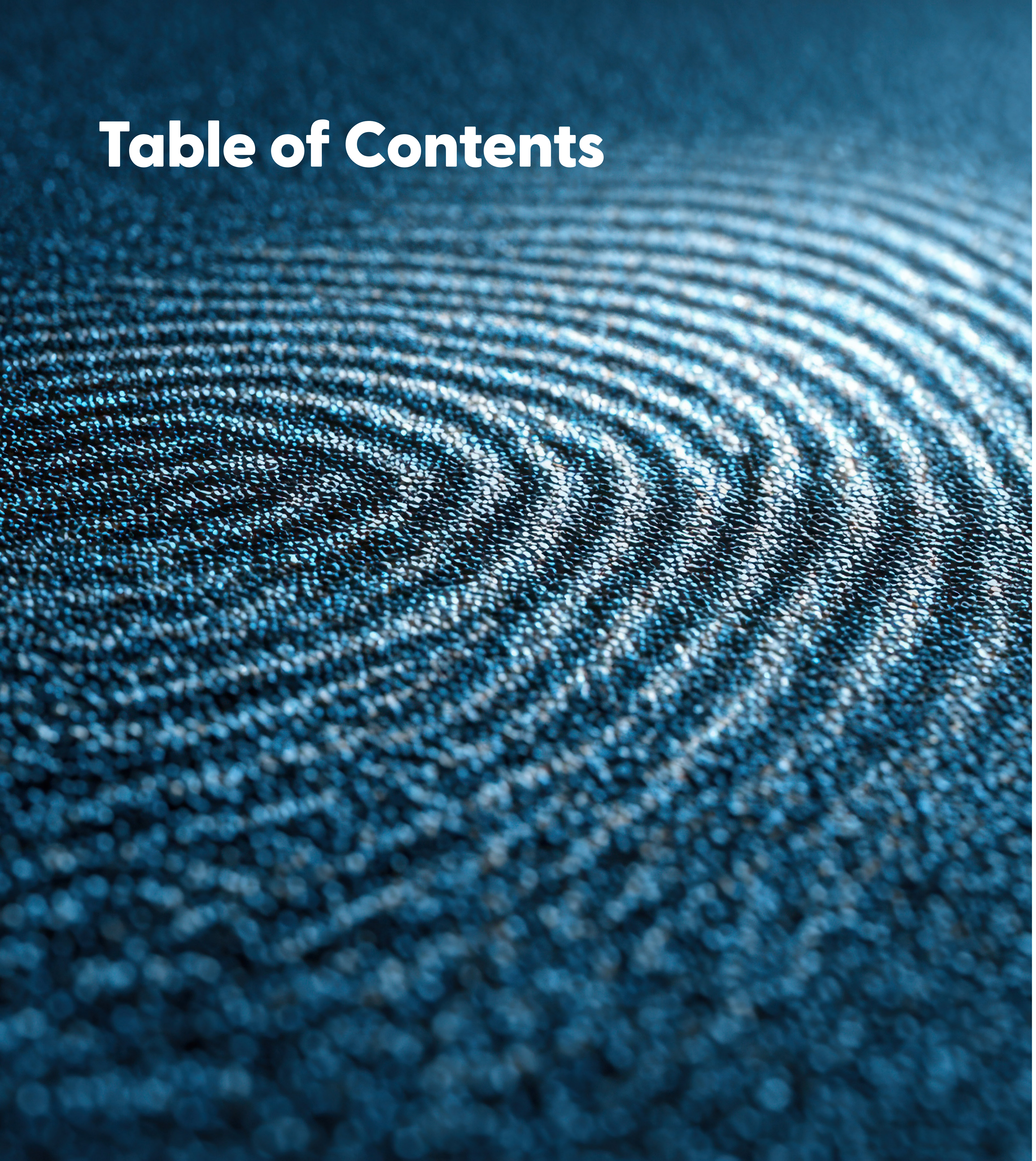
Engineering Reliable Industrial Automation With Sensor Fusion

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

MOUSER ELECTRONICS

Table of Contents



Introduction

When a critical 400 kW air compressor in a busy manufacturing plant develops an early-stage bearing fault, traditional monitoring approaches might completely miss it—until catastrophic failure brings production to a standstill. But what if that same fault could be detected weeks ahead through subtle vibration signatures processed by edge AI algorithms that automatically trigger maintenance alerts? This is the power of intelligent sensor fusion in modern industrial automation.

Sensors have emerged as the driving force behind transforming traditional factories into intelligent, adaptive, and self-optimizing facilities. They serve as the smart factory's eyes, ears, and hands—quietly collecting vast amounts of real-time data that flows through networks of connected systems, which feed into analytics and AI algorithms that enable manufacturers to make quicker decisions and respond to changes with unprecedented agility.

Today's manufacturers encounter a convergence of challenges: unplanned downtime accounts for 24% of total production costs, global competition intensifies daily, labor shortages strain operations, and the growing demands of the robotics industry require new levels of precision and flexibility. To succeed, manufacturers must go beyond traditional linear production models and embrace smart factory technologies where modern robots work as flexible, collaborative partners alongside human teams, learning from their environment and adjusting their actions in real-time.

This ebook explores how advanced sensor fusion creates a new reality. You'll discover how modern MEMS accelerometers match the performance of traditional piezoelectric sensors while enabling wireless, battery-powered condition monitoring systems. Learn how edge AI processing can reduce power consumption by 80% while providing real-time insights that prevent costly failures. Explore how inertial measurement units enable robots to navigate complex environments without external references, and how breakthrough multi-turn position sensors eliminate the need for re-homing automation equipment—addressing one of the most persistent challenges in industrial automation.

Each chapter integrates fundamental principles with real-world applications, showcasing innovative solutions from Analog Devices, Inc. (ADI), a global leader in high-performance sensing technologies. From vibration analysis that identifies bearing faults at their earliest stages, to edge processing platforms that extend battery life to seven years, to multi-turn position sensors that preserve accuracy during power outages—you'll discover how this blend of sensors, robotics, AI, and machine learning establishes the foundation of truly autonomous manufacturing systems.

Whether you are designing condition monitoring systems, implementing autonomous robotics, or developing next-generation industrial automation, this ebook offers the technical insights and proven solutions—easily accessible through Mouser Electronics—that you need to create agile, adaptive, and self-optimizing production facilities that keep up with the demands of the 21st century. The smart factory revolution isn't coming—it's here.

Chapter 1

Condition Monitoring and Predictive Maintenance

The Challenge of Unplanned Downtime

In a busy manufacturing plant, a critical 400 kW air compressor runs non-stop, powering the production line. When Analog Devices' smart motor sensor detects subtle, early-stage vibrations signaling a bearing fault, maintenance teams quickly intervene. Catching the problem long before any visible or audible signs appear, the plant avoids costly downtime, demonstrating how advanced condition monitoring transforms maintenance from reactive repairs into proactive problem-solving.

Smart manufacturing is undergoing a transformation as automation technologies become increasingly prevalent in the industry. However, unplanned downtime remains a significant challenge, accounting for 24% of total production costs. Despite the implementation of maintenance programs, 82% of companies still struggle with unexpected equipment failures. This issue is further exacerbated by the impending retirement of experienced workers, resulting in a critical shortage of machine expertise.

Forward-thinking manufacturers are embracing advanced solutions like condition monitoring and predictive maintenance to tackle these challenges and maintain competitiveness. These proactive approaches utilize real-time data from various sensors to identify early warning signs of potential issues, allowing companies to resolve problems before they lead to costly downtime. While traditional wired monitoring systems can be expensive and difficult to implement, the industry is transitioning toward more flexible and scalable battery-powered wireless tools.

Environmental Impact and Sustainability Benefits

The benefits of predictive maintenance go beyond merely minimizing downtime. By proactively identifying and addressing faults, such as inefficient motors, manufacturers can significantly lower energy consumption and CO_2 emissions. This not only saves costs but also aids in achieving sustainability goals, making condition monitoring an essential part of the future smart factory.

Defining Condition Monitoring vs. Predictive Maintenance

At its core, condition monitoring involves consistently tracking machine health using real-time data from sensors that measure key indicators such as vibration, temperature, pressure, and electrical signals. Unlike traditional maintenance methods that depend on fixed schedules, condition-based monitoring (CBM) initiates maintenance actions only when data signals signs of deterioration.

Predictive maintenance advances CBM by utilizing historical and real-time data, advanced analytics, and machine learning algorithms to predict when a machine is likely to fail. This allows manufacturers to schedule repairs in advance, reducing unplanned downtime and optimizing maintenance resources for improved operational efficiency.

