional measuring system using an external linear encoder.

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## Compact, Precise, Integrated: MINISCALE PLUS

The MINISCALE PLUS is a precision miniature linear guide with an integrated optical measuring system, developed as a cost-effective and less error-prone solution to the challenges of integrating a linear scale into a motion system.

The MINISCALE PLUS system is based on SCHNEEBERGER's high-precision MINIRAIL guideway. The measuring system consists of a laser-etched incremental scale with reference marks, which is embedded into the guide rail. The scale has the same coefficient of thermal expansion as the rail, eliminating errors caused by different thermal behaviors of the scale and the guide rail. The sensor – which contains two LED light sources, optics, and a sensor chip – is integrated into the MINIRAIL carriage, flush with its top surface.

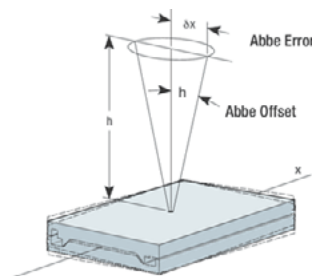


What makes the MINISCALE PLUS unique is that it's truly integrated, not a "bolt-on" design. Despite incorporating a linear encoder, the system's dimensions are identical to the MINIRAIL alone. In other words, the addition of the linear scale and sensor doesn't add height, width, or length to the guide rail or carriage. This means an existing MINIRAIL can be replaced with a MINISCALE PLUS system – both rail and linear encoder – with no additional space requirements or mounting changes.

This compact design provides a high-performance measuring system with an accuracy of  $\pm 5 \mu\text{m}$  per 1000 mm and a resolution of  $0.1 \mu\text{m}$ . And because the sensor is integrated into the carriage, Abbé errors are significantly reduced.

Abbé error is the amplification of an angular error due to the offset between the measuring point and the source of the error.

By integrating the linear encoder sensor into the carriage, the MINISCALE PLUS places the measuring point at or very near the point of interest (the load or workpiece), meaning there is little or no offset between the two, so Abbé error is kept to a minimum.

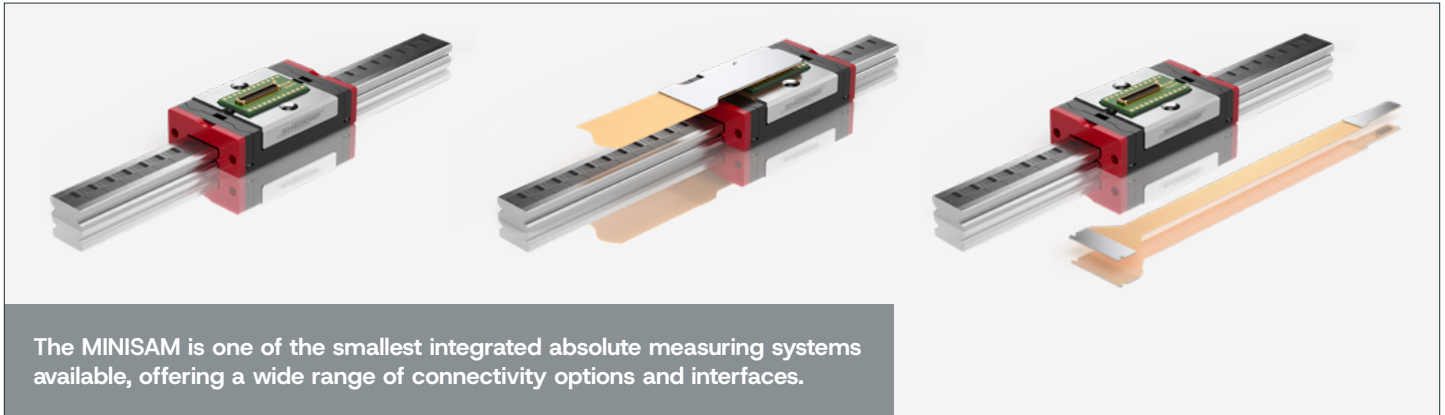


For connection to the customer's electronics, the sensor is supplied with a flat printed circuit board (FPCB) with a ground layer for improved EMC resistance. The FPCB terminates with a zero insertion force (ZIF) connector. For applications that prevent placing the interface at the sensor, a flexible flat cable (FFC) with an adapter board can be provided for up to 600mm of extension. Outputs for the MINISCALE PLUS include analog (1 Vpp) and digital (TTL).

## MINISAM: Absolute Positioning in the Smallest Space Possible

Building on the principles and success of the MINISCALE PLUS, the MINISAM is one of the smallest integrated absolute measuring systems in the market, available on MINIRAIL systems down to size 5.

