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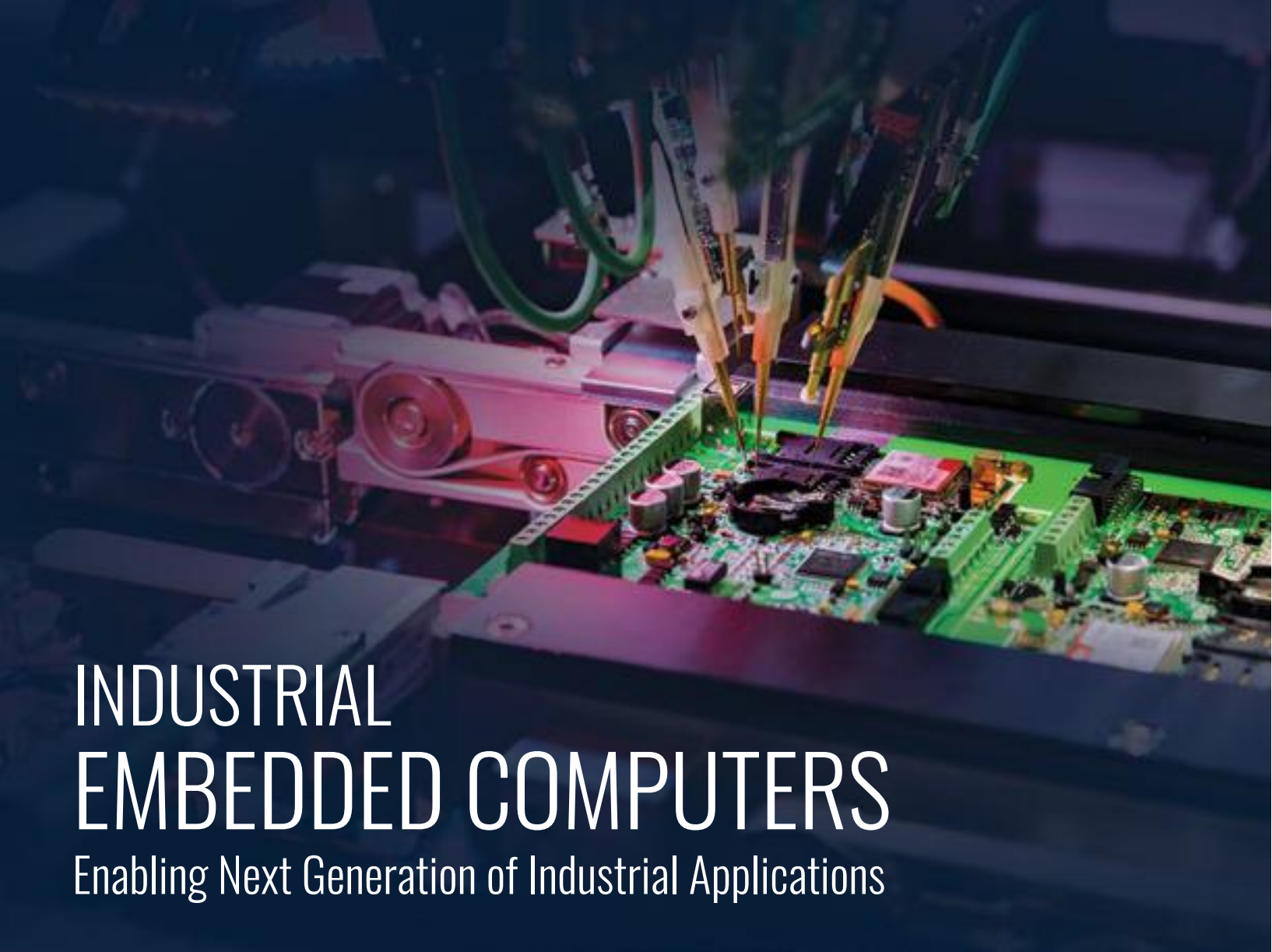AN AVNET COMPANY

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NEXT-GENERATION MOTOR ENCODERS

INDUSTRY 4.0: TOP TRENDS

ETHERNET AND 10BASE-T1S TECHNOLOGY

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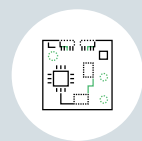
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CONTENTS

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WELCOME

We collectively witness the ongoing evolution of Industry 4.0 through a digital transformation accelerated by rapidly advancing technologies worldwide. Many organisations prioritise understanding, developing, and implementing integrated strategies leveraging Industry 4.0 technologies. A robust correlation exists between the integration of automation into strategic frameworks and the pivotal role played by the Industrial Internet of Things (IIoT) as the digital infrastructure underpinning the emergence of Industry 4.0. Companies and their industrial processes are in a race to swiftly adapt to this rapid change, lest they lag behind industry advancements and competitors. The challenge now is to identify the intermediate steps necessary to harness the benefits of Industry 4.0, considering that a comprehensive set of automation and operational principles is poised to deliver the more intelligent factories of the future by seamlessly combining sensor data, machine communications, and automation systems.

This latest edition of e-TechJournal encapsulates the spirit of exploration and discovery, providing you with a front-row seat to the latest breakthroughs that promise to redefine how we conceive, design, and implement industrial solutions, from the intricacies of sustainable motor encoder design to the simplicity of Arduino Pro in Industry 4.0, and from the revolutionary potential of 10BASE-T1S technology to the critical role of Single Pair Ethernet in factory automation. Our esteemed authors have shared their expertise to serve as a beacon guiding you through the intricate landscapes of sustainable design, open-source empowerment, cutting-edge Ethernet technologies, and the dynamic evolution of Industry 4.0.

We hope you enjoy this edition and welcome your comments and suggestions. Please feel free to drop us a note.

Cliff Ortmeyer Editor, eTech Journal
Email: editor-TJ@element14.com

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HOW TO DESIGN MOTOR ENCODERS FOR NEXT-GENERATION SUSTAINABLE APPLICATIONS

Author: Richard Anslow, Senior Manager, Systems Engineering

Moving from fixed speed to variable speed motors with position and current feedback provides a path to huge process and energy savings. This article provides an overview of motor encoders (position and speed), including types and technologies, and application use cases. It also answers key questions such as what encoder performance metrics are the most critical for my system. Key future trends for electronics used in encoder applications will be discussed, including machine health monitoring, intelligence, and robust longer life sensing. Finally, we'll explain why complete signal chain designs are fundamental for designing next-generation motor encoders.

MOTOR ENCODER PERFORMANCE METRICS, TRENDS, AND ELECTRONICS

After reading this article, you should be able to answer the following key questions:

> What is an encoder and how does it improve the performance of my inverter and motor-driven system?

> What encoder performance metrics are the most critical for my system? After reading this article, you will understand how to match encoder resolution, accuracy, and repeatability specifications to motor and robot system specifications.

> What are the electronics commonly used in encoders, and what are the future trends? After reading this article, you will understand how machine health monitoring, edge intelligence, robust sensing, and high speed connectivity are enabling future encoder designs.
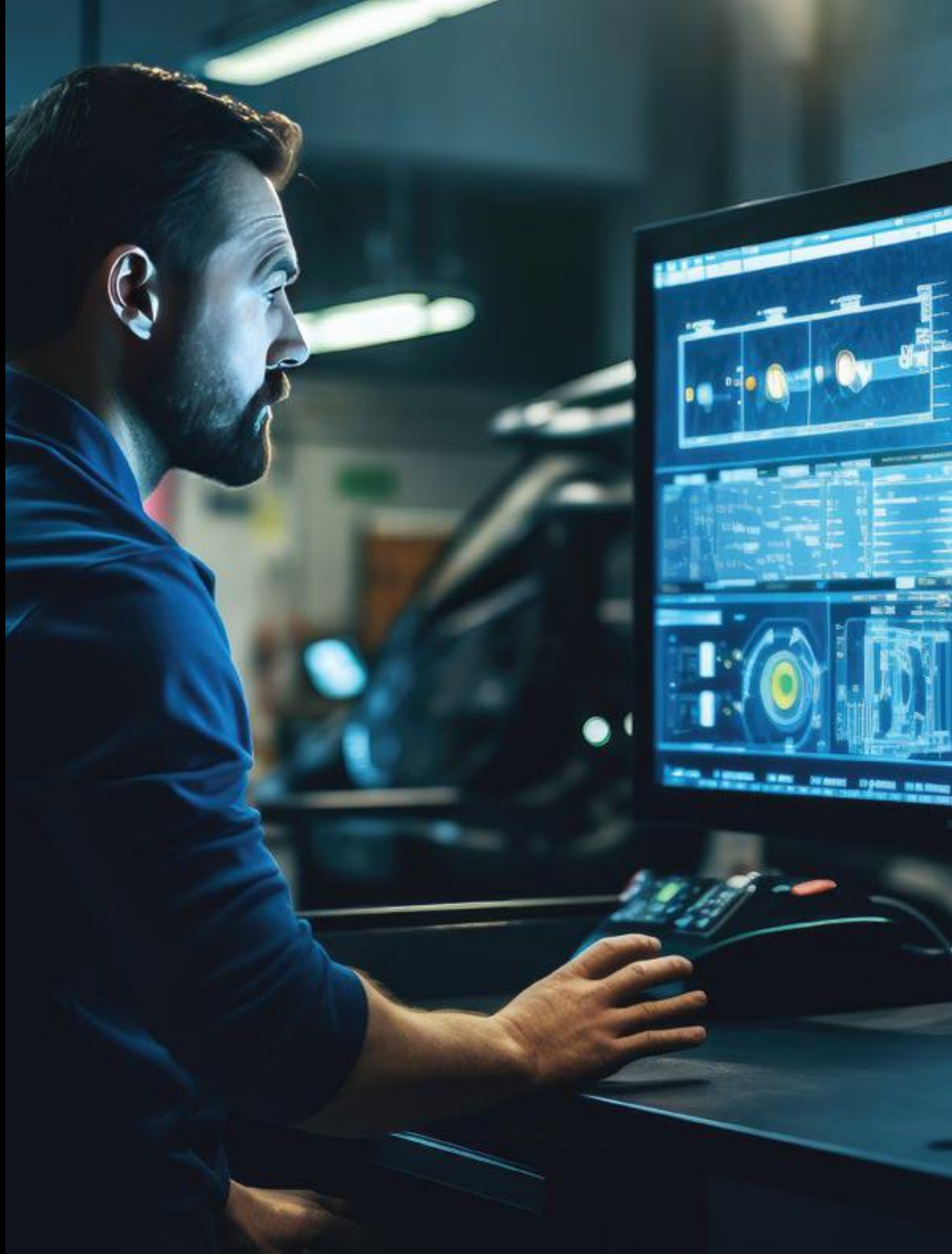
CLOSED-LOOP MOTOR CONTROL FEEDBACK SYSTEM

There has been a steady and constant move from traditional grid-connected motors to inverter-driven motors in the last couple of decades. This has been, and is continuing to be, a significant transition in industrial rotating equipment and has resulted in huge process and energy savings with motors and end equipment being used more efficiently. Higher quality motor control performance with variable speed drives and servo driven systems now offer enhanced quality and synchronization for the most demanding applications. Motor performance and efficiency are improved by using the power inverter, high performance position sensing, and current/voltage closed-loop feedback for the power stage as shown in Figure 1.