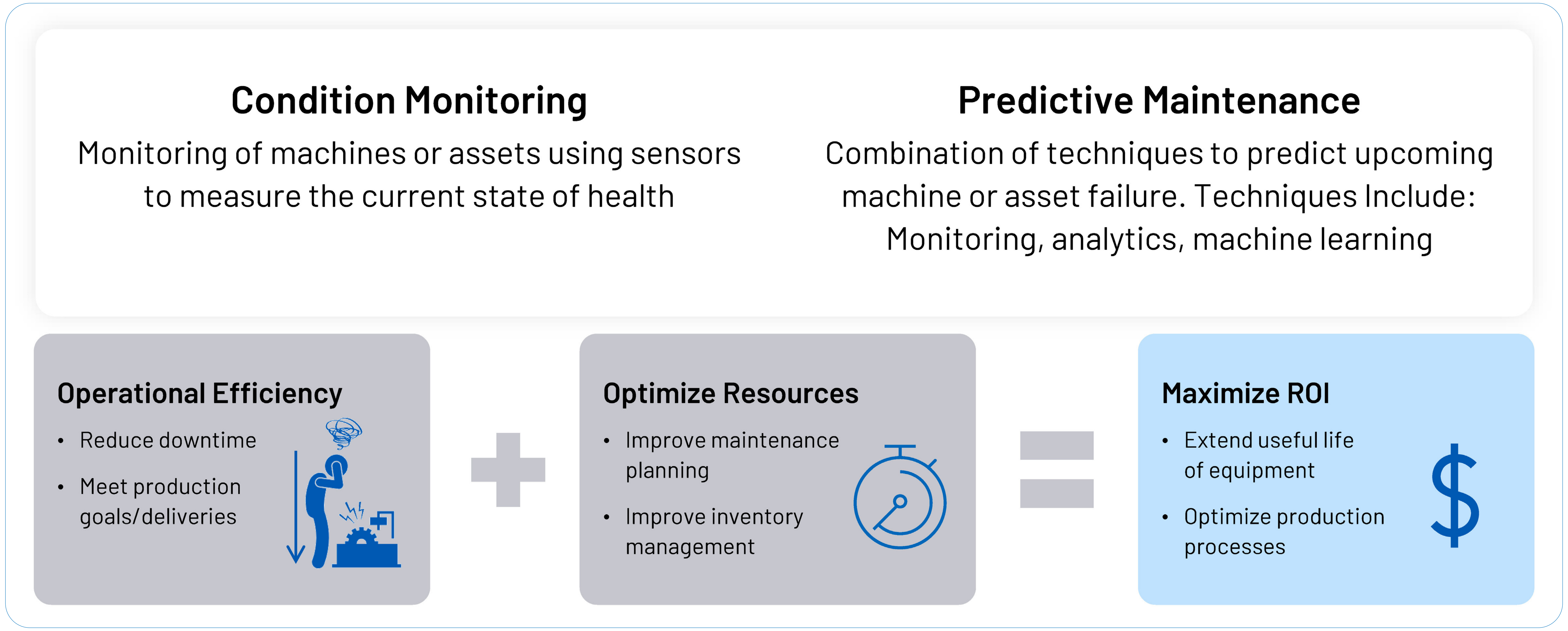
Key Sensing Modalities for Equipment Health

To effectively implement CBM and predictive maintenance, manufacturers rely on several sensing modalities:

1. Vibration sensing: Widely utilized for monitoring rotating equipment, changes in vibration patterns frequently indicate issues such as imbalance, misalignment, or bearing wear.
2. Temperature monitoring: Tracks heat buildup that may signal friction, electrical faults, or lubrication failures.
3. Magnetic field sensing: Identifies problems in electric motors and generators, such as broken rotor bars or winding faults, by observing anomalies in magnetic flux patterns.
4. Electrical measurements: Voltage and current sensing provide insights into motor health, load conditions, and power quality, with abnormalities often preceding mechanical and thermal faults.

By integrating data from multiple sensing modalities, manufacturers gain a comprehensive understanding of equipment health, enhancing fault detection accuracy and enabling targeted maintenance strategies.

As the manufacturing industry evolves, embracing predictive maintenance and automation technologies will be essential for companies aiming to optimize operations, reduce costs, and maintain a competitive edge. Manufacturers can unlock new levels of efficiency, reliability, and sustainability by harnessing the power of real-time data and advanced analytics, paving the way for a smarter, more resilient future.



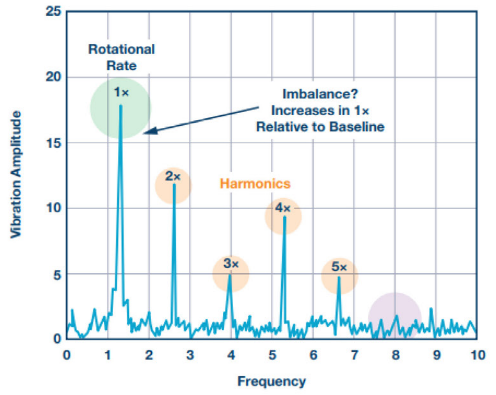
Chapter 2

Vibration Sensing Technology

On a high-speed packaging line, minor roller-bearing wear in a motor goes unnoticed amid factory noise. However, an Analog Devices ADXL382 accelerometer—designed specifically for precise, low-noise vibration detection—picks up subtle shifts in vibration frequency. By alerting maintenance early, the sensor allows for a planned replacement during routine downtime, preventing a minor issue from escalating into a major breakdown and ensuring the line continues to run smoothly.

Vibration analysis has become a key tool for identifying and addressing mechanical issues and faults. Maintenance teams can detect potential problems early by accurately measuring and interpreting vibration signals, which helps prevent costly downtime and extends equipment lifespan. Modern accelerometers play a crucial role in collecting high-quality vibration data, featuring key characteristics that enable effective fault detection.

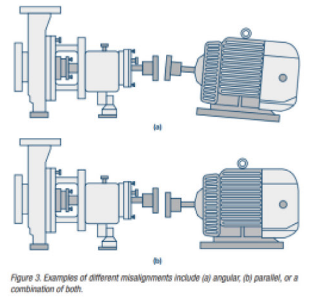
Imbalance

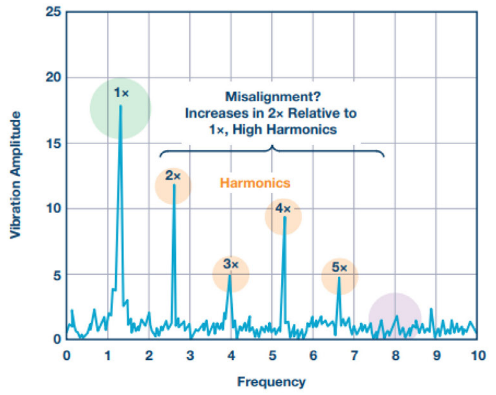


Sensor and System Considerations

- Low noise
- Sufficient resolution
- Bandwidth ~5× fundamental
- Multi-axis sensing
- Low frequency response for slow rotating machines

Misalignment

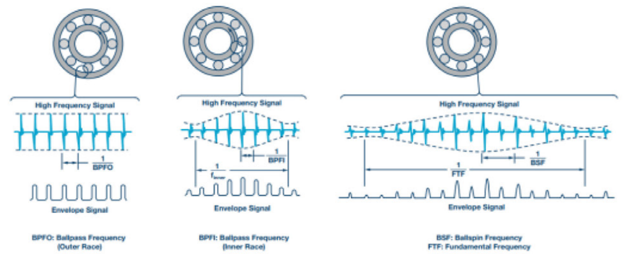




Sensor and System Considerations

- Low noise
- Bandwidth 10× fundamental
- Multi-axis sensing is important
- Phase matched simultaneous sampling

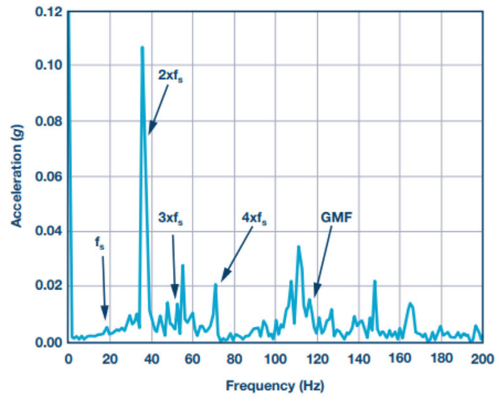
Bearing Defects



Sensor and System Considerations

- Low noise to detect early defects
- Wide bandwidth is critical
- High g range

Gear Defects



Sensor and System Considerations

- Wide bandwidth is critical
- Low noise is critical due to limited sensor mounting location

Vibration-based Faults and System Considerations

Industrial machinery is vulnerable to various mechanical faults, each having its unique vibration signature. Imbalance, for instance, is marked by strong vibrations at 1x the motor's rate of rotation, along with a steady phase angle during rotation. In contrast, misalignment shows elevated vibrations at both 1x and 2x RPM, often accompanied by axial components. Bearing defects cause high-frequency vibration spikes and specific fault frequencies tied to bearing geometry. Conversely, gear defects lead to vibrations at gear mesh frequencies and sidebands, frequently accompanied by an increase in noise level.