The MINISAM system uses an optical measuring principle, reading an interference pattern from the scale, which is laser-etched directly onto the guide rail. In the case of the MINISAM, the state-of-the-art electronics are integrated into the sensor itself, so no additional signal converter or interface is required.



The MINISAM is one of the smallest integrated absolute measuring systems available, offering a wide range of connectivity options and interfaces.

With absolute position accuracy better than  $2\ \mu\text{m}$  (3-sigma) and linear resolution of  $0.1\ \mu\text{m}$ , the MINISAM also maintains position information even if the system is powered off or inadvertently loses power – no battery needed. The system supports multiple interfaces simultaneously, including BiSS/SSI (single ended), ABZ, UVW, SPI, analog Sin/Cos, and BiSS-c (differential).

The sensor is provided with a miniature connector (inspired by smartphone designs) or with a customer-specific flexible printed circuit (also referred to as the “flexprint”) and a cable designed to withstand dynamic motions. SCHNEEBERGER can also provide the necessary specifications for the flexprint, allowing customers to design and optimize it on their own.

Like the MINISCALE PLUS, the MINISAM does all this without increasing the dimensions (height, width, or length) of the carriage or the guide rail, providing the optimum solution for absolute measuring for space-constrained applications.

## Integrated Measuring for Long Stroke Applications

Although high precision is often associated with applications involving small payloads and short stroke lengths, many longer-stroke, high-load applications, such as machine tools, also require very accurate, repeatable positioning.

When the application calls for a standard (size 15 and above) MONORAIL guide, the AMS integrated measuring system provides a solution based on magnetic sensing that can withstand harsh environments, including contamination and debris build-up directly on the scale. The read head is rated IP68 for ingress protection, and the AMS is one of the only integrated encoder systems that can be used on joined guide rails, providing integrated guiding and measuring for virtually unlimited travel lengths.

### Real-world Applications

The range of applications that benefit from high accuracy linear encoder feedback in the smallest possible footprint is extensive. The extremely compact, integrated form factor of the MINISCALE PLUS and MINISAM makes these systems well-suited for medical device applications, semiconductor manufacturing and testing equipment, and micro-actuators and micro-stages. And the absolute positioning feedback of the MINISAM makes it ideal for delicate or critical applications such as metrology equipment and surgical robots, where a loss of position information could cause physical harm or misdiagnosis.

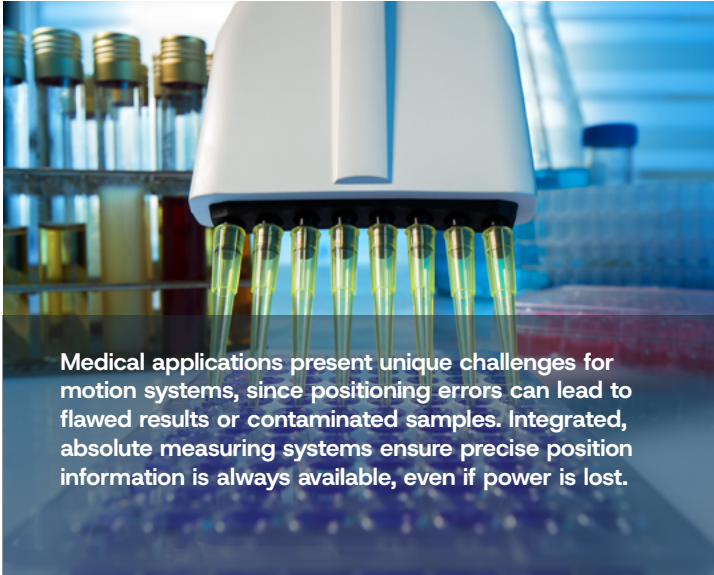
Take, for example, a dental scanner. The scanner is placed inside a patient's mouth – a small and difficult space to maneuver – to capture images of the patient's teeth. Inside the dental scanner, a MINISCALE PLUS system moves a lens at high frequency, allowing the scanner to take an image every 0.2  $\mu\text{m}$ . Given its use inside a patient's mouth, the carriage of the MINIRAIL is lubricated with a special grease, and the assembly is designed to operate in this high-speed, confined, and sensitive environment for five years of life with no required maintenance. In this application, using a separate linear encoder simply wasn't feasible – an integrated design was needed to meet both space and performance requirements.



In a dental scanner application, the MINISCALE PLUS provides high-precision motion in the smallest possible form factor.

Absolute positioning feedback, as provided with the MINISAM, is a necessity when loss of position information can cause damage, scrap, or even safety issues. Take, for example, IVD analyzers used for blood sample processing. With shrinking microplate geometries and increasing throughput demands, precise positioning of the dispensing head is essential. Even minor deviations can lead to testing errors or contamination of valuable samples and reagents. MINISAM addresses these challenges by providing absolute positioning feedback in an ultra-compact integrated design that does not increase system footprint.