Open-loop speed control of motors is possible by applying a variable frequency voltage to the motor using pulse width modulation in the inverter. In steady state or slowly varying dynamic conditions, this will work reasonably well, and many motor drives in lower performance applications utilize open-loop speed control, without resquiring an encoder. However, there are several disadvantages to this approach:

> Speed accuracy is limited as there is no feedback

> Motor efficiency is poor, as the current control cannot be optimized

> Transient response must be strictly limited so that the motor does not lose synchronization

Figure 1 – The closed-loop motor control feedback system
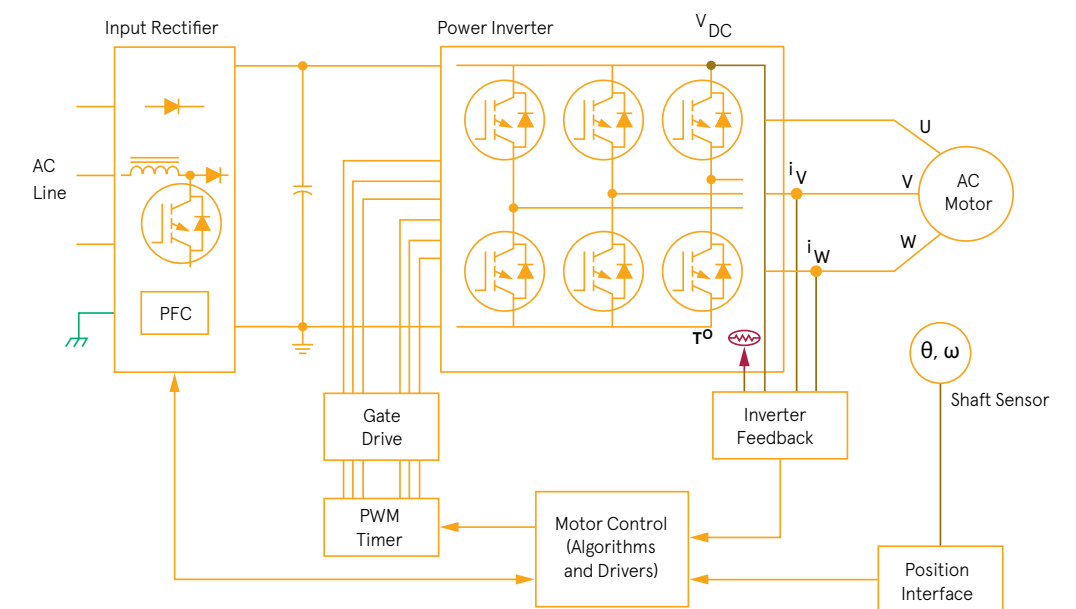
WHAT IS A POSITION ENCODER?

An encoder provides closed-loop feedback signals by tracking a rotating shaft speed and position. Optical and magnetic encoders are the most widely used technologies, as shown in Figure 2. In general-purpose servo drives, encoders are used to measure the shaft position, from which the drive rotational speed is derived. In robotics and discrete control systems, precise and repeatable shaft position is required. Optical encoders consist of a glass disk with fine lithography slots.

Photodiode sensors detect light variation as it passes through or is reflected off the disk. The analog output of the photodiode is amplified and digitized and then sent over wired cabling to the inverter controller. Magnetic encoders consist of magnets mounted to the motor shaft, with a magnetic field sensor providing sine and cosine analog output, which is amplified and digitized. The optical and magnetic sensor signal chains are similar as shown in Figure 2.
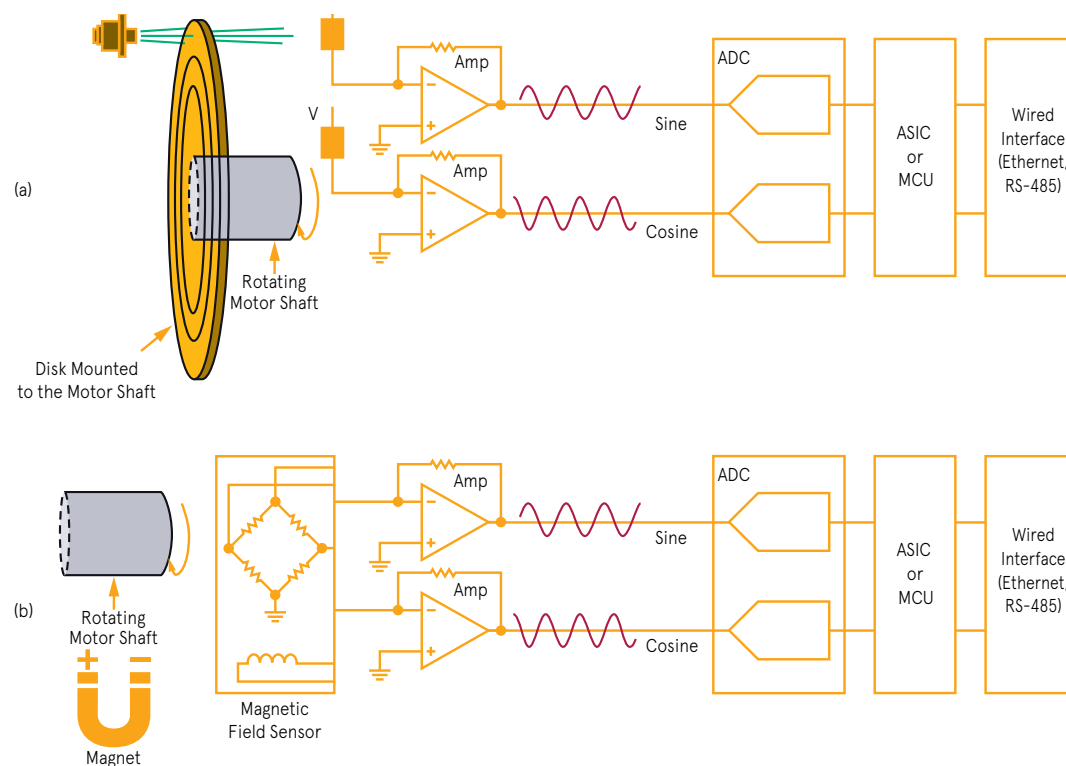

Figure 2 – (a) An optical encoder and (b) a magnetic encoder

MOTOR ENCODER TYPES, TECHNOLOGIES, AND PERFORMANCE METRICS

Absolute single-turn encoders return the absolute position, either within mechanical or electrical 360° once power is applied. The position of the motor shaft can be read immediately. Absolute multiturn encoders include both absolute functions and count the number of 360° turns.

In contrast, incremental encoders provide position relative to the rotation starting point. Incremental encoders provide an index pulse to indicate 0° and a single pulse to count turns or a dual pulse to give direction information. The resolution of an encoder is the number of positions that can be distinguished per 360° rotation of the motor shaft.

In general, the highest resolution encoders use optical technology, while medium resolution/high resolution encoders use magnetic or optical sensors. Resolvers (rotary transformers) or Hall sensors are used for low to medium resolution encoders. Optical or magnetic encoders use high resolution signal conditioning.

The majority of optical encoders are incremental. Encoder repeatability is a key performance metric and is a measure of how consistently the encoder returns to the same commanded position. This is critical for repetitive tasks such as robotics or pick and place machines for semiconductor placement during PCB manufacture.
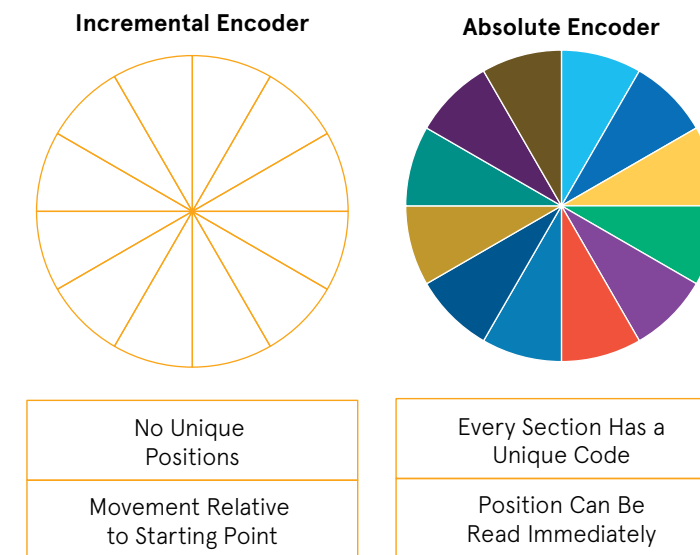
Figure 3 – Encoder types.

Metric	Definition	Comments
Resolution	The number of positions (n) an encoder can distinguish per revolution	High resolution: 16 bits to 24 bits Medium resolution: 13 bits to 18 bits Low resolution: <12 bits
Absolute Accuracy	The difference between the actual position and the reported position through one rotation (like INL)	Position control applications depend on absolute accuracy
Differential Accuracy	The difference between the reported distance between two neighbored positions and the ideal distance between positions (like DNL)	Speed control applications depend on differential accuracy
Repeatability	How consistently the encoder returns to the same commanded position	Repeatability is important for repetitive tasks such as those involving robotics

Table 1 – Encoder Key Performance Metrics

THE IMPORTANCE OF MOTOR ENCODER ACCURACY AND REPEATABILITY

Pick and place machines/ robots are commonly utilized automation machines in the food packaging and semiconductor manufacturing industries. A machine or robot with high accuracy and repeatability is required for process efficiency. The accuracy, repeatability, and efficiency are achieved using high performance motor encoders.

Figure 4 illustrates an encoder use case in robotics. Motors drive each joint in a robot arm via precision speed reduction gearboxes. The robot joint angles are measured via a precision motor-mounted shaft angle encoder (θ_m) and often an additional arm-mounted encoder (θ_j).

For robots, the main performance specification listed on data sheets is repeatability and typically the order of magnitude is at a submillimeter level. By knowing the repeatability specification and the robot reach, you can extrapolate back to the rotary encoder specifications.

The angular repeatability (θ), required at the joint encoder, can be derived from trigonometry: tan inverse of robot repeatability divided by reach.

$$\theta = tan^{-1}\left(\frac{Repeatability}{Reach}\right)$$

Multiple joints combine to achieve the overall robot reach. The sensor should have a higher performance than the target angular accuracy. The repeatability specification per joint must be improved, and a factor 10 improvement is assumed here. For the motor encoder, the repeatability is defined by the gearbox ratio (G).

For example, robot systems shown in Table 2, 20-bit to 22-bit repeatability specifications are required for the joint encoder while 14-bit to 16-bit resolutions are necessary for the motor encoder.
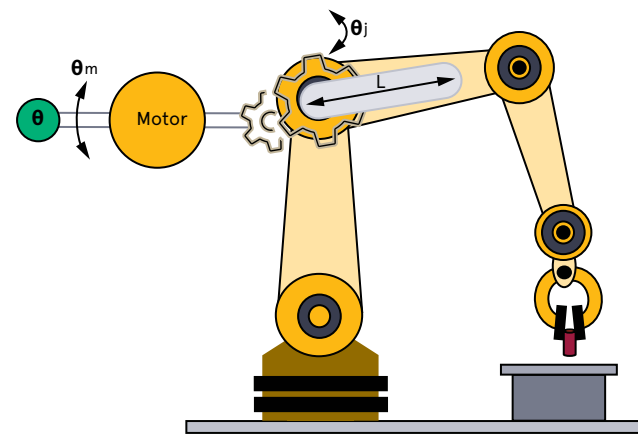

Figure 4 – Angular repeatability at the motor encoder (θ_m) and the joint encoder (θ_j), with the robot reach (L).

Robot System		Robot 1	Robot 2
Assumed Gear Ratio, G		100	
Repeatability Spec		±0.05 mm	±0.01 mm
Reach, L		1.30 m	1.10 m
Encoder Repeatability Spec	θ	0.0022°	0.0005°
	$\theta_j/10^1$	0.00022° (~20-bit)	0.00005° (~22-bit)
	$\theta_m = \theta_j \times G$	0.02° (~14-bit)	0.005° (~16-bit)

[1]Individual encoder must be higher accuracy to achieve overall system accuracy as the robot reach consists of multiple joints.

Table 2 – Encoder Repeatability and Robot Repeatability Specification

FUTURE TRENDS FOR MOTOR ENCODER TECHNOLOGIES

Future encoder trends and technologies that will enable these trends are described in Figure 5.

Research from Rockwell1 for servo drives, encoders, and encoder communication ports shows an annual growth of 20% in transceivers for feedback communication. Single-Pair Ethernet (SPE) transceivers that support 100 Mbps communications over two wires (IEEE 802.3dg standard 100BASE-T1L)1 are currently under investigation, with future encoder drive interfaces benefitting from low latency, with ≤1.5 μs targeted. This low latency will support quicker feedback data acquisition and faster control loop response time.

Condition-based monitoring (CbM) of robotics and rotating machines, such as turbines, fans, pumps, and motors, records real-time data related to the health and performance of the machine to enable targeted predictive maintenance, as well as optimized control. Targeted predictive maintenance, early in the machine life cycle, reduces the risk of production downtime resulting in increased reliability, significant cost savings, and increased productivity on the factory floor. Using MEMS accelerometers, placed in the encoder, provides vibration feedback for machines where quality control is critical.