To accurately distinguish between these faults, condition monitoring experts rely on signal processing techniques such as spectral analysis, time waveform analysis, and envelope detection applied to accelerometer data. However, the success of fault diagnosis heavily depends on the quality of the acquired vibration data. Three critical characteristics of accelerometers determine their effectiveness in fault detection:

1. **Low Noise:** Lower noise allows for the detection of faults in their earliest stages, enabling timely intervention.
2. **Wide Bandwidth:** A wider bandwidth captures more comprehensive spectral content, improving fault classification accuracy.
3. **High Measurement Range:** Enables complete coverage for assets which generate larger vibrations.

Evolution of Accelerometer Technology

Traditionally, piezoelectric accelerometers have been the preferred choice for measuring high-frequency, low-noise vibrations in industrial settings. While they provide a wide dynamic range, their AC-coupled nature restricts their capacity to measure static acceleration. Enter MEMS (Micro-Electromechanical Systems) accelerometers, a technology that is transforming vibration monitoring.

Modern MEMS accelerometers, exemplified by the ADXL1000 series, feature wide bandwidths up to 24 kHz, low noise density down to 25 μG/√Hz, and high sensitivity, matching the performance of piezoelectric devices in many industrial applications. Furthermore, MEMS accelerometers offer distinct advantages, including DC response, compact size, energy efficiency, and seamless integration into wireless and battery-powered systems, enabling flexible deployment in various monitoring scenarios.

ADXL382: Advanced Triaxial Digital Sensor

Among MEMS accelerometers, the ADXL382 is a triaxial digital wideband sensor designed for advanced condition-based monitoring applications. This sensor excels in three critical areas for effective fault detection:

1. **Ultra-Low Noise:** With noise levels below 55 μG/√Hz, the ADXL382 establishes a new standard for early fault detection capability.
2. **Extensive Bandwidth:** Its 8 kHz bandwidth ensures the capture of comprehensive spectral content, enabling accurate fault classification.
3. **Ample Measurement Range:** With a full-scale range of up to 60 G, the ADXL382 offers the SNR headroom necessary to comply with all four classes of the ISO2816 standard for vibration measurement.

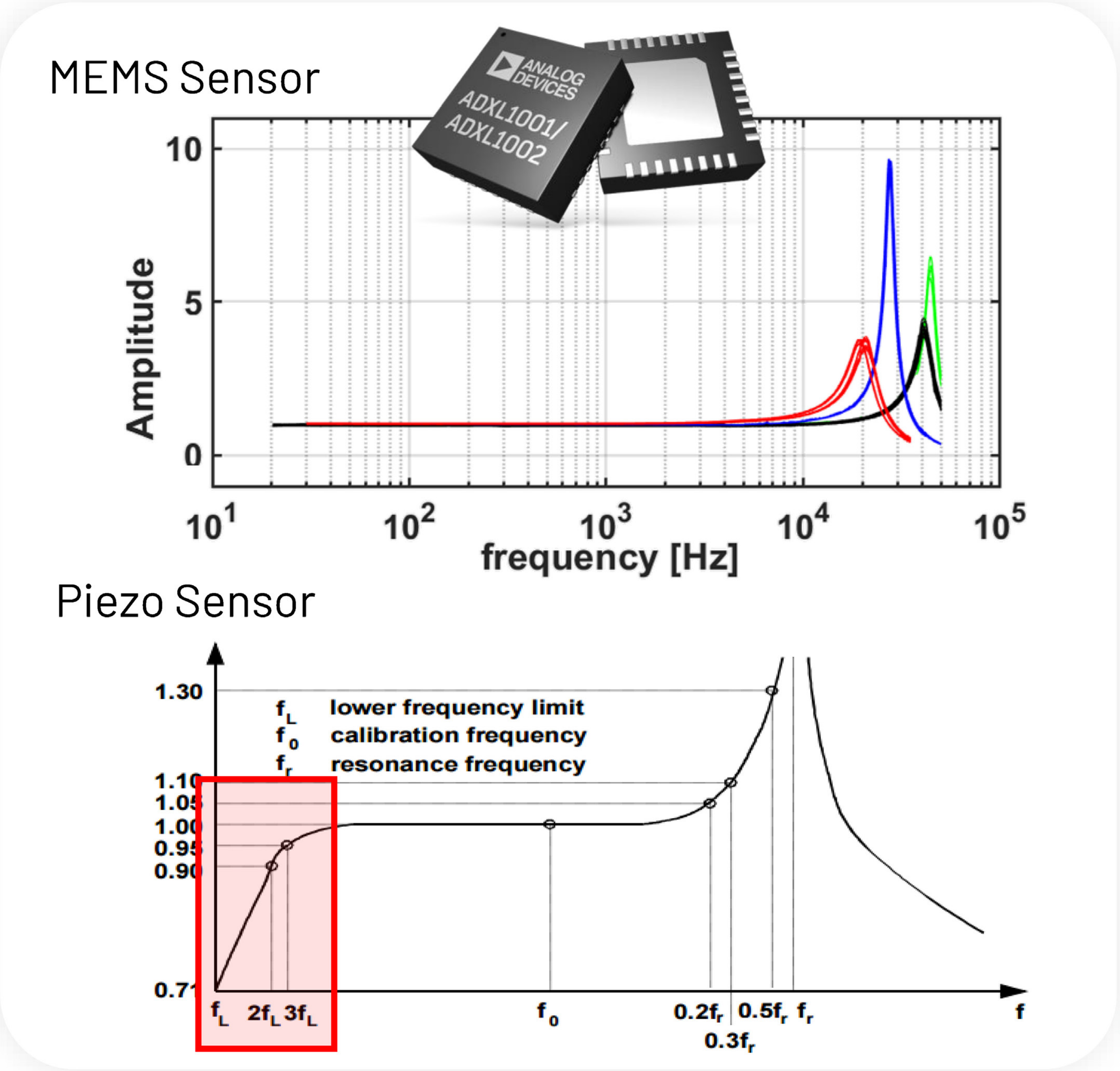
The ADXL382 has an ultra-low power consumption of just 520 µA in its highest performance mode, combined with a compact package and a wide temperature range (up to 125°C), making it an ideal choice for wireless condition monitoring systems with battery constraints. Its array of features further enhances its utility in demanding industrial environments.

As the demand for effective condition monitoring grows, the role of modern accelerometers in acquiring high-quality vibration data becomes increasingly important. By leveraging the low noise, wide bandwidth, and high measurement range offered by MEMS accelerometers like the ADXL382, maintenance teams can unlock the full potential of vibration analysis for early fault detection and diagnosis. Embracing these technologies empowers organizations to optimize equipment reliability, minimize downtime, and drive operational excellence in today's industrial market.

MEMS vs. Piezo Vibration Sensor

Traditional PZT Sensors limitations

	Piezo Sensor	MEMS
DC Response	No	Yes
Noise	Excellent	Very Good
Shock Recovery	Poor	Excellent
Performance variation	Large	Small
Linearity	Poor	Excellent
Scale factor flatness	Poor	Excellent
Self Test	NA	Yes
Cost	High	Low