Similarly, metrology systems for semiconductor manufacturing require sub-micron positioning but are designed to be easily and quickly serviced for minimal downtime. MINISAM delivers the sub-micron resolution required to measure extremely small wafer and chip features. Its dimensionally compatible design enables direct 1:1 replacement of conventional linear guides without requiring mechanical modifications or changes to the system design.



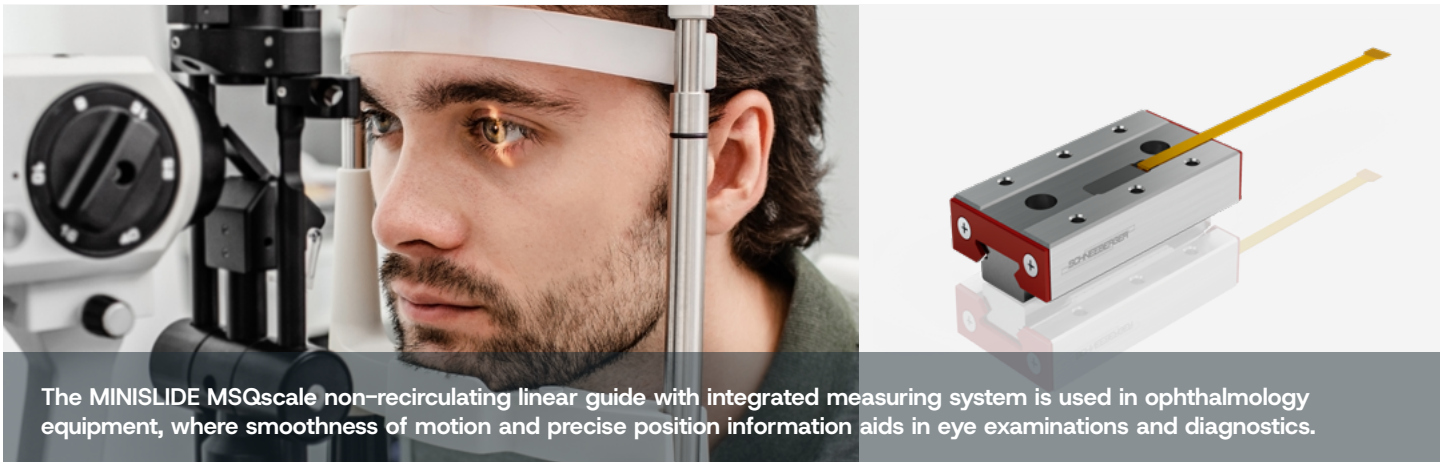
Medical applications present unique challenges for motion systems, since positioning errors can lead to flawed results or contaminated samples. Integrated, absolute measuring systems ensure precise position information is always available, even if power is lost.



Metrology systems not only require sub-micron positioning accuracy, but when used in high-throughput industries such as semiconductor manufacturing, ease of service is also critical. Integrated linear encoders are the ideal solution, with interchangeable parts and simple plug-and-play interfaces.

## Integrated Measuring for Non-recirculating Linear Bearings

Precision applications that require not only high positioning accuracy, but also very smooth motion during travel often use non-recirculating bearings to avoid the pulsations that occur when recirculating balls enter and exit the load zone. These non-recirculating linear ball bearings – often referred to as slides – provide extremely smooth motion for stroke lengths up to approximately 100 mm.



The MINISLIDE MSQscale non-recirculating linear guide with integrated measuring system is used in ophthalmology equipment, where smoothness of motion and precise position information aids in eye examinations and diagnostics.

As accuracy requirements increase and available space decreases, integrated linear measuring systems move from being a convenience to being a necessity.

In addition, the time, complexity, and risk associated with mounting and aligning separate encoder components can significantly affect both cost and performance reliability. Integrated linear encoder solutions address these problems by eliminating potential assembly errors, reducing start-up time, and improving positioning accuracy through reduced Abbé error.

To learn more about our integrated measuring systems from SCHNEEBERGER, [visit our website](#).

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## About SCHNEEBERGER

Founded in 1923 as a precision mechanical workshop, SCHNEEBERGER began producing linear guides more than 70 years ago. In 1984, the Systems Business Unit was founded for the production of customized, multi-axis motion systems, and in 1992, SCHNEEBERGER introduced the first integrated measuring system for roller bearing linear guides. With plants now located in Switzerland, the U.S., and China, industries served range from machine tools to medical devices to semiconductor manufacturing.

From initial consultation to full production, SCHNEEBERGER focuses on delivering solutions that combine technological leadership with operational excellence, ensuring that our systems perform at the highest level while remaining cost-effective. This approach has solidified SCHNEEBERGER's position in the high-end application market, where precision, performance, and reliability are paramount.

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