Adding a MEMS accelerometer to an encoder is convenient as the encoder already has existing cabling, communications, and power to provide vibration feedback to the controller. In some applications, such as CNC machines, the MEMS vibration data sent from the encoder to the servo can be used to optimize the performance of the system in real time.

Extending the useful life of industrial assets using CbM can be complemented with robust longer life position sensors. Magnetic sensors, which produce analog outputs that indicate the angular position of the surrounding magnetic field, can be used instead of optical encoders. Magnetic encoders can be used in areas that have higher humidity, dirt, and dust. These harsh environments impair the performance and lifetime of optical solutions.

For robotics and other applications, the position of the mechanical system must always be known, even in the event of a power loss. One of the major costs and inefficiencies associated with standard robots, cobots, and other automated assembly equipment is the resulting downtime required for rehoming and initializing power-up following a sudden loss of power while operating.

Faster, Lower Latency Transceivers

> Intelligent Edge—more sensors and more data to transfer.

> IEEE 802.3dg 100BASE-T1L future encoder drive interface supporting high speed over long distances with low latency.

Condition Monitoring of Industrial Assets

> Enabling predictive maintenance to reduce motor downtime.

> MEMS and temperature sensors to gather raw data from the motor to provide insights for machine health trending.

More Robust Longer Life Position Sensors

> Magnetic sensors are more robust, with longer life compared to optical, enabling factory sustainability.

> Absolute and absolute multiturn magnetic sensors are available.

Higher Accuracy and Repeatability

> Robotics repeatability requires 16-bit to 18-bit and >22-bit resolutions.

> Increased ADC resolution performance for encoders is required.

Figure 5 – Encoder trends and the technologies that will enable these trends

The magnetic multiturn memory that has been developed by Analog Devices2 requires no external power to record the number of rotations of an external magnetic field. This leads to reduced system size and cost.

For robots and cobots, motor encoders and joint encoders typically require 16-bit to 18-bit ADC performance, with the 22-bit ADCs required in some cases. High performance ADCs, with up to 24-bit resolution, are also required for some optical absolute position encoders.

MAGNETIC ENCODER (AMR)

SENSING

In the field of magnetic-based position sensors, AMR sensors provide the best combination of robustness and accuracy. The sensor is typically positioned opposite a dipole magnet attached to the motor shaft as depicted in Figure 6.

Figure 6 – An AMR sensor system

AMR sensors are sensitive to magnetic field direction changes, unlike Hall technology that is sensitive to field intensity. The resulting advantage is that the sensor is very tolerant to airgap and mechanical tolerance variation in the system. Also, as there is no operating magnetic field upper limit with AMR sensors, the sensor is extremely robust to stray magnetic fields when operating with a high magnetic field.

The ADA4571 is an AMR sensor with low latency integrated signal conditioning and provides a single-ended analog output. The ADA4571 single-chip solution provides guaranteed angular accuracy (only 0.10 typical angular error) and can operate at speeds up to 50k rpm. The ADA4571-2 is a dual version that provides full redundancy without compromising performance in applications that are safety critical.

The ADA4570 is a derivative of the AAD4571 with the same performance but with a differential output for use in harsher environments. The high angular accuracy and repeatability provided by the ADA457x family improve closed-loop control, reducing motor torque ripple and noise. The single-chip architecture improves reliability, reduces size and weight, and is easier to integrate compared to competing technologies.

SIGNAL CONDITIONING AND POWER

The AD7380 4 MSPS dual simultaneous sampling, 16-bit SAR ADC provides many system-level benefits, including a space-saving 3 mm × 3 mm package important for space-constrained encoder PCB boards. The 4 MSPS throughput rate ensures that detailed sine and cosine cycles are captured, and encoder positions are up to date. The high throughput rate enables oversampling on-chip, which reduces the time penalty of digital ASICs or microcontrollers feeding the precise encoder position to the motor. An extra benefit of the AD7380's on-chip oversampling is that it allows for an additional 2 bits of resolution, which can be easily used with an on-chip resolution boost feature. Application note AN-2003[3] details this oversampling and resolution boost feature of the AD7380. The V_{CC} and V_{DRIVE} of the ADC and the supply rails of the amplifier driver can be powered by an LDO regulator, such as the LT3023.

Multiple output low noise LDOs such as the ADP320, LT3023, and LT3029 can be used to power all components in the signal chain.

TRANSCEIVER

The ADM3066E RS-485 transceiver features ultralow transmitter and receiver skew performance, which makes these devices ideal for transmission of a precision clock, which is often featured in motor encoding standards, such as EnDat 2.2.4 The ADM3065E has been demonstrated to show less than 5% deterministic jitter across typical cable lengths encountered in motor control applications. The wide supply range of the ADM3065E means this level of timing performance is available for applications that require either a 3.3 V or 5 V transceiver power supply. For more information, see the technical article "Going Faster and Further with Fieldbus."[5]

MICROCONTROLLER

For applications that require lower resolutions of 12 bits or less, an alternative to using an AD7380 ADC is a microcontroller with integrated ADC. The tiny MAX32672 ultra low power Arm® Cortex®-M4F microcontroller includes a 12-bit 1 MSPS ADC with enhanced security, peripherals, and power management interfaces.

ASSET HEALTH MONITORING

The ADXL371 is an ultralow power, 3-axis, digital output, ±200 g microelectromechanical system (MEMS) accelerometer for machine monitoring. The ADXL371 is cost-effective, available in a small 3 mm × 3 mm package, and operates at up to +105°C. In instant on mode, the ADXL371 consumes 1.7 µA while continuously monitoring the environment for impacts. When an impact event that exceeds the internally set threshold is detected, the device switches to normal operating mode fast enough to record the event.

The ADT7320 is a high accuracy digital temperature sensor, which requires no user calibration or correction and excellent long-term stability and reliability. The ADT7320 is rated for operation over an extended range of –40°C to +150°C and is available in a small 4 mm × 4 mm LFCSP package.

Component	Recommended Part Numbers
MEMS Accelerometer	ADXL371, ADXL372, ADXL314, ADXL375
Temperature Sensor	ADT7320
Power (LDO Regulator)	ADP320, LT3023, LT3029
ADC, 12-Bit, 16-Bit SAR	MAX11198, AD7380, AD7866
AMR Magnetic Sensor	ADA4570, ADA4571, AD4571-2
Dual Comparator	LTC6702
Transceiver (RS-485, RS-422)	MAX22506E, ADM3066E, ADM4168E, MAX22500E
Microcontroller, Integrated ADC	MAX32672, MAX32662

Table 3 – Magnetic Encoder (AMR) Signal Chain Recommended Components

Figure 7 – Magnetic encoder (AMR) signal chain

MOTOR ENCODER SIGNAL CHAINS

Figures 6, 7, 8, and 9 illustrate encoder signal chains for magnetic (anisotropic magnetoresistive (AMR) and Hall technologies), optical, and resolver encoders. The components are grouped into five main categories:

1. Tracking shaft position and speed using magnetic sensors (AMR, Hall)

2. Machine health monitoring
   a. MEMS sensors
   b. Temperature sensors

3. Intelligence
   a. Microcontroller with/ without integrated ADC
   b. Resolver-to-digital converter (RDC)

4. Cable interface
   a. High speed RS-485/ RS-422 transceiver
   b. SPI to RS-485 extender transceiver

5. Signal conditioning
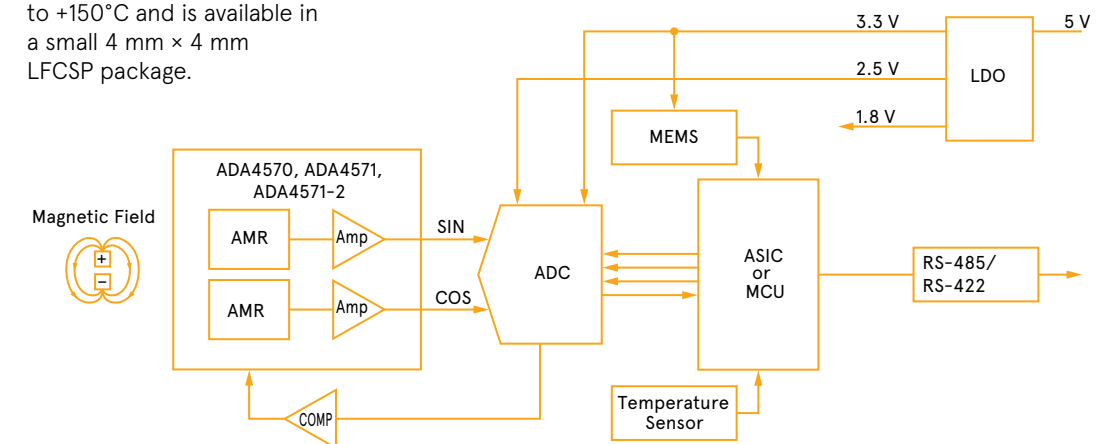   a. High performance ADCs (12-bit to 24-bit resolution)
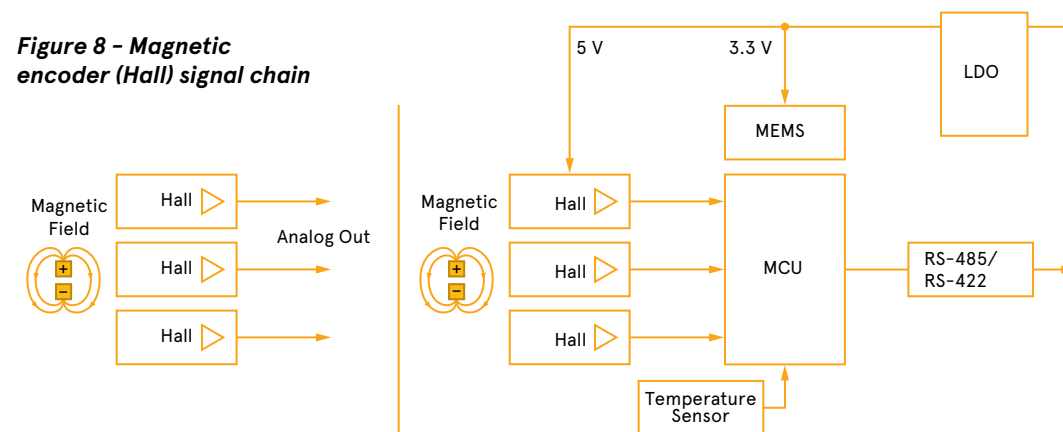
MAGNETIC ENCODER (HALL)

A Hall encoder can be designed using the AD22151 or the AD22151G. The AD22151G is a linear magnetic field transducer. The sensor output is a voltage proportional to a magnetic field applied perpendicularly to the package top surface. To design the encoder system, equally spaced magnets are placed on a rotating motor shaft. As the rotating shaft magnets pass the Hall sensors, the voltage output from the sensor peaks. Using more magnets or sensors produces more resolution.

The Hall effect encoder can use the MAX32672 and ADM3066E for the wired interface. The ADXL371 MEMS and ADT7320 offer condition monitoring for harsh encoder environments. The Magnetic Encoder (AMR) section provides more information on these signal chain components.

Component	Recommended Part Numbers
MEMS Accelerometer	ADXL371, ADXL372, ADXL314, ADXL375
Temperature Sensor	ADT7320
Power (LDO Regulator)	ADP120, ADP220, ADP320, LT3023, LT3029, LT3024, LT3027
Transceiver (RS-485/RS-422)	MAX22506E, ADM3066E, ADM4168E, MAX22500E
Hall Sensor	AD22151, AD22151G
Microcontroller, Integrated ADC	MAX32672, MAX32662

Table 4 – Magnetic Encoder (Hall) Signal Chain Recommended Components

Figure 8 – Magnetic encoder (Hall) signal chain

OPTICAL ENCODER

The optical encoder signal chain components are almost identical to those described in the Magnetic Encoder (AMR) section. However, to support higher encoder resolutions, the AD7760 2.5 MSPS, 24-bit, 100 dB sigma-delta (Σ-Δ) ADC is recommended. It combines wide input bandwidth and high speed with the benefits of sigma-delta conversion to achieve a performance of 100 dB SNR at 2.5 MSPS, making it ideal for high speed data acquisition.