Chapter 3

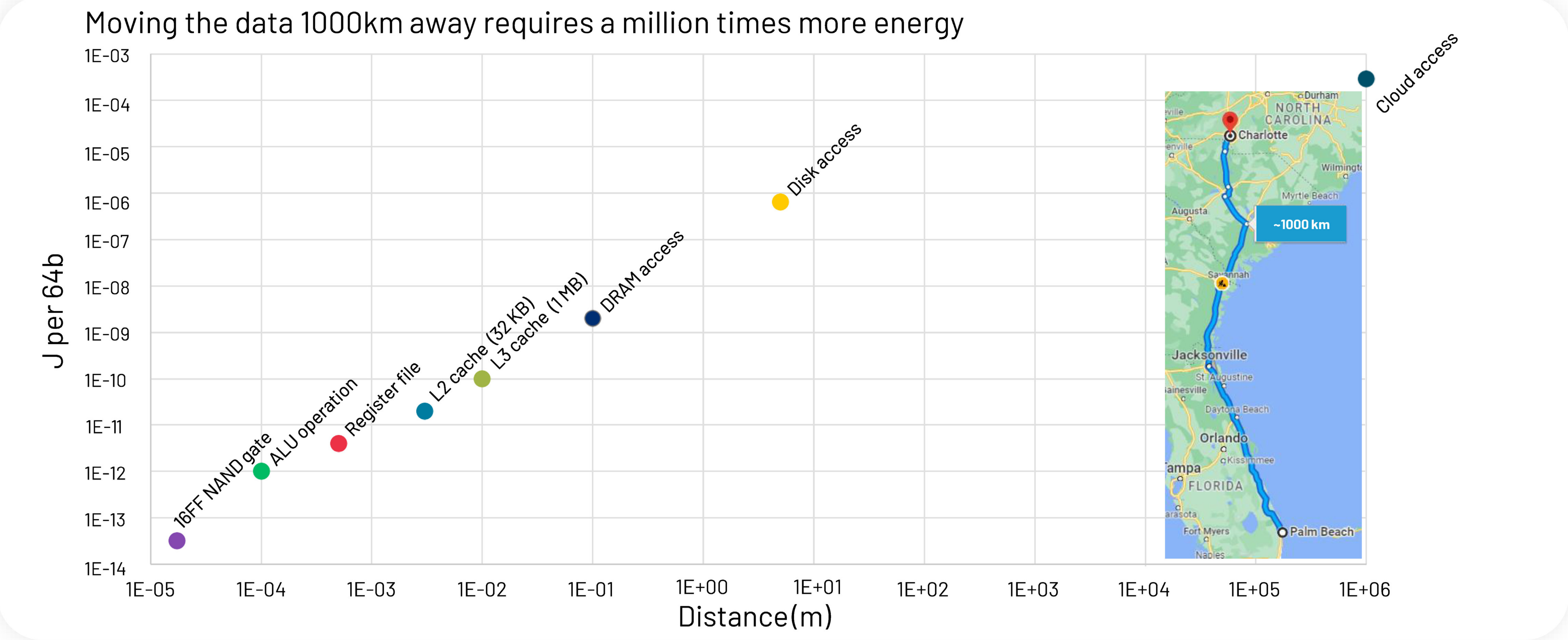
Edge Processing and Analytics

In a remote pumping station, Analog Devices' Voyager4 edge AI sensor continuously analyzes pump vibrations and temperature on-site. When it detects an unusual vibration pattern indicative of early-stage impeller imbalance, it immediately triggers an alert—without the delay or power consumption linked to cloud transmission. By delivering critical analytics directly at the source, Voyager4 significantly reduces energy usage, enhances response speed, and ensures consistent, reliable operations in isolated environments.

The exponential growth of IoT devices, along with the massive volumes of data they generate, has revealed the limitations of traditional cloud-based data processing. As you continue to deploy more sensors and connect more devices, the energy costs and inefficiencies of transmitting every bit of data to remote servers have become increasingly evident. This is where edge processing emerges as a solution, providing a smarter, more efficient, and sustainable approach to data management.

Keep Your Data Close: The Physics of Data

At the heart of edge processing lies a simple yet profound concept: bringing computation closer to the



data source. By processing data locally on the device itself or at nearby edge servers, you can significantly reduce the amount of data transmitted over networks, minimizing energy consumption and latency while enhancing security and resilience.

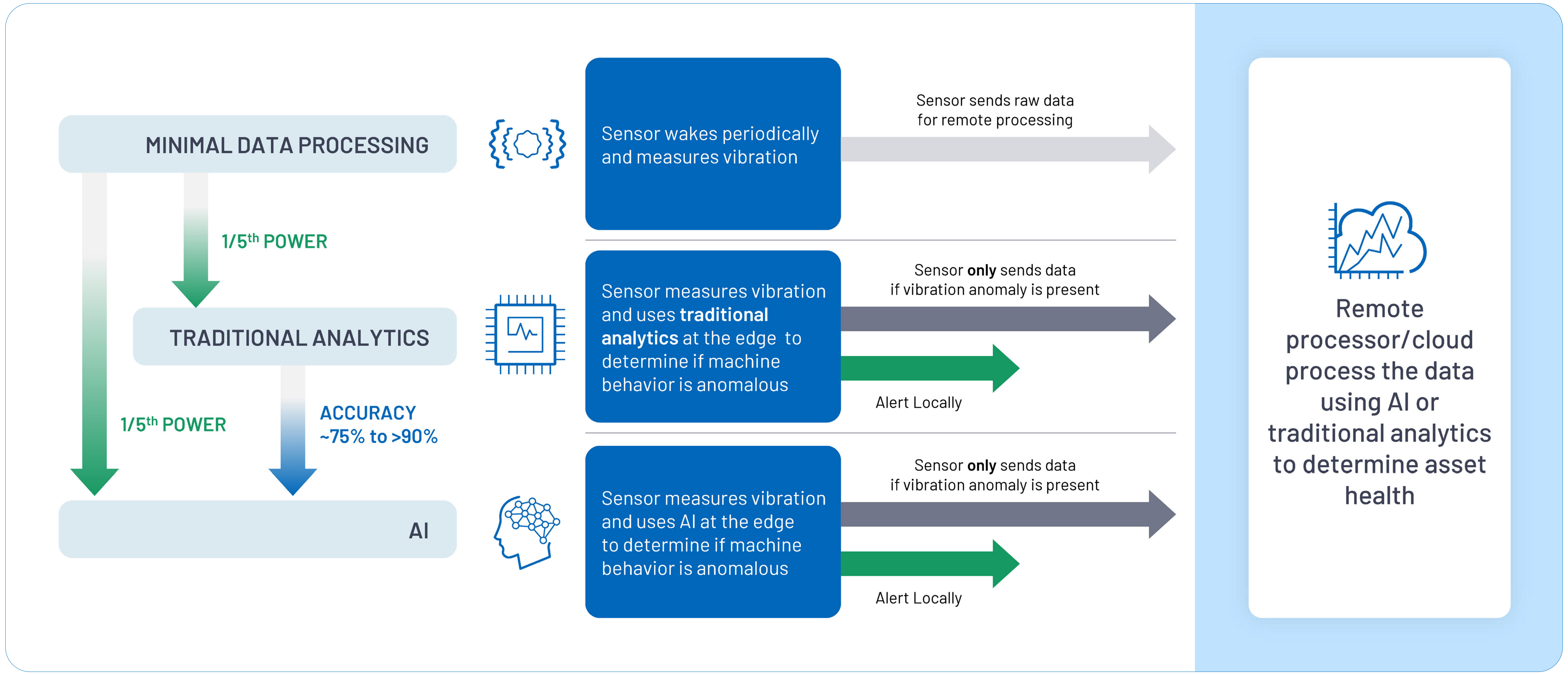
To appreciate the potential of edge processing, you must first understand the energy cost of data transmission. Landauer's principle states that moving or processing one bit of data requires a minimum energy of kT natural log of two. Transmitting one gigabyte of data can consume between five to seven watt-hours, depending on the type of network, distance, and efficiency. When you consider the millions of IoT devices generating data around the clock, the cumulative energy cost of transmitting all that data to the cloud becomes staggering.

Edge Analytics and AI for Power Optimization

Edge processing alleviates the energy burden by strategically processing data at its source. Implementing edge analytics to detect anomalies locally through the use of thresholds or spectral features can reduce power consumption by up to 80%. This is particularly important for IoT devices deployed in remote locations or with limited power resources, where every bit of saved energy can significantly extend the device's lifespan and lower maintenance costs.

Edge processing becomes even more compelling when combined with artificial intelligence. Leveraging edge AI optimizes computational efficiency while maintaining high accuracy, enabling IoT devices to make smart decisions in real-time without relying on cloud servers. This approach reduces energy consumption, minimizes latency, and enhances security by decreasing the attack surface and the risk of data interception during transmission.

The benefits of edge AI extend beyond energy efficiency. By processing data locally, edge AI enables faster response times, making it ideal for applications that require real-time decision-making. Furthermore, edge AI allows for greater privacy and data sovereignty, as sensitive data can be processed and acted upon without leaving the device.



Voyager 4 Platform and Implementation Benefits

The effective use of artificial intelligence necessitates tools and technologies capable of efficient real-world implementation. Analog Devices Inc. (ADI) has been at the forefront of this development, creating solutions such as the Voyager 4 Smart Condition Monitoring Sensor and the ADXL367 Nanopower Accelerometer.

The Voyager 4 serves as a development platform that integrates ADI's sensing technology with the ultra-low-power MAX78000 Microcontroller with neural network hardware accelerator. This combination empowers the Voyager 4 to execute edge AI-based anomaly detection, providing a turnkey solution for implementing edge processing in condition monitoring applications. By utilising Voyager 4's edge AI capabilities, power consumption can be reduced by up to 50% when compared to an equivalent monitoring system that simply reports all gathered data. The battery life of the Voyager 4 is up to 7 years with just a couple of AA batteries."

Complementing the Voyager 4 is the ADXL367 Nanopower Accelerometer, a sensor that exemplifies the energy efficiency of edge processing. With its wake-up mode that consumes just 180 nanoamps, the ADXL367 can detect motion and activate a system without draining the battery. Its ability to operate directly from a battery down to 1.1 volts makes it ideal for low-power monitoring solutions where battery life is critical.

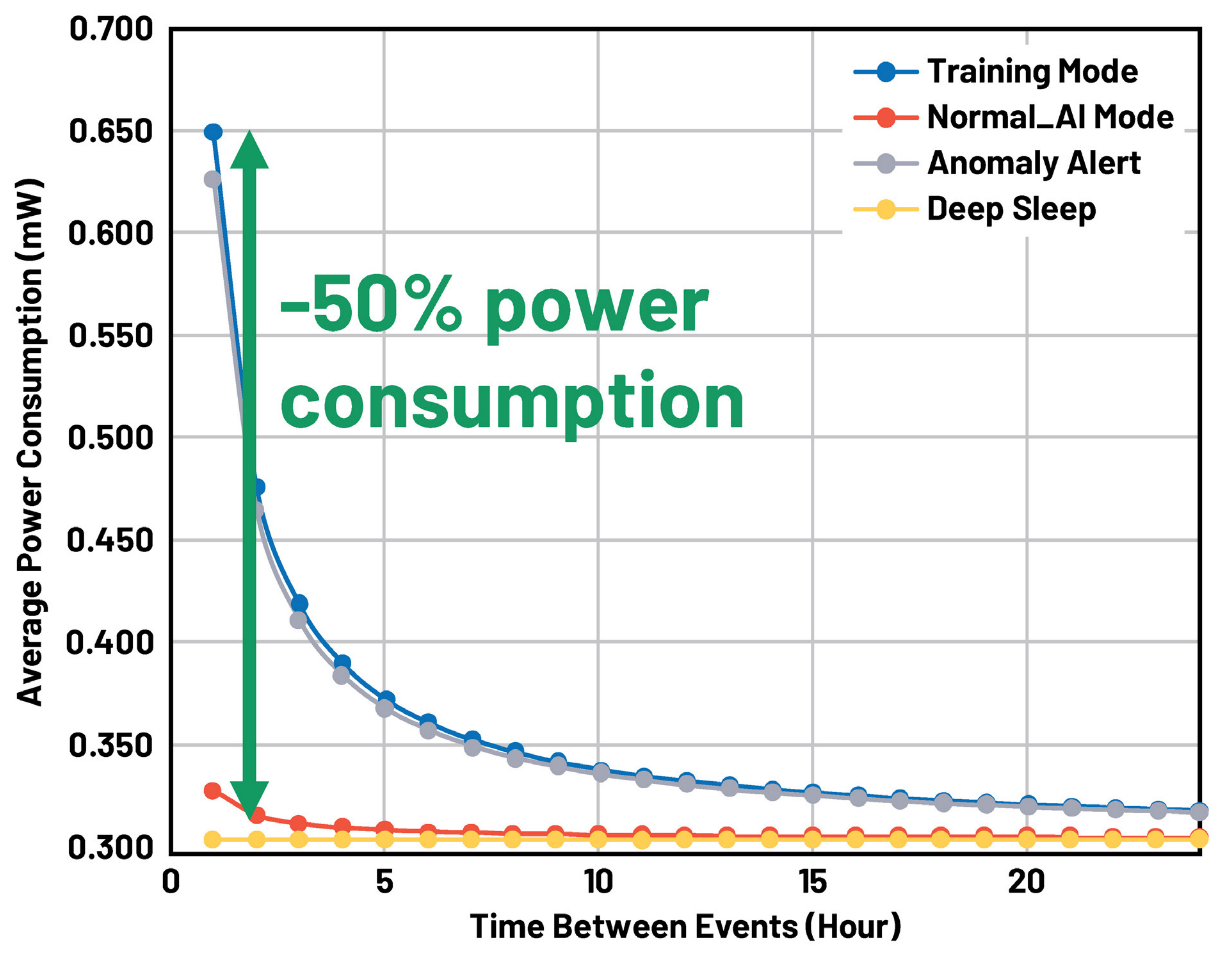
Edge processing is poised to revolutionize data management in the IoT era, offering a paradigm shift that will redefine how you harness data. By bringing computation to the data source, edge processing reduces inefficiencies and opens up new possibilities in intelligent, autonomous systems. The convergence of edge processing and AI will transform various industries, from smart cities to healthcare, enabling real-time decision-making and adaptive learning at scale.

Tools like ADI's Voyager 4 and ADXL367 will play a vital role in unlocking the potential of edge processing, empowering developers to implement efficient and intelligent local data processing in IoT devices. Edge processing signifies a shift in how you perceive and interact with the world, driving the next wave of data innovation, reshaping industries, and leading us toward a smarter, more sustainable future. As you push the boundaries of IoT and AI, edge processing will serve as the catalyst for new possibilities.

- ❑ Evaluation kit
  - ❑ shows that a sensor, which does not have to transmit raw BLE data, can consume up to 50% less power
- ❑ At 0.3mW battery Life is
  - ❑ 7 years using 2x AA size 2.6Ah LS14500 Saft
  - ❑ 2 years using 1x 1500 mAh ASR00073

Voyager4 Mode	BLE Advertising	BLE Connection	BLE Data Streaming	AI Inference	DeepSleep
DeepSleep	0	0	0	0	1
Training	1	1	1	0	1
Normal/AI	0	0	0	1	1
Peripheral	0	0	0	0	1

1 = Feature is active, 0 = Feature is inactive



Chapter 4

Robotics and Autonomous Systems

Inside a sprawling distribution warehouse, an autonomous mobile robot relies on multiple sensors for navigation. However, when it encounters featureless aisles where visual landmarks disappear, navigating becomes challenging. Analog Devices' ADIS1657x inertial measurement unit steps in, providing precise orientation and positioning data to ensure the robot maintains accuracy and confidence even without external references. This inertial sensor exemplifies how robust sensor fusion enables robots to operate reliably in complex industrial settings.

Industrial automation is progressing, with robotics and autonomous machines at the forefront. As companies encounter persistent labor shortages, increasing costs, and a need for more flexible manufacturing, they are turning to robotic systems to remain competitive.

Robotics Revolution in Industrial Settings

While traditional industrial robots have long been utilized for tasks such as welding, assembly, and material handling, recent advancements in robotics are pushing the boundaries even further. Humanoid robots and mobile autonomous robots (AMRs) can now adapt to dynamic, unstructured environments, creating new possibilities for automation.

Humanoid robots, in particular, are emerging in factories designed around human workflows. Rather than incurring the high costs of facility retooling, these robots can take on physically demanding and repetitive logistics, warehousing, and maintenance tasks. Meanwhile, AMRs and autonomous industrial vehicles are revolutionizing material transport and inventory management by safely navigating complex layouts and collaborating alongside human employees.

Inertial Sensors for Robotic Applications

Driving this robotics transformation are high-performance inertial sensors. With enhanced precision, reduced noise, and increased miniaturization, these sensors facilitate better navigation, balance, and motion control without depending solely on external references. This enables robots to function safely, adaptively, and efficiently in dynamic industrial environments.

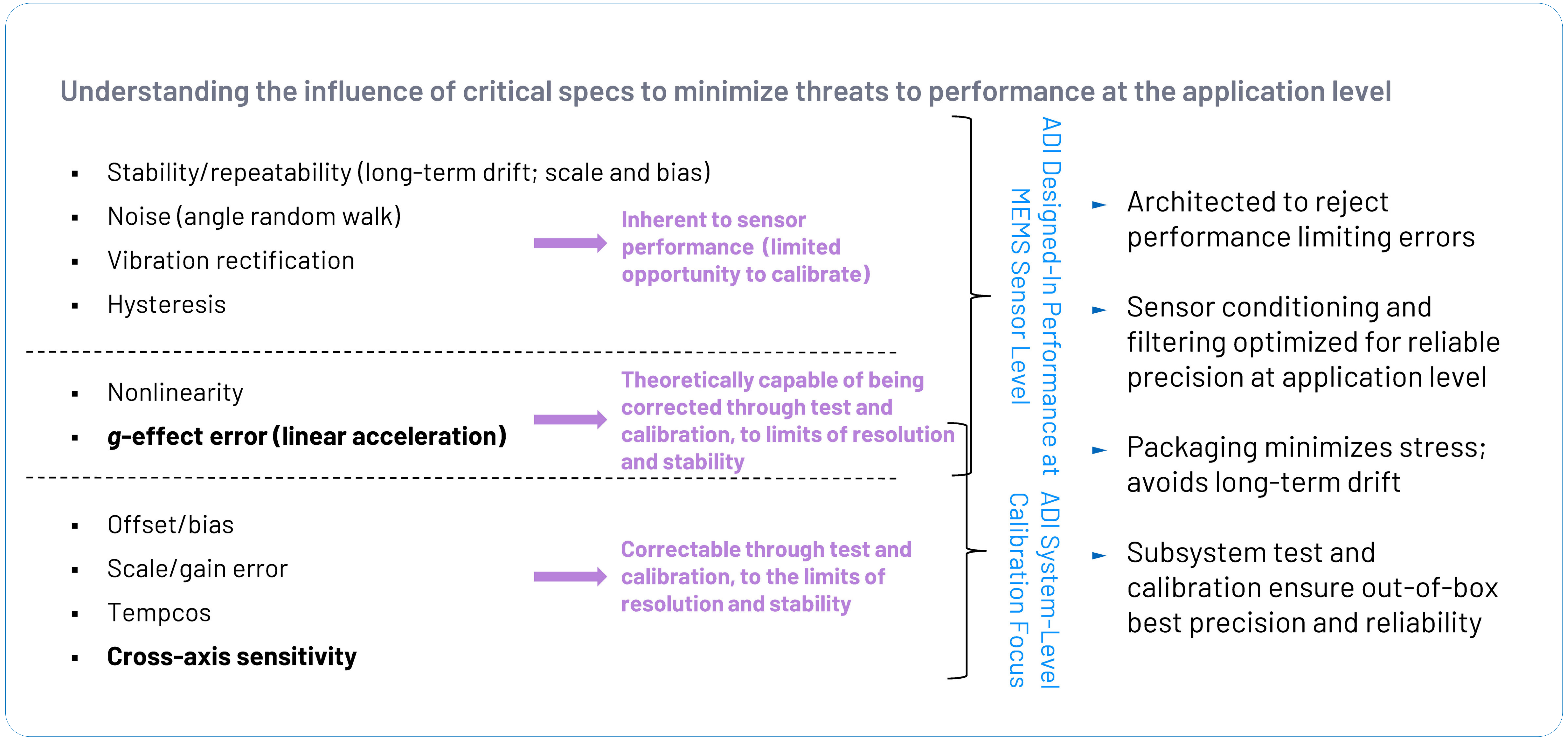
However, creating these complex robotic systems presents its own set of challenges. Optimizing inherent sensor parameters limited by design and physics, such as noise, vibration susceptibility, and hysteresis, can be a time-intensive process. To streamline development, fully calibrated sensor modules that correct biases, sensitivity, temperature codes, and axial alignment are available, offering an out-of-the-box subsystem that enhances time-to-market.