Figure 9 – Optical encoder signal chain
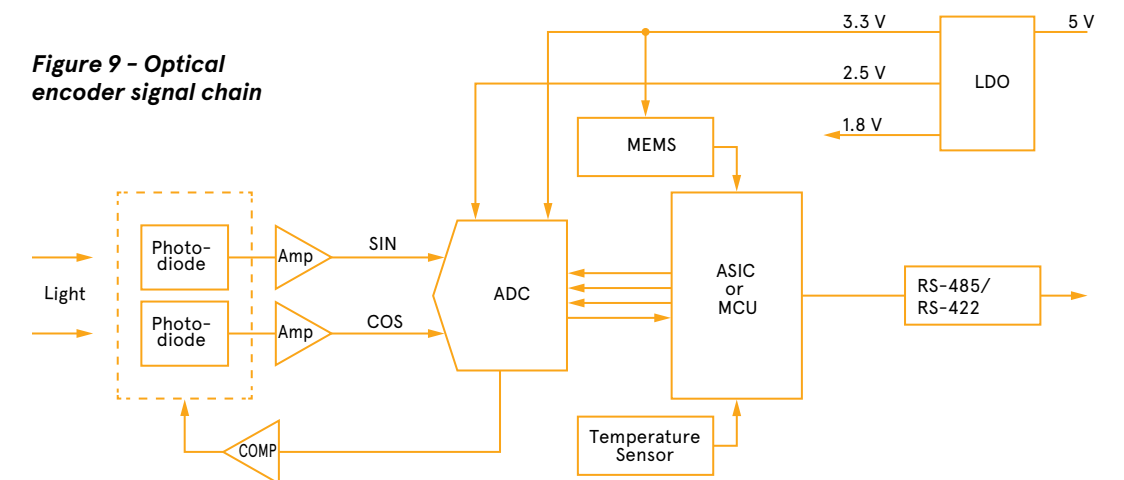
RESOLVER (COUPLED) ENCODER

A resolver encoder has some advantages, such as high mechanical reliability and accuracy; however, compared to a magnet and ADA4571, a resolver is expensive.

The AD2S1200 converts the signal from the resolver to the digital angle/angular rate. Figure 10 shows the resolver signal chain. Two amplifiers are used to create a third-order Butterworth low-pass filter to pass the resolver signals to the AD2S1200. Refer to Circuit Note CN0276 for more information.

To save space and reduce design complexity, the LTC4332 SPI extender is recommended. The LTC4332 enables system partitioning, providing the option of placing the microcontroller at the servo, rather than at the encoder. If a microcontroller is required at the encoder, the MAX32672 SPI interface can be used as the direct link to the AD2S1200 and the ADM3065E RS-485 transceiver can be used instead of the LTC4332.

If the LTC4332 is used, the AD2S1200 SPI output is converted to a robust differential fieldbus interface. The LTC4332 includes three subordinate select lines, so additional sensors such as MEMS and temperature sensors can be wired on the same bus as the AD2S1200.

Component	Recommended Part Numbers
MEMS Accelerometer	ADXL371, ADXL372, ADXL314, ADXL375
Temperature Sensor	ADT7320
Power (LDO)	ADP320, LT3023, LT3029
ADC, 12-Bit, 16-Bit, 24-Bit	MAX11198, AD7380, AD7866, AD7760
Precision Op Amp	ADA4622-4
Dual Comparator	LTC6702
Transceiver (RS-485, RS-422)	MAX22506E, ADM3066E, ADM4168E, MAX22500E
Microcontroller, Integrated ADC	MAX32672, MAX32662

Table 5 – Optical Encoder Signal Chain Recommended

Figure 10 – Resolver encoder signal chain
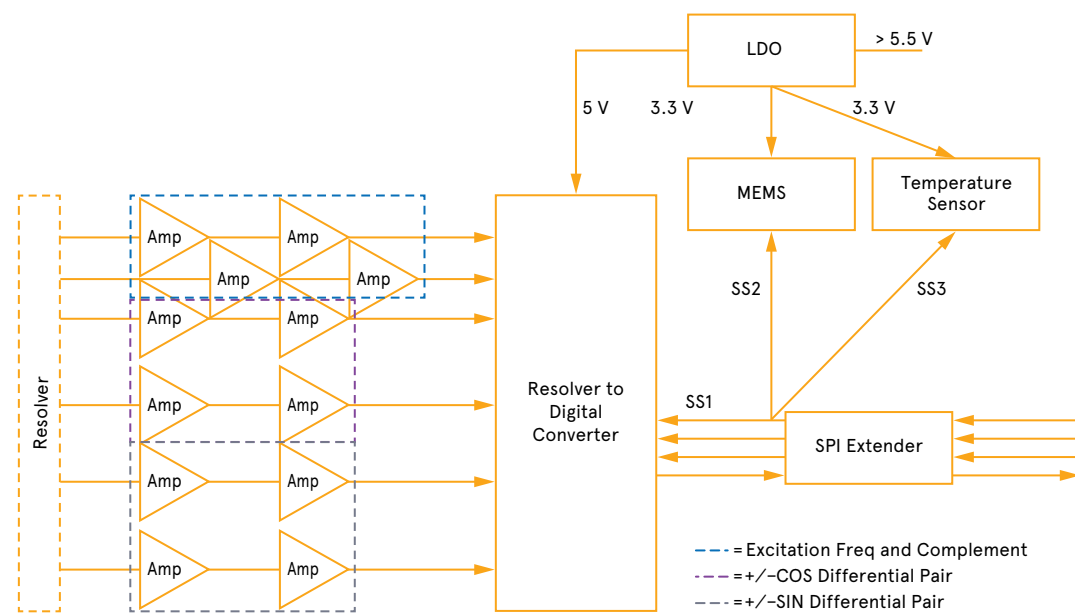
Component	Recommended Part Numbers
MEMS Accelerometer	ADXL371, ADXL372, ADXL314, ADXL375
Temperature Sensor	ADT7320
Power (LDO Regulator)	ADP120, ADP220, ADP320, LT3023, LT3029, LT3024, LT3027
Precision Op Amp	AD8694, AD8692, AD8397
Transceiver (SPI/RS-485, RS-485)	LTC4332, ADM3065E
Resolver-to-Digital Converter	AD2S1200, AD2S1205, AD2S1210

Table 6 – Resolver Encoder Signal Chain Recommended

ABOUT THE AUTHOR

Richard Anslow is a senior manager, working in the field of software systems design engineering within the Industrial Automation Business Unit at Analog Devices. His areas of expertise are condition-based monitoring, motor control, and industrial communication design. He received his B.Eng. and M.Eng. degrees from the University of Limerick, Limerick, Ireland. Recently, he completed a postgraduate program in AI and ML with Purdue University.

CONCLUSION

Analog Devices' deep domain expertise and advanced technologies help partners design the industrial motor encoders and networks of the future. Integrating asset health insights in encoders is made easy with tiny and powerful microcontrollers, ADXL371 MEMS, and ADT7320 temperature sensors. ADI's industry-leading AMR magnetic sensors, such as the ADA4571, improve reliability, reduce size and weight, and are easier to integrate into an encoder compared to optical or resolver sensing solutions. High accuracy and repeatability for pick and place machines and robots are possible with mid to high end ADCs such as the AD7380 or AD7760.

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Born in the wake of Arduino's success in the maker community and in the educational field, Arduino Pro has quickly made a name for itself in the professional market, from R&D prototyping to mass-production deployment.

ARDUINO PRO UNLOCKS THE SIMPLICITY AND SUCCESS OF OPEN SOURCE FOR INDUSTRY 4.0

With a veritable ecosystem of hardware products, software tools and Cloud services, the brand has made great strides in the industrial world, offering a range of products that are versatile, customizable, powerful and reliable, while maintaining the ease of use and convenience that have determined the company's success since its founding in 2008.

Too good to be true? Let's have a look at some of the offerings that are putting Arduino Pro front and center in the Fourth Industrial Revolution.
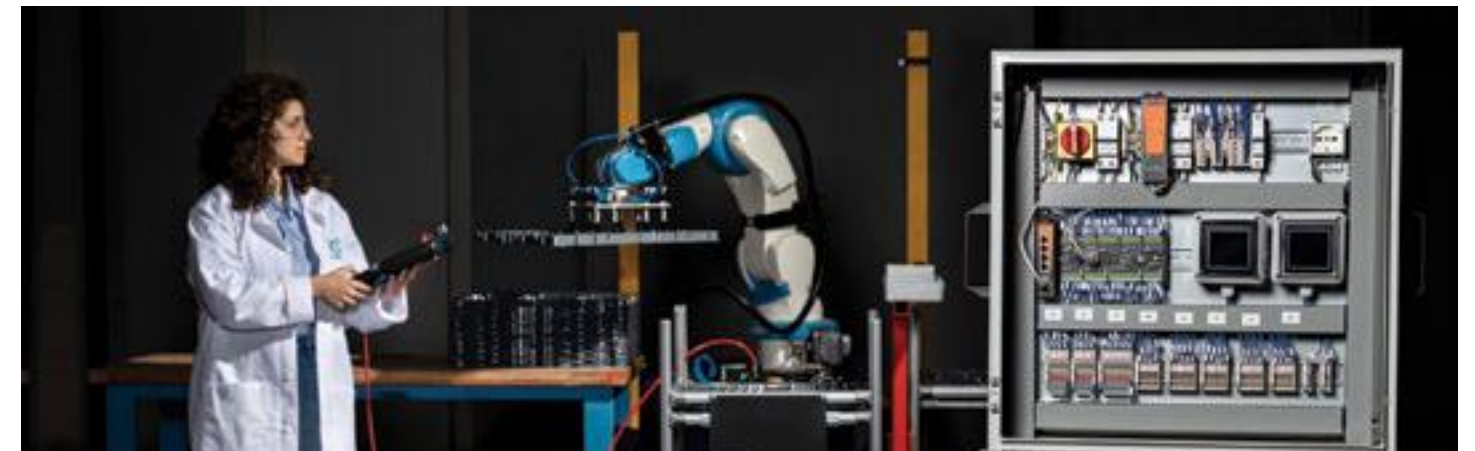
OPTA: FOR INDUSTRIAL AUTOMATION

Opta is Arduino Pro's first micro PLC. Designed in partnership with Finder, a leading industrial and building automation device manufacturer, Opta is born for high-level IoT (Internet of Things). Programmable within the Arduino environment, including with standard PLC languages, it offers a powerful STM32H747XI dual-core Cortex®-M7 +M4 MCU to perform real-time control, carry out monitoring and implement predictive maintenance applications. Secure and durable, it supports OTA firmware updates and ensures full data security, from the hardware to the Cloud, thanks to an onboard secure element and X.509 standard compliance.

Opta accelerates any automation project's turnaround, because it combines industrial-grade features with the ease-of-use and speed that the Arduino ecosystem is known for – also thanks to numerous readily available software libraries and sketches.

Released in three connectivity variants (Opta Lite, Opta RS485 and Opta WiFi), it is the ideal solution to keep everything under control in a simple and intuitive way, through dashboards constantly updated via the Arduino Cloud (or third-party services).

NICLA: ADVANCED SENSING

The Nicla family consists of super-compact modules (the form factor is just 22.86x22.86 mm!) designed to integrate AI and machine learning into a wide range of industrial applications. High sensor quality and low power consumption are the perfect combination to sense, see and hear any event, anywhere it may happen – at the heart of autonomous, battery-operated systems.

In particular, Nicla Sense ME, developed in collaboration with Bosch Sensortec, integrates motion and environmental sensors with Bluetooth® connectivity and is suitable for industrial and building automation projects capable of leveraging advanced sensor fusion and TinyML.

Nicla Vision features a 2 MP color camera and the intelligence required to process its images, so it can extract useful information from what it sees – so you can keep your eye on the big picture.

Finally, Nicla Voice was developed with a powerful NDP120 Neural Decision Processor by Syntiant, which mimics human neural pathways to enable the integration of speech recognition into any project, running multiple AI algorithms and automating even the most complex of tasks. But that's not all: Nicla Voice comes with a comprehensive package of sensors: in addition to its high-performance microphone, it features a smart 6-axis motion sensor and a magnetometer, making it your perfect ally for predictive maintenance, gesture/voice recognition and contactless applications.

PORTENTA MACHINE CONTROL: INDUSTRY-GRADE INTELLIGENCE

Portenta Machine Control is a fully centralized, low-power, compact industrial control unit ready for DIN-rail installation, capable of driving a wide range of equipment and machines. Simply put, it's the IoT brain you can add to existing machinery or new projects to retrofit, upgrade or develop your ideas in entirely new directions.