ADIS1657X Series IMU for Robotics

One effective solution is the ADIS1657X series of inertial measurement units (IMUs). This product family delivers the precision found in much larger, more expensive sensors within a compact, scalable package. By integrating low noise and low interim bias stability across various environmental conditions, the ADIS1657X is highly suitable for use in humanoid robots and other demanding applications.

In humanoid robots, for instance, the many moving joints driven by servos can create challenging out-of-band high-frequency vibrations, while metal parts impacting surfaces generate broadband shocks. The ADIS1657X's vibration rectification capability reduces the impact on accuracy, making it a suitable development tool for the robotics revolution.

As industrial automation continues to advance, robotics and autonomous machines will play a central role. With the assistance of sensor technologies like the ADIS1657X, companies can remain at the forefront of this transformation, driving efficiency, flexibility, and competitiveness in the years ahead.



Chapter 5

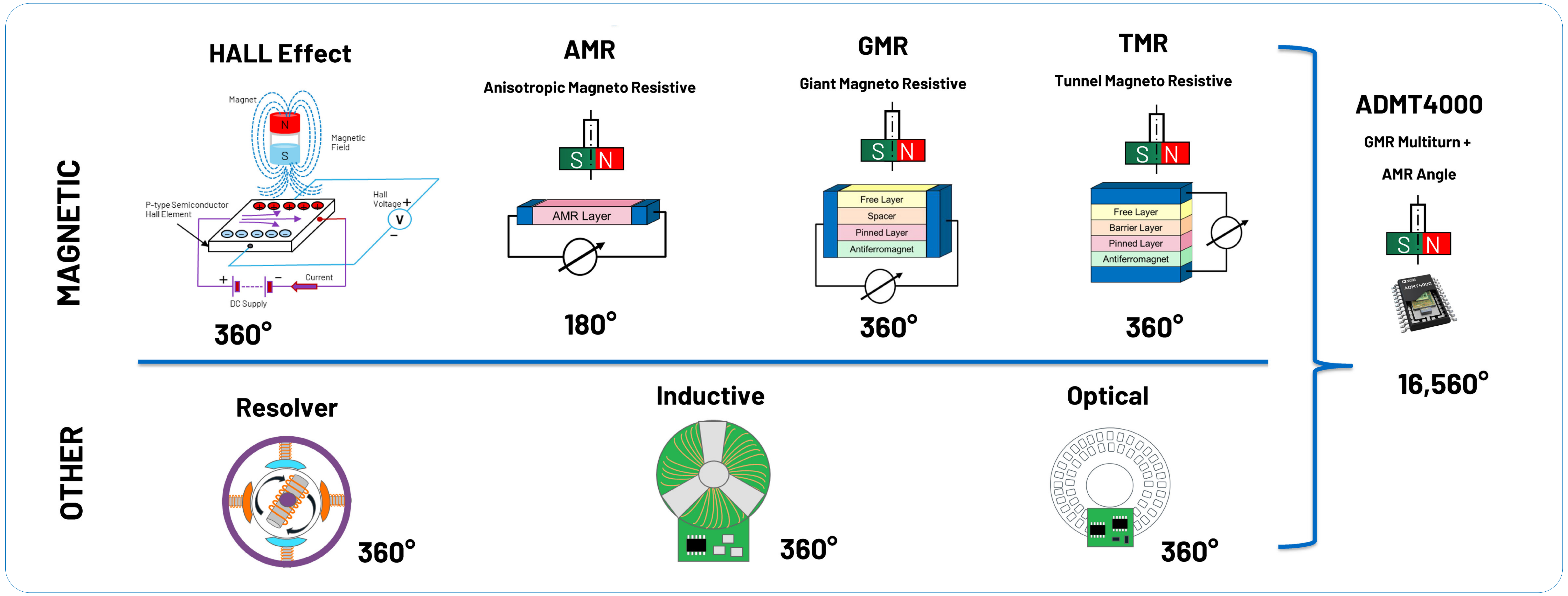
Multi-Turn Position Sensing Fundamentals

When an automated assembly line unexpectedly loses power, traditional robotic systems often require lengthy recalibration procedures, leading to costly downtime. However, modern multi-turn position sensors retain precise position data even without power, enabling immediate and accurate restarts. This capability eliminates cumbersome homing sequences, boosts efficiency, and significantly reduces downtime—highlighting the growing importance of advanced position tracking technology.

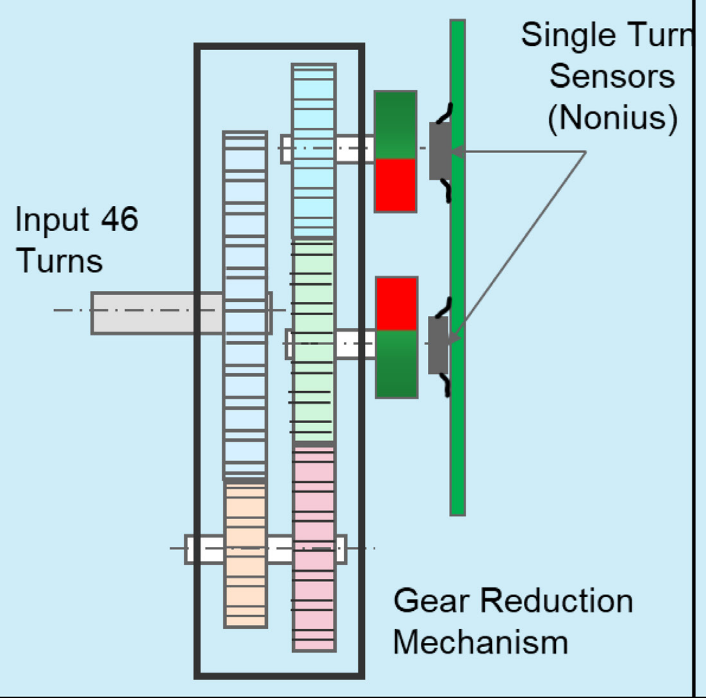
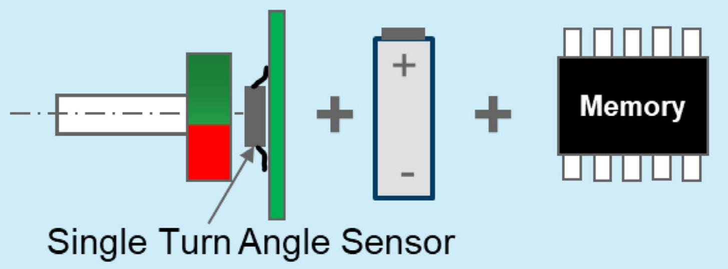
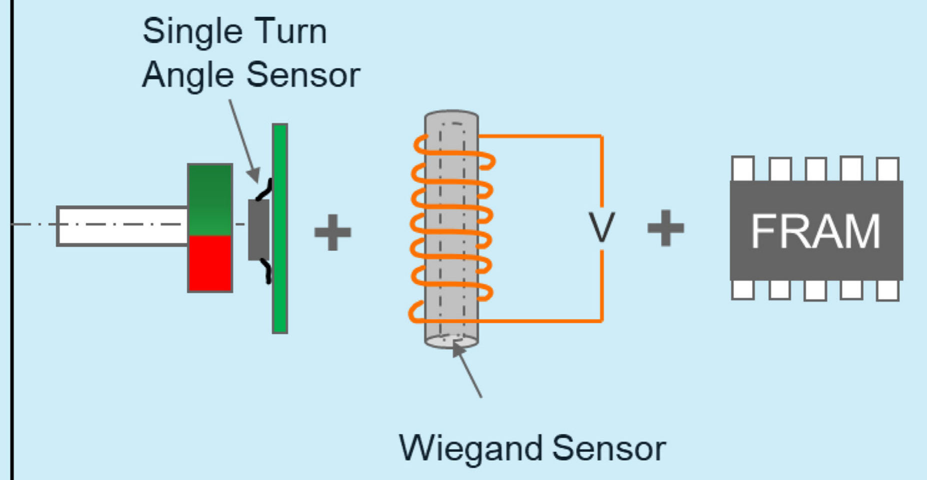
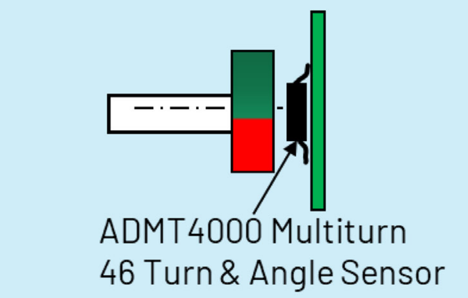
The demand for efficient, reliable, and compact position sensing solutions has never been greater in industrial automation. The ADMT4000 is a single-chip multi-turn position sensor set to transform the management of encoders and actuators in industrial automation, robotics, and the emerging humanoid field.

Traditional Multi-Turn Solutions and Their Limitations

Traditionally, angle sensors available on the market, such as Hall Effect, XMR family (AMRs, GMRs, TMRs), resolvers, inductive solutions, and optical encoders, have been limited to an absolute measurement range of 360 degrees. While these sensors operate without power and contact within this range, they are insufficient for applications that require multi-turn position sensing. The AMR angle sensor, which repeats signals every 180 degrees, is the only exception to the 360-degree restriction.



Engineers have long sought workarounds to achieve multi-turn position sensing, but these solutions come with drawbacks. Gearing mechanisms, designed to reduce multi-turns to a single-turn, result in bulky, heavy systems that suffer from mechanical wear, hysteresis, and limited accuracy. They often require multiple single-turn sensors, adding complexity to the system. Furthermore, backup batteries combined with memory chips and single-turn sensors increase size, weight, and maintenance needs, with batteries being particularly undesirable in robotics and specific operating environments. Even energy harvesting solutions that utilize Wiegand sensors and FRAM chips remain cumbersome and necessitate additional components.

	Gear reduction with Single Turn Sensors	Back-Up Battery with Single Turn sensor + Memory	Energy Harvesting Wiegand Sensor + Single Turn sensor + FRAM	ADMT4000 Multiturn + Angle
				
CON	Large Size & Weight Mechanical Gear Wear Mechanical Hysteresis Single Turn Sensor (s) Low Accuracy	Medium Size Back-up Battery Battery Maintenance Single Turn sensor Memory	Medium Size Wiegand Sensor Single Turn sensor Memory (FRAM) Robustness	None
PRO	Inherent Redundancy with 2 Single turn sensors	High Accuracy	High Accuracy	Small & Compact High Robustness High Accuracy

ADMT4000 Overview and Benefits

ADI's release of the ADMT4000 in November 2024 represents a breakthrough in position sensing technology. This single-chip solution extends the absolute position sensing range from 360 degrees to 16,560 degrees, effectively providing a single device with a 46-turn full absolute magnetic encoder. By eliminating the need for complex workarounds, the ADMT4000 allows engineers to streamline their designs, reduce system size and weight, and enhance overall performance.

The technology of ADMT4000 enables tracking of multiple rotations without power, making it ideal for monitoring actuators in robotic or humanoid joints. By eliminating the need for re-homing, this sensor streamlines the control process and reduces downtime. It can substitute linear transducers in rotary-to-linear actuators, backup batteries with single-turn sensors, and gearing with single-turn sensors, allowing mechanical designers to enhance their actuators regarding size, weight, and cost.

The ADMT4000 is integrated into linear and rotary actuators, providing versatility. In a typical rotary-to-linear actuator, placing the ADMT4000 at the end of the shaft enables it to track the number of rotations even when the power is turned off. By knowing the pitch of the lead screw, engineers can accurately ascertain the linear position of moving components, such as gears, clutches, or humanoid limbs (e.g., elbows or knees). With an integrated 360-degree sensor accurate to 0.25 degrees, the ADMT4000 delivers resolution across its full range of 16,560 degrees.

As industries strive to enhance efficiency and reliability, the ADMT4000 single-chip multi-turn position sensor from Analog Devices, Inc. is set to become a change agent. By overcoming the limitations of traditional angle sensors and offering a compact, robust, and accurate solution, the ADMT4000 empowers engineers to streamline their designs and improve the performance of their systems. As the demand for position sensing escalates across industrial automation, robotics, and humanoid applications, the ADMT4000 is prepared to face the challenge, reducing downtime and increasing productivity in modern industry.

Chapter 6

ADMT4000 Design, Implementation, and Applications

In a high-speed bottling plant, precision and uptime are paramount. Rotary actuators control the capping mechanisms, ensuring each bottle is sealed correctly. However, unexpected power outages previously led to misaligned caps and production halts, as traditional systems lost track of their position. By integrating Analog Devices' ADMT4000 multi-turn position sensors into the rotary actuators, the plant now maintains precise positional data even during power interruptions. This advancement eliminates the need for manual recalibration, reduces downtime, and ensures consistent product quality, showcasing the ADMT4000's pivotal role in enhancing industrial automation reliability.

Rotary actuators play a crucial role in various applications, ranging from robotics to humanoid joints. These actuators often utilize gearing to increase torque, enabling the motor on the input side to complete multiple rotations. Recent advancements in rotary actuator technology include the ADMT4000 sensor, which features next-generation improvements in multi-turn sensing.

Domain Wall Generation Technology

Determining the output angle in a rotary actuator with gearing is a challenge that has led to various approaches. One method involves placing a single-turn sensor on the output side, while another option is to add a battery and memory chip on the input side, eliminating the need for an output sensor or a Wiegand wire solution with an FRAM chip. However, these solutions can be complex and add unnecessary weight to the system.

The ADMT4000 sensor, introduced to the market in November of 2024, offers simplified rotary actuators. By placing the single sensor chip opposite a dipole magnet rotating on the motor shaft, the sensor's 360-degree capability can serve dual purposes. It acts as a motor commutation sensor for brushless motors and an absolute multi-turn position sensor, providing the output angle. This design simplifies actuator construction, reduces overall solution costs, and decreases the system's weight.

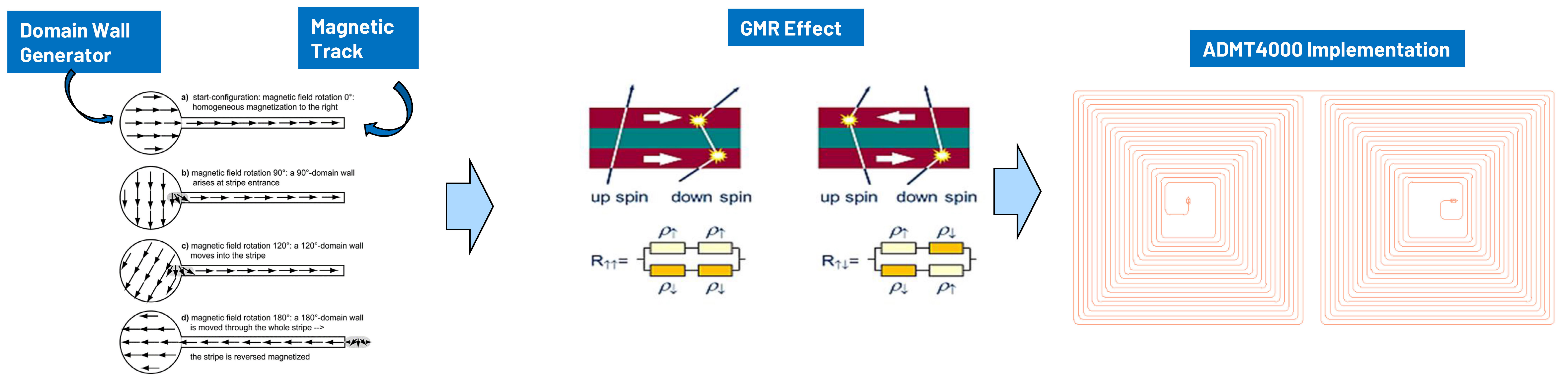
Sensor Operation Principles

The ADMT4000 sensor's technology enables movement detection without power or contact, relying on the principle of shape anisotropy. The sensor consists of two core structures: a domain wall generator with low-shape anisotropy and a narrow magnetic nanowire track with high-shape anisotropy.