Perfect for real-time data collection, Portenta Machine Control supports local and remote equipment control, even via the Cloud. How? It can connect to the network directly through Ethernet or use Wi-Fi and Bluetooth® Low Energy technologies to ensure low-cost, fast and stable data transmission, all while guaranteeing safe information exchanges thanks to its internal crypto chip. It is ideal for predictive maintenance and AI integration in the factory, and easy to program according to the Arduino framework or with standard PLC languages.
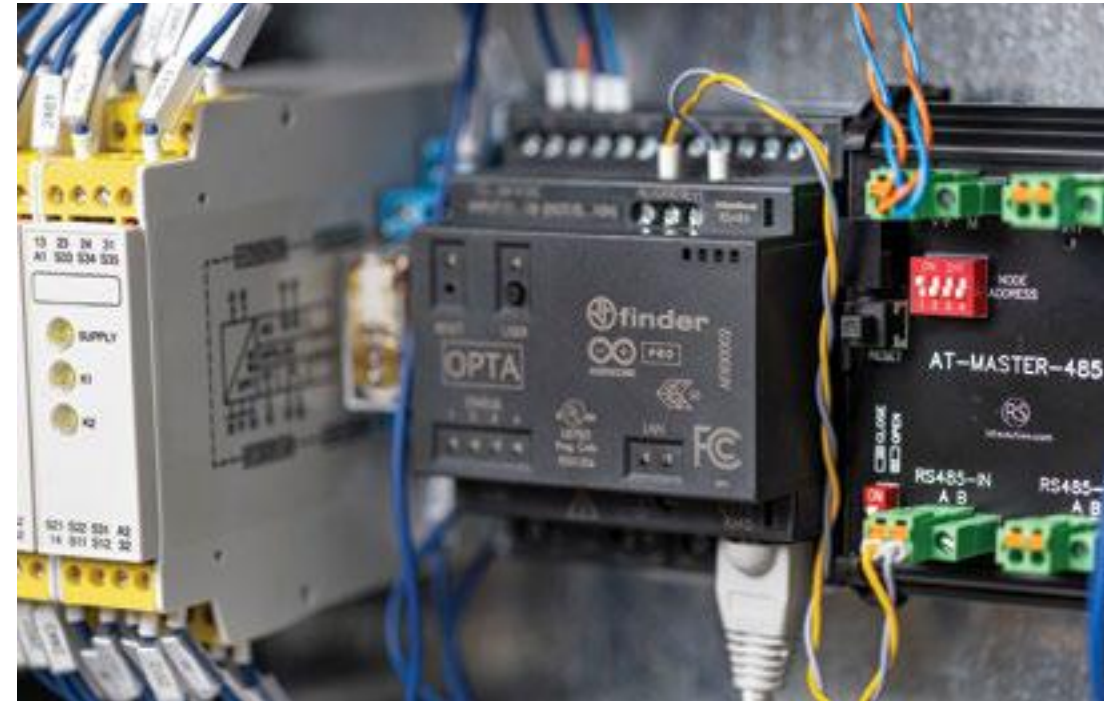
AUTOMATING AUTOMOTIVE: HOW PORTENTA H7 ROSE TO THE CHALLENGE

Arduino Pro's Portenta range includes high-performance, industry-rated boards such as Portenta H7, Portenta X8 and the more recent Portenta C33. Countless companies have already adopted these powerful modules to improve their production processes and product offering. A great example of this is Mercedes-Benz subsidiary Montajes y Estampaciones Metálicas (MEM), which manufactures the leading carmaker's V-Class and Vito frames near Barcelona. Arduino partnered with Engapplic, a Spanish IIoT solutions provider, to create an Automated Guided Vehicle (AGV) controller for them based upon Portenta H7.

Portenta H7 can be programmed with high-level languages and AI while performing low-latency operations. It has two parallel cores to simultaneously run high-level code along with real-time tasks: its main processor is the STMicroelectronics dual-core STM32H747 including a Cortex® M7 running at 480 MHz and a Cortex® M4 running at 240 MHz. The two cores communicate via a Remote Procedure Call mechanism that allows calling functions on the other processor seamlessly.

This was the perfect answer when Mercedes needed to replace a 25-year-old machine with a new AGV controller that would transport pieces around the factory to different vehicle assembly stations, with the intelligence to collaborate into the production process, enabling managers to track manufacturing parts and better monitor activities in the factory – in other words, take a new step towards Industry 4.0.

The final solution also needed to be capable of having different drivers of communication, such as the CAN protocol, and be a modular system that was able to work with and resolve incidents. It also had to have low power consumption, monitor battery data, switch on in less than one second, and guarantee long-lasting performance with a 10-year warranty.

Engapplic chose Arduino Pro's Portenta H7 for its high modularity, creating a solution where a single dashboard allows users to monitor energy, inputs and outputs and control engines. The dual core functionality of Portenta H7 is beneficial in controlling the actions in the AGV: the real-time management is carried out with the M4 core that regulates the inputs and outputs, while the M7 core is utilized for the motorization of the battery.

Being both easy to program and highly customizable, Portenta H7 enabled rapid development of the solution with a 50% cost saving versus equivalent controllers. Furthermore, basing the project on open-source hardware allows for the addition of other functions in the future, making it ready for Industry 4.0 and any new evolution in the manufacturing field.

WHY CHOOSE OPEN SOURCE?

With products such as these available, it is clear why a growing number of companies today recognize the benefits of the open source approach. Highly flexible, scalable and customizable, these solutions are able to meet the specific needs of different industries and adapt quickly to market conditions and emerging needs, avoiding so-called "vendor lock-in". This versatility is also often combined with a significant reduction in costs compared to proprietary alternatives, also thanks to the large and growing community of open-source developers. On the other hand, Arduino Pro's support in licensing management ensures that companies can effectively protect their intellectual property.

So, are you ready to explore the cutting-edge of technology for your business – from IoT to AI – and reap the benefits of a new level of innovation that is readily available, easy to customize and, of course, open to all? Arduino Pro's ecosystem is ready to introduce you to the many benefits and opportunities of Industry 4.0, and to be at your side every step of the way.

CONCLUSION

Learn more about industrial-grade Nicla sensor platform, Portenta H7 family and Arduino Opta microPLC with Industrial IoT capabilities.

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MICROCHIP

VISIT MICROCHIP

BRINGING ETHERNET TO THE EDGE WITH 10BASE-T1S TECHNOLOGY

By Henry Muyshondt, Senior Manager, Microchip Technology

Today, many different technologies are used to interconnect devices in industrial applications, whether for factory or process automation, building or home automation, computer server backplanes, or automotive networks. These technologies include field buses, RS-485, UARTs, CAN and other technologies are found in these systems.

All these technologies pose their own challenges in implementation, with each having their own hardware and software interfaces and differing characteristics such as EMC performance.

One of the best options is to use an all-Ethernet architecture, which greatly simplifies how a system is created and managed. This brings a number of benefits:

> The same protocols are used, whatever the speed of the physical layer

> The security infrastructure is well understood and proven. Devices can be reliably authenticated and data can be encrypted in standardized ways. Software and firmware can be securely updated in remote devices.

> Ethernet is commonly used, both in the information technology (IT) and operational technology (OT) worlds.

CLOSER TO THE EDGE

Ethernet fits well with the trend to move from distributed systems, which tend to be defined by the hardware involved, to more centralized, software defined systems. In this technique, a number of application-specific buses are replaced by an IP-based and ubiquitous Ethernet network.

This eliminates the need for gateways to translate between different hardware approaches, cutting the complex wiring needed. Instead, low-cost, single-pair cabling brings Ethernet all the way to the edge of the network.

Traditional IT networks enable communications at the highest levels, while OT networks are used within buildings to control processes and assembly lines. As we get closer to the edge of the enterprise network, sensors, actuators, and other low-level devices become common.

Ethernet allows a common way to connect and communicate with all these elements to make their data available to higher levels.

Legacy systems use many different hardware approaches, each with its own software infrastructure.

By contrast, in an All-Ethernet implementation, the communication software stack is the same for all Ethernet devices, meaning it is much easier to scale the bandwidth to move increasing amounts of data.

The result is a more powerful, flexible network to meet a range of industrial challenges. It also aids in producing functional safety, where automatic protections make sure systems fail in a predictable manner (fail-safe). Functional safety is a system-level concept. Many Microchip products are functional-safety ready to help system designers create complete systems.

Figure 1 – Legacy systems use many different hardware approaches, each with its own software infrastructure

Single Pair Ethernet reduces system cost, weight and wiring complexity
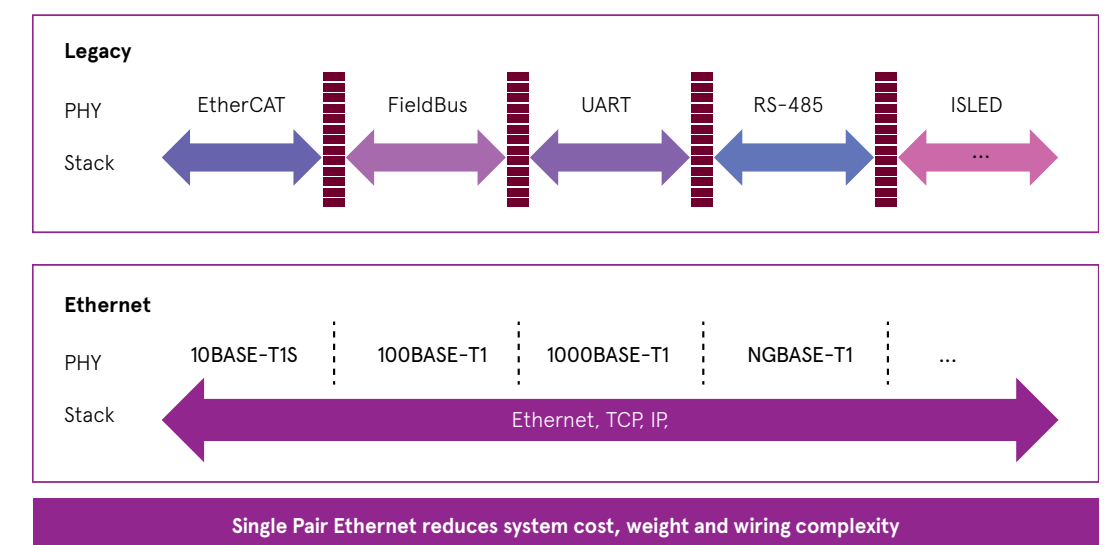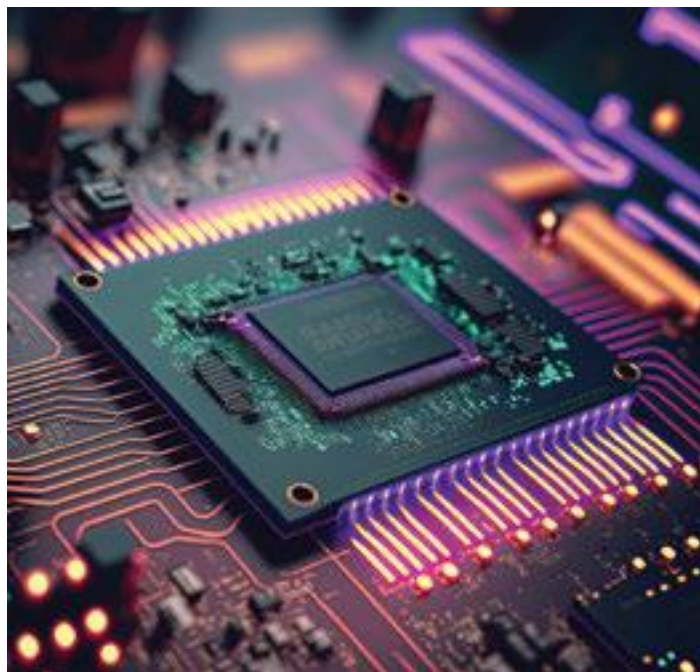
SINGLE PAIR ETHERNET

Bringing Ethernet all the way to actuators and sensors at the edge is achieved using Single Pair Ethernet or SPE.

SPE is also referred to as T1 or T1 Ethernet, which refers to one balanced pair of wires. Some applications use a twisted pair of wires, but others use just two wires running alongside each other.

SPE only defines the physical connections of an Ethernet system, with all the higher software layers remaining unchanged. This ensures a seamless architecture that encompasses all speeds.

One of these SPE Ethernet technologies is 10BASE-T1S.

The first part of the name specifies the bandwidth in Mbit/s – thus 10BASE means 10 Mbit/s, while the letter after T1 refers to the range of the technology, in this case S for short reach. There are standards for 10BASE-T1S, 10BASE-T1L (L for Long reach), 100BASE-T1 and 1000BASE-T1. Even higher data rates are being defined for 2.5, 5 and 10 Gbit/s.

10BASE-T1S support the mechanisms used in Audio Video Bridging (AVB) and Time Sensitive Network (TSN) applications. Networks can be fully synchronized using the IEEE 1588 protocols, along with other TSN mechanisms.

DEFINING THE STANDARD

10BASE-T1S technology is defined by the IEEE 802.3cg standard published in 2019, with Microchip being one of the key participants. It uses a single balanced pair of conductors, which can be a single twisted pair of wires, other configurations for wire pairs, or even parallel traces on a printed circuit board or server backplane.

The standard was developed to expand Ethernet to the edge of OT networks. 10 Mbit/s was deemed a good bandwidth to provide for future growth, as existing systems had bandwidths of hundreds of kilobits per second.

The technology uses half-duplex communication and allows a flexible topology, with options from point-to-point to multidrop configurations, where multiple devices connect to a bus line formed of a single pair of wires.

A WIDE RANGE OF APPLICATIONS

It is often thought that SPE or T1 devices are just for the automotive world. In reality, they have many different applications in industry, home and building automation, computer servers, and other transportation fields.

Factory automation typically involves many sensors and actuators to control assembly lines and packaging machines. Other industrial applications include racks built into cabinets with an intra-system management interface along with temperature sensors, fans, voltage monitors, DC-to-DC converters and other modules.

Control units will have many on/off switches, buttons, converters, relays and I/O cards that need to be controlled and which provide data for the overall system.

Building automation includes lighting applications, elevators, HVAC, solar power systems and a variety of sensors. This is another example where many devices with relatively low bandwidth requirements can benefit from communication over a common network interface.

Computer servers and other electronic systems have many of the same requirements as industrial applications in compact frames. They also have intra-system management interfaces with switches, temperature sensors, fans and voltage monitors, among others.

Backplanes are used to configure and monitor boards plugged into slots.

Traditionally, I2C has been used for this purpose – however, 10BASE-T1S provides much more flexibility and a simpler mechanism to control and communicate with multiple devices.

Essentially, SPE can be used for any application that involves communicating with different sensors and actuators and requires the movement of information and control data.

INCREASE REVENUES

One of the major benefits of 10BASE-T1S is that it improves revenue, because it helps create new and innovative products that bring Ethernet to the edges of IIoT networks.

Data can be accessed at the far reaches of the network – all levels of the network can access the data, since it uses one common format. Operations can be controlled more easily and insights can be gained through comprehensive access to all connected components.

Costs are also reduced through the use of simpler components, simpler software and common wiring. With Ethernet, there is no need for complex gateways to translate between the different legacy hardware and software used in the past. Ethernet switches already know how to send different data rates to different ports, and a common frame structure between the ports removes the need to modify the data as it is transmitted.

The multidrop architecture of 10BASE-T1S reduces cost by cutting the number of ports needed in Ethernet switches, as multiple devices connect to a common bus line.

The single pair of wires of 10BASE-T1S is also easier to install, lighter, more flexible and more cost effective.

REDUCE RISK

Along with increasing revenue and reducing cost, 10BASE-T1S helps mitigate risk by using unified interfaces and well-established security mechanisms throughout the enterprise.

Having Ethernet connectivity at the edge of the network can make use of design resources and reduce risk by enabling compatible hardware and software design, development, testing and maintenance at all levels of IT and OT networks.

MICROCHIP OFFERS RESOURCES FOR DESIGNERS

Microchip offers resources to design and develop complete networks. Its 10BASE-T1S RMII and MII Evaluation boards fit onto many Microchip microcontroller boards – they can also be attached to customer designs. They are compact and include an Ethernet Bus Interface Network or BIN, also known as an Analog Front End or AFE.

The 10BASE-T1S PHY USB Evaluation Board can be plugged into a USB host to make it a 10BASE-T1S node. This evaluation board comes with drivers for both Linux and Windows.

Microchip's MPLAB® Harmony Development Framework includes support to integrate 10BASE-T1S technology with Microchip microcontrollers and microprocessors.

These products make it easier to design solutions that bring Ethernet closer to the edge, allowing many more companies to easily capture data from remote sensors and benefit more fully from the Industrial Internet of Things.
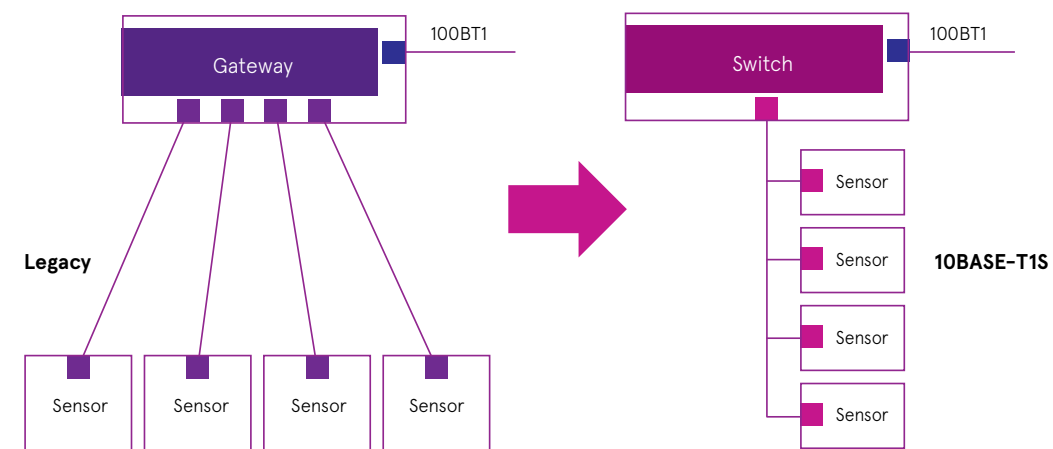
Figure 2 – Costs are reduced by simpler components, software and wiring

CONCLUSION

Jump-start your designs that require 10BASE-T1S Single-Pair Ethernet (SPE) communication and high-performance cores with deterministic response and rich peripherals.

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THE ONGOING EVOLUTION OF INDUSTRY 4.0:

TOP TRENDS WORTH WATCHING

Ever since the first programmable logic controller (PLC) was developed in the late 1960s, pundits have been predicting when the fourth industrial revolution would occur. This long-anticipated milestone, dubbed Industry 4.0, is now upon us—and it carries the promise of integrated, real-time data accessibility that can control costs and curtail downtime.

While the third industrial revolution enhanced assembly line operations with greater automation and computerized control, the fourth actually builds on those capabilities by incorporating internet-driven connectivity. Consequently, in many respects, this new phase may actually represent something of an evolution. Smart factories essentially combine operational technology (OT) like software-defined assembly line equipment with advanced information technology (IT) like cloud computing and artificial intelligence (AI) to bring high-speed, low-latency responsiveness to the factory floor.

In the Industry 4.0 ecosystem, the underlying objective is capturing and analyzing information to reduce bottlenecks, optimize throughput, enact preventive maintenance and avoid delays—thereby unlocking supply chain and operational efficiencies that create competitive advantage.

Fully embracing this new frontier means leveraging machine learning (ML) and robotic process automation across the Industrial Internet of Things (IIoT) to design smart factories that can self-regulate in real time for more informed, autonomous decision making.

Succinct as that may sound, however, the actual Industry 4.0 implementation roadmap isn't necessarily simple to navigate. Because so many of the systems underpinning these applications are proprietary, integrating new technology that fuels smart manufacturing can be daunting. At the same time, engineering more intelligent equipment introduces hurdles that can't be realistically resolved by expanding physical space or rebuilding existing facilities. More autonomous operation also introduces unique safety and cybersecurity concerns.

All this means that flexibility, awareness and persistence are imperative for organizations hoping to maximize the possibilities of Industry 4.0. A clear understanding of evolving trends can lead to coordinated strategies that identify future-proof approaches, address potential pain points and encourage multi-level business buy-in.

As an array of comprehensive advances converge to revolutionize capabilities across the value chain, here are three unfolding Industry 4.0 technology trends to watch.

TREND 1:

SMARTER MACHINES ARE TRANSFORMING SYSTEM-WIDE COMMUNICATION

Achieving the full potential of Industry 4.0 means making relevant data available in ways that enable timely decision making and utilize next-generation technologies. Today's industrial automation (IA) supply chain is already incorporating these next-generation technologies in smart machines that feature augmented computational capabilities to perform more advanced analytics.

Unfortunately, engineers are encountering existing IA command structures that are often outdated or unwieldy. Successfully addressing this challenge can directly support streamlined flexibility and smarter connectivity across a robust, scalable and integrated manufacturing platform. One way to achieve this flexibility increase is by incorporating dedicated machine logic that eliminates the PLC altogether.

Eliminating the PLC can considerably reduce cabinet size while improving overall cost structures PLC elimination also boosts the efficiency of advanced robotics by applying logic locally, on a machine-to-machine (M2M) basis instead of top-down. M2M communication thereby facilitates automatic production and assembly line adjustments without episodic equipment resetting or human intervention.

Because Industry 4.0 advances add considerable systemic complexity, it's equally crucial to help these smart machines identify issues and communicate meaningfully with elements and operators across the entire distributed network. This is where innovative sensor functionality helps today's manufacturers maximize smart machine capabilities and optimize real-time data access. It's not enough for sensor solutions to simply identify a wide variety of objects and properties—they also need to withstand harsh industrial conditions while fitting into size-constrained areas.

FEATURED PRODUCT

Molex offers specialized sensors that are engineered to enable smarter, more agile factories. Our self-contained Contrinex Inductive and Photoelectric Sensors, for instance, offer the following advantages:

> Single-piece metal housings that make them virtually impervious to shock, vibration or rough handling, which could cause signal interference

> Full compliance with IP67, 68, 69K and Ecolab standards to withstand debris ingress and external hazards

> Compact size and extensive sensing range, making them ideal for limited-space environments comprised of numerous integrated components

> Integrated I/O link, which continuously monitors process-related input for uninterrupted assessment of operational status and more robust communication

> Application-specific integrated circuit (ASIC) technology, which helps ensure long life and dependable performance

> Patented ultraviolet (UV) technology integrated into the photoelectric option, which detects thin or transparent objects at distances of up to 1200mm

Sensors serve as a vital link that can make smart machines more self-aware, so Molex is equipping customers with ruggedized innovations that reflect 80+ years of industrial communications and miniaturization expertise.

TREND 2:

POWER DEMANDS ARE EXPANDING SUBSTANTIALLY

Engineering professionals who responded to the latest Molex "State of Power" survey indicate that industrial power management is their number-one concern by a whopping 40% margin. This is likely because self-monitoring assembly lines are governed by sophisticated ML modules that inspect products, analyze information, calculate appropriate adjustments and course-correct as issues arise. That degree of integrated functionality represents an extensive information network—one that consists of sizeable machines, specialized wiring and numerous interconnected devices like cameras, actuators, control units and sensors.

All these advanced capabilities introduce a higher demand for electrical power and potential electrical upgrades such as transformers, switchgear and power distribution panels. Those signal and power elements need to be engineered for extremely unforgiving and often space-constrained operating conditions, while delivering high current carrying capacity and uninterrupted performance. Under these exacting circumstances, safe and reliable connectivity is a critical priority.

FEATURED PRODUCTS

Recognizing this vital need, Molex offers several solutions designed to help advanced industrial environments optimize efficient power management.

Sentrality High-Current Pin and Socket Interconnects are one example. They incorporate several advantageous features, including:

> The patented Molex COEUR socket design, a conical shape that creates multiple contact beams to provide added surface area at the contact interface—fostering very low contact resistance

> Extremely low voltage drop across the contact interface, resulting in minimal heat generation and higher current-carrying capacity compared to other contact designs

> Proprietary OmniGlide technology from Molex, which enables an industry-leading radial self-alignment of up to 1.00mm—avoiding tolerance stack-up issues while minimizing potential connector and contact beam damage during mating

> Multiple connectivity options to address a diverse range of industrial needs—including board-to-board, busbar-to-board and busbar-to-busbar

The Molex Brad M12 Power L-Code Connector System is another offering that's optimized for Industry 4.0 demands. This compact yet high-capacity solution:

> Adheres to PROFIBUS and PROFINET International (PI) standards for PROFINET systems, making it fully compatible with existing infrastructure

> Delivers up to 4 times the power of standard M12 connectors

> Is engineered to mitigate wiring and assembly errors

> Offers added ingress protection and peace of mind in harsh industrial environments, thanks to Molex Flamar weld-slag and oil-resistant (WSOR) cabling and an IP67-sealed interface

Industry 4.0 equipment requires leading-edge power solutions that can endure the rigors of automated smart factory environments. Molex is helping customers enhance the value chain with intelligent and robust power management innovations.

TREND 3:

SAFETY INITIATIVES ARE AN EVEN HIGHER PRIORITY

Particularly in light of the high-current power demands, integrated systems running largely unsupervised need active safety protocols. This is especially true given the humidity, shock, vibration, harsh chemicals and temperature extremes typically present on factory floors. Machinery in constant motion also creates its own inherent safety concerns.

Additionally, despite the autonomous foundation of Industry 4.0, a genuine "lights-off" factory floor isn't necessarily attainable—because while numerous aspects of production can be addressed by intelligent automation, some level of human oversight will always be required. Personnel will still need to access the factory floor for maintenance or troubleshooting, for example. These human operators require safe conditions to carry out their various roles.

Cybersecurity is another key aspect of safety when it comes to Industry 4.0. This is because interconnected devices sharing information via the internet can introduce potential information vulnerabilities as various OT and IT elements converge—and interception tactics are constantly evolving.

All these issues underscore the need for dependable interconnectivity options that support safe operation, rapid communication and timely mitigation should hazardous concerns arise. In addition to facilitating rigorous external awareness, connectivity solutions also need to accommodate the broad range of distributed control protocols currently employed by industrial manufacturing networks—thereby supporting implementation of both physical safety and cybersecurity measures.

FEATURED PRODUCT

This is why Molex offers machine-mountable Harsh I/O Modules that serve as simple yet reliable solutions for connecting industrial controllers to I/O devices in unpredictable factory environments. Harsh I/O Modules offer:

> Housings that are IP67-rated to withstand dust and moisture ingress

> Full compliance with all major fieldbus standards including CANopen, EtherNet/IP, CIP Safety and PROFINET, to optimize flexibility

> Diagnostic LEDs that enable ongoing visual awareness of network, I/O and power status for safe, consistent productivity

As Industry 4.0 continues to evolve, sustained safety is imperative for smooth, efficient equipment operation. Molex supports customers with rugged yet adaptable interconnect solutions that perform reliably in hazardous environments, while aligning with current communication and security protocols at every level.

INDUSTRY 4.0 ILLUSTRATES THAT STEADFAST CONNECTIONS ARE KEY

The interconnected systems that comprise Industry 4.0—including robots, ML and machine-to-machine communications—are enabling smarter factories that improve real-time responsiveness while measurably enhancing efficiency. Updating and evolving existing systems creates an array of unique challenges that include integrated M2M communication, power management, operational safety and more. To successfully address these complex issues, organizations can align themselves with experienced industry allies who are able to provide trend-related insights and deliver targeted solutions. If there's one crucial long-term takeaway from Industry 4.0, it's the enduring importance of dependable connections.

CONCLUSION

As Molex continues to establish new standards in industrial automation, Farnell is expanding its product range to offer you the latest innovations and essential connectivity solutions that have been integral to our portfolio for generations. Explore the newest innovations from Molex.

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Reliable Connectivity for the Factory of the Future

The interconnected systems that comprise Industry 4.0 are enabling smarter factories that improve real-time responsiveness and increased efficiency. But if there's one crucial takeaway from Industry 4.0, it's the enduring importance of dependable connections.

From robotics to machine learning and machine-to-machine communication, it's the cables, connectors, and communication systems that bring everything together.

Discover the Molex rugged, high-performance industrial automation solutions engineered to help take on the toughest conditions and empower adaptive efficiency.

Discover our broad range of industrial connectivity solutions, in stock and available today from Farnell:

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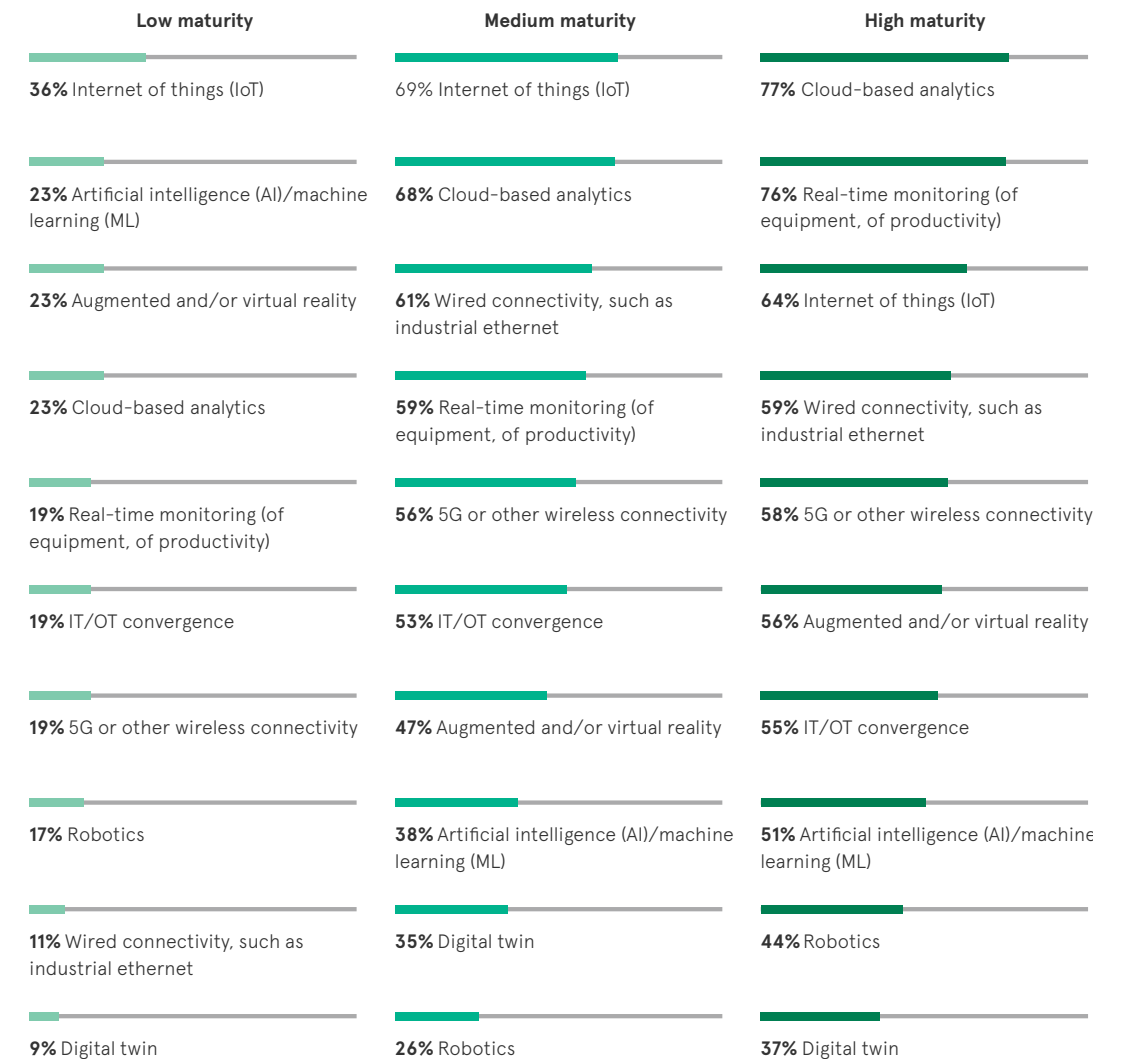
creating connections for life

WHY SINGLE PAIR ETHERNET IS BECOMING INCREASINGLY CRITICAL TO **FACTORY AUTOMATION**

In asset-intensive industries such as manufacturing, the industrial internet of things (IIoT) provides a connection between physical objects and digital systems elsewhere in the business. In today's data-driven environment, it allows businesses to better understand their own operations, leading to innovation and ongoing prosperity. IIoT connectivity delivers remote monitoring and visibility, and, when combined with technologies such as machine learning, it can unlock more advanced capabilities, such as predictive maintenance or insights for strategy developments.

In fact, a Forrester thought leadership paper commissioned by Analog Devices contained an online survey of 312 senior manufacturing leaders responsible for defining industrial connectivity strategy at their organisations. This found that connectivity is the foundation for the insights that drive innovation. It also compared the technology investments that companies are currently prioritising: Fig 1 shows some of the results.

"How does your company prioritize the following technology investments?"
(Showing critical priority)

Low maturity	Medium maturity	High maturity
36% Internet of things (IoT)	69% Internet of things (IoT)	**77%** Cloud-based analytics
23% Artificial intelligence (AI)/machine learning (ML)	68% Cloud-based analytics	**76%** Real-time monitoring (of equipment, of productivity)
23% Augmented and/or virtual reality	**61%** Wired connectivity, such as industrial ethernet	**64%** Internet of things (IoT)
23% Cloud-based analytics	**59%** Real-time monitoring (of equipment, of productivity)	**59%** Wired connectivity, such as industrial ethernet
19% Real-time monitoring (of equipment, of productivity)	**56%** 5G or other wireless connectivity	**58%** 5G or other wireless connectivity
19% IT/OT convergence	**53%** IT/OT convergence	**56%** Augmented and/or virtual reality
19% 5G or other wireless connectivity	**47%** Augmented and/or virtual reality	**55%** IT/OT convergence
17% Robotics	**38%** Artificial intelligence (AI)/machine learning (ML)	**51%** Artificial intelligence (AI)/machine learning (ML)
11% Wired connectivity, such as industrial ethernet	**35%** Digital twin	**44%** Robotics
9% Digital twin	**26%** Robotics	**37%** Digital twin

Nb. Low, Medium or High Maturity refers to the level of strategic importance a company gives to their innovation efforts

Figure 1 – How companies prioritise their technology investments (From Forrester Consulting Thought Leadership Paper, 'Seamless Connectivity Fuels Industrial Innovation', commissioned by Analog Devices)

Among other points, it is interesting to note that, for medium and high maturity companies, wired connectivity has slightly higher importance than 5G and wireless. However, the key point is that, overall, wired connectivity is one of the critical issues for such companies – but how is this being implemented, and how will it change in the future?

Simon Seereiner, Head of Product Management SAI & IE at Weidmüller, explains: We now use IP-based communication pretty much everywhere - in smartphones and on our computers but also in industrial facilities. Over the last 20 years, we have seen more and more Ethernet-based communication architectures being implemented in industrial applications, such as Profinet, Ethernet IP and Ethercat.

All of these are Ethernet-based field-bus systems. However, there is a lack of consistency right at the last hurdle, i.e., at sensor-actuator level. At this level, we are still using bus architectures such as Profibus, CAN and ASI. This issue grows with an enterprise's IoT-based, Industry 4.0 infrastructure, which involves dense data volumes being generated by each sensor on every machine or equipment item on the factory floor; this calls for multiple gateways to convert to Ethernet-based communication.

By contrast, today's approach is to establish consistent connectivity so that IP-based communication can be implemented even at the very lowest sensor-actuator level. This brings the promise of a simplified, unified network solution covering the entire factory infrastructure; a concept not previously possible with standard Ethernet-based networks which were too expensive and complicated to use in this context.

However, it is now being achieved with an increasingly popular version of Ethernet networking, called Single Pair Ethernet (SPE). While driven by the automotive industry, SPE is equally useful in factory automation – replacing analogue sensors or industrial bus systems, especially if they are multi-protocol.

SPE has been around for 10 – 12 years or so, but engineers are now becoming aware of its advantages over conventional Ethernet, which requires at least two wire pairs at 100 Mb, and four wire pairs for Gigabit cables. With SPE technology, only one pair of wires is needed for the same transfer rates, meaning that only a quarter of the amount of copper is required, as well as only a quarter of the processing time. This not only saves space, but also a huge amount of installation effort and money.

A further key benefit is that the single-pair SPE cable can transfer power as well as data. This is based on a technology called Power over Data Line (PoDL), which allows delivery of up to 60 W to an interface during simultaneous data transmission (100 Mbit), over distances of up to 1000 m. Sensor systems, for example, can therefore be supplied with just one single two-wire cable. As a result, such systems can be easily and cheaply set up in industrial applications with a high density, which in turn helps to increase levels of automation and networking while also implementing processes with an ever-increasing degree of automation.

A CLOSER LOOK AT SPE BENEFITS

We have seen from the above that SPE can be a single-technology, IP-based replacement for older systems based on sensors and actuators connected to an industrial Ethernet system via fieldbus links. Here are some ways in which SPE overcomes the challenges of the more traditional approach :

The first advantage to a single twisted pair is more reliable mechanical connectors. Instead of needing eight different conductors to carry signals, only two conductors are used, and only two physical contacts are required for the system to work.

This also allows the use of more robust connectors that require stronger mechanical links, such as Mx connectors which can provide environmentally sealed connections.

The second advantage is the significant decrease in cable size. This allows for an increase in cable density when routing networks, thus allowing for more devices to be connected simultaneously (as a result of laying more cable in the same cable ducts). Reduced cable size also reduces the weight of the cable, meaning easier installation when compared to thicker, heavier cables.

This also makes it easier for operators to adjust the network as the cable is easier to move and manipulate.

Next there is cost; reducing the number of conductors in a cable reduces its price. Cheaper cables allow for lower-cost installations, which incentivise industrial facilities to upgrade their networks.

Since a cable cannot become simpler than a single-twisted-pair, such a cable installation will most likely be compatible with future changes to the network.

The fourth advantage is simplified mechanical connectivity. While such a cable can be fitted with strong, dedicated connectors, the use of just two wires allows for a designer to choose any connection type they want with ease. If, for example, a sensor system that requires power and a network connection were incredibly small, then an installer could connect a twisted pair using directly soldered connections. Failing that, terminal blocks can be implemented with ease. An installer could also use a cable crimping system to attach their own custom connector that fits with the hardware in question.

SPE STANDARDISATION

Ethernet is defined by a number of IEEE 802.3 standards; a subset of these defines the SPE options. These are IEEE 802.3 1000Base-T1, IEEE 802.3 100Base-T1 and IEEE 802.3 10Base-T1. The standards use a single twisted pair cable, Unshielded Twisted Single Pair (UTSP), Category 6A, with differential signals transmitted in full duplex .

Signals between two SPE electronic control units are transmitted simultaneously in both directions. They overlap and run in opposite directions on the SPE cable. Since the respective transceivers know their transmit signals, they can filter out the receive signals.

The 1000Base-T1 interface is based on BroadR-Reach and has been standardised as Single-Pair Ethernet (SPE) by the IEEE working group 802.3bp. 1000Base-T1 corresponds in its technical values to classic Ethernet. Thus, the frame format and the minimum and maximum frame lengths are retained. The error rate is 10−1010-10 and the data rate is 1 Gbit/s. The standard can work with autonegotiation and bridge distances of up to 15 m (1000Base-T1A) or 45 m (1000Base-T1B), as found in buses and trucks. As a modulation method, 1000Base-T1 uses the multivalued pulse amplitude modulation PAM3.

The IEEE working group 802.3bu has standardised a procedure for 1000Base-T1 for the transmission of supply voltages via the STP cable under the designation Power over Data Lines(PoDL).

ISO/IEC JTC1 SC25 WG3 defines the cabling required for the standard, and in turn relies on component standards for cables and connectors created in IEC standardisation groups. Several standards have already been published as part of the introduction of SPE.

IEEE 802.3bp 1000 BASE-T1 "Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable" defines single-pair transmission by way of a 15 m UTP channel (type A, unshielded) and a 40 m STP channel (type B, shielded). Both channels are specified for a bandwidth of 600 MHz, may include up to four connectors, and guarantee a transmission capacity of 1 Gbit/s.

The large-scale deployment and successful marketing of SPE depends on full compatibility between all devices, cables and connectors. Two connector faces have managed to win through in the international standardisation selection:

Figure 1 – HARTING modular SPE connectors according to IEC63171-6

> The connector face as per IEC 63171-1 for wiring premises: This is based on a suggestion by CommScope and known under the synonym variant 1 (LC style) for M1I1C1E1 environments.

> The connector face as per IEC 61076-3-125 is recommended for industry and industry-related applications: This is based on a suggestion by Harting , specifically designed for use in environmental conditions up to M3I3C3E3, and known as variant 2 (industrial style)

MICE describes environmental conditions for installations and provides planners and users with valuable advice for the specification of technical equipment and cabling systems.

This involves a description of requirements for their mechanical robustness (M), IPxx degree (I), chemical and climatic resistance (C), and electromagnetic safety (E). In the broadest sense, M1I1C1E1 describes the kind of environment found in an office building, for example, and M3I3C3E3 a rather extreme environment that can potentially occur in industry or outdoors.

Based on the connector face defined in the standard, Harting is preparing a comprehensive product portfolio for industry. Prototypes of this connector face were first introduced around two years ago at the SPS 2016 exhibition, along with the two further connectors ix Industrial and M8 d-coded. Following the standardisation of the Harting ix Industrial, this is now the second connector to become an industry standard.

Specification of key components

Cables: Based on the needed transmission speed and link length, two basic types of SPE cables are available and standardised. For 10 Mb/s networks of up to 1000 metres cable length, the following standards specify the cable design:

> IEC 61156-13-SPE data cable up to 20 MHz bandwidth for fixed installation

> IEC 61156-14-SPE data cable up to 20 MHz bandwidth for flexible installation

For one Gb/s networks up to 40 metres these standards are available:

IEC 61156-11-SPE data cable up to 600 MHz bandwidth for fixed installation

IEC 61156-12-SPE data cable up to 600 MHz bandwidth for flexible installation
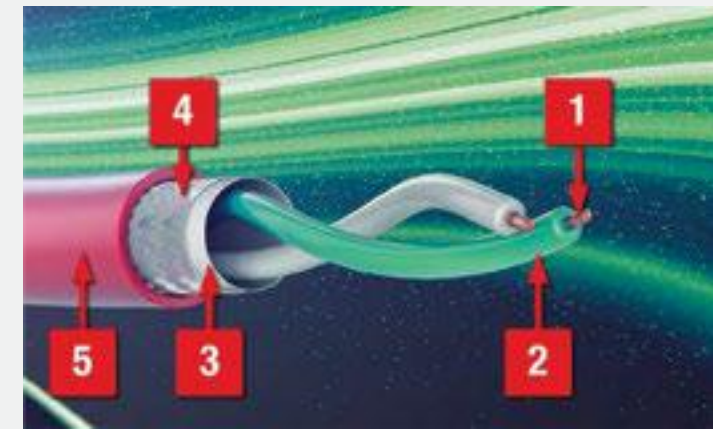
Figure 2 – Design for a typical SPE cable (1-copper wire, 2-wire isolation, 3-shielding foil, 4-shielding braid, 5-cable jacket)

All these cables are shielded to provide the needed crosstalk resistance for the 40 metre 1GBASE-T1 and 1000 metre 10BASE-T1L as demonstrated in Fig 2. Depending on the use case, different cable jacket materials are possible. The copper cross section of the cable must be selected according to the needed link length and the power over data line (PoDL) requirement. 26AWG and 22AWG wires are typically taken for link lengths of up to 20 metres and 40 metres respectively. For longer link lengths up to 1000 metres 16 AWG or 18 AWG cables must be used.

To realise 1 Gigabit per second transmission rate over a single pair, the standards define high electrical properties for an SPE cable.

These include the -parameters insertion loss (IL), return loss (RL), and alien crosstalk (AXT) over a frequency range up to 600 MHz.

The foil shield provides a high shielding effectiveness against high frequency electromagnetic fields. The braided shield is used for mechanical stabilisation and shielding of low frequency electromagnetic fields.

The effect of a braid depends on the thickness of individual wires and on the degree of coverage. SPE cables for industrial environments should provide a coverage of a minimum 85%. The braiding of a cable also mainly defines the values for the transfer impedance of a cable shielding.

The shielding effect of a cable works in both directions, which means that the shielding attenuation reduces both the radiation of disturbances of the cable signal as well as disturbances of other devices acting on the cable from outside.

Figure 3 – Different recommended SPE connectors according to IEC 63171-6

Return Loss Limit 10 BaseT1
Return Loss Limit 100 BaseT1
Mode Conversion Limit 10 BaseT1
Mode Conversion Limit 100 BaseT1

Figure 4 – Limits of return loss and mode conversion for MDI 10BASE-T1 (Black) and 100BASE-T1 (Grey)

Connectors: SPE needs completely new types of connectors. These connectors are smaller than the typical RJ45 and offer the same robustness as the often used industrial style M12D- and X-coded connectors. This new SPE interface is defined in the IEC 63171-6 standard and includes different M8/M12 versions for very harsh industrial applications and an IP20 interface for in-cabinet applications. All these connector types are based on the same connector inserts and use a robust pin and socket contact system. This modular design concept with identical terminal inserts in all versions allow the mating of IP20 plugs to IP65/67 jacks for testing or set up.

This SPE connector series is specified for 60V DC/4 amps at 60°C and fulfils the requirements for all power over data line (PoDL) classes. For harsh industrial environments with a heavy EMC disturbance the connector has a 360° shielding shell to provide the shielding connection from the cable shielding to the PCB with four shielding pins. These through hole reflow (THR) solder pins also offer a robust connection between the jacks and the PCB. The connector mating face design is symmetrical, and the contacts are arranged in parallel with the identical contact length. The RF compliant connected technology allows signal transmissions up to 1000BASE T1.
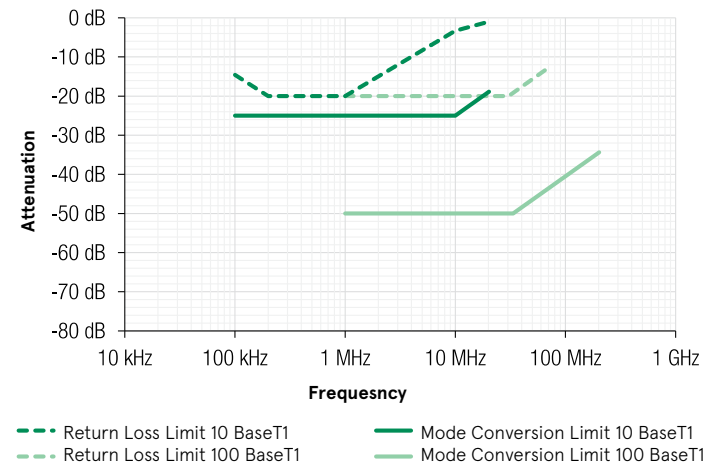
Filter topologies: the MDI [Medium Dependent Interface] forms the connection between the cable and the physical medium - the PHY chip - which generates bits from data signals and passes them on for further processing.

The passive components of the MDI have various tasks such as correct forwarding of data signals, signal interference suppression, and electrical isolation or transport of electrical energy up to 60 W in the case of Power Over Data Line (PoDL).

To ensure error free data communication, limits for return loss and mode conversion loss have been defined in various IEEE 802. 3 standards. Figure 4 illustrates the MDI limits for 10BASE-T1 according to IEEE 802.3cg and 100BASE-T1 according to IEEE 802.3bw.

EXAMPLES OF SPE COMPONENTS

Microchip LAN8670/1/2[vi] is a high performance 10BASE-T1S single-pair Ethernet PHY transceiver for 10Mbits/sec half duplex networking over a single pair of conductors. Utilising standard Ethernet technology in sensor/actuator networks reduces application costs by eliminating gateways necessary with legacy networking technologies. The ability to connect multiple PHYs onto a common mixing segment further saves implementation costs by reducing cabling and switch ports. The LAN8670 is designed for use in high reliability, cost-sensitive industrial, backplane, and building automation sensor/actuator applications.

Note that the transceiver has full 10BASE-T1S capability. 10 Mbps IEEE 802.3cg 10BASE-T1S is a slightly different type of Single Pair Ethernet.

Not only does it benefit from using a single twisted pair of wires, but it also offers bus topology connectivity, in addition to the conventional switched point to point. Connecting devices on a common bus offers further