As a magnet rotates in front of the domain wall generator, the magnetic lines align with the magnet's direction due to low shape anisotropy. However, in the narrow nanowire, the magnetization direction is restricted to either parallel or anti-parallel because of its nanometer-scale geometry. When the magnet rotates 180 degrees, a domain wall forms at the entrance of the nanowire and propagates through it, altering the magnetization direction in the narrow strip.

This change in magnetization direction is detected using a GMR (Giant Magnetoresistance) process, where the resistance value shifts with the magnetic field direction. The GMR structure includes a pinned layer at the base and a top layer that moves with the magnetic field direction.

The ADMT4000 sensor features a 46-turn spiral design, consisting of 23 turns on the left side extending from the center outwards and another 23 turns on the right side retracting from the outside inwards. However, the next-generation part aims to increase the turn count more than fivefold, enhancing the sensor's capabilities and addressing the growing demands of the market.



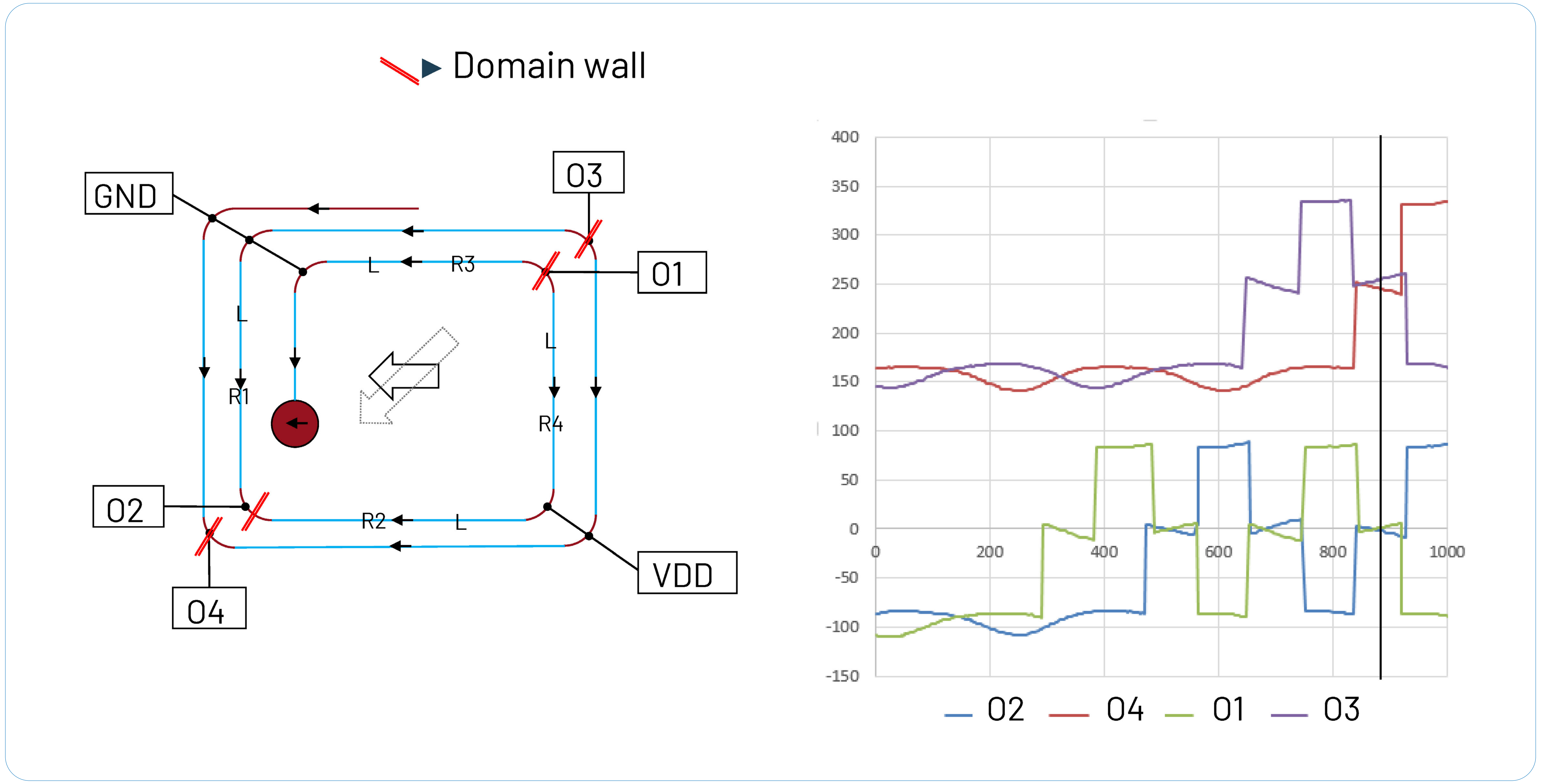
To illustrate the working principle, consider a simplified two-turn sensor. This sensor includes a domain wall generator, depicted by an arrow within a bubble, and a solid arrow representing the sensor itself. The ADMT4000 sensor and its next-generation improvements embody advancements in rotary actuator technology and multi-turn sensing.

By utilizing the principle of shape anisotropy and sensor design, these sensors enable accurate and efficient multi-turn sensing while simplifying actuator design, reducing costs, and decreasing weight. As the technology continues to evolve, it opens the door to enhanced performance and new possibilities in various applications, from robotics to humanoid joints and beyond.

Multi-Turn Sensor Technical Details

At the core of the magnetic position sensor is a nanowire spiral structure that enhances its performance. As the magnet rotates, domain walls are generated and shifted through the spiral, altering the resistance at different measurement points. The spiral's color-coded diagram illustrates the direction of the magnetic field and the resistance levels of the nanowire tracks, with blue indicating low resistance and red signifying high resistance.

The sensor's capability to track the magnet's position even when the system is powered down makes it suitable for applications requiring continuous position monitoring. As the magnet rotates either clockwise or counterclockwise, domain walls fill the spiral, changing the resistance of its arms. This process continues until the sensor reaches its maximum turn count of two turns, ensuring precise position tracking at all times.



Product Specifications and Features

The magnetic field sensor consists of three die: an AMR angle sensor, an ASIC, and a GMR spiral. Each component contributes to the sensor's high precision and functionality.

The AMR angle sensor provides accurate 180-degree angle information, while the GMR spiral's quadrant sensor complements it to achieve 360-degree coverage. By combining the quadrant data with the precise 180-degree angle information from the AMR sensor, the system attains complete 360-degree coverage. The ASIC then integrates this data with the multi-turn sensor to deliver absolute position across the sensor's 46-turn range, while maintaining an accuracy of ±0.25 degrees.

However, the sensor must operate within a specific magnetic window of 16 mT to 31 mT to ensure optimal performance. Failure to remain within this range can lead to insufficient energy to move the domain walls or cause saturation and unintended resets.

Shielding and Environmental Protection

In demanding applications, sensor robustness is essential. ADI has developed a reference design magnet featuring an integrated shield to ensure reliable performance in harsh environments. The shield's two-part design, consisting of a rotating component and a PCB shield with standoffs, protects against straight fields from all angles. When tested with a ±5 mT straight field, the combined shields demonstrate 85-90% effectiveness, safeguarding the sensor's integrity under challenging conditions.

Sensor Reset Methods

Resetting the sensor is a process that ensures a known good state following transportation, assembly, or after exposure to strong magnetic fields. By turning the sensor more than 46 times, you can clean the spiral of any unwanted domain walls, much like using a pipe cleaner. Exposing the sensor to a strong magnetic field greater than 55 mT, whether with an external magnet, the system magnet, or a small coil embedded in the PCB beneath the sensor, can also trigger a reset.

ADI offers a reference design for the reset circuitry to simplify the reset process. It can be connected externally and used once during final assembly to reset the sensor's maximum turn count.

Engineers can apply their potential in position-tracking applications by understanding the intricacies of magnetic position sensors, from their nanowire spiral structure to their key components and application considerations. With ADI's reference designs and guidance, integrating these sensors into systems becomes seamless, enabling precision and reliability even in the most challenging conditions.

ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

MOUSER ELECTRONICS

Bridging the physical and digital world for breakthrough innovation

Analog Devices converts real-world phenomena into actionable insight, fundamentally impacting how leading companies will change the future.

We create unmatched technologies and solutions to solve our customers' problems in instrumentation, automation, communications, healthcare, automotive and numerous other industries.

Mouser Electronics is an authorized semiconductor and electronic component distributor focused on New Product Introductions from its leading manufacturer partners. Serving the global electronic design engineer and buyer community, the global distributor's website, www.mouser.com, is available in multiple languages and currencies and features more than 6.8 million products from over 1,200 manufacturer brands. Mouser offers 28 support locations worldwide to provide best-in-class customer service in local language, currency and time zone. The distributor ships to over 650,000 customers in 223 countries/territories from its 1 million-square-foot, state-of-the-art distribution facilities in the Dallas, Texas, metro area. For more information, visit www.mouser.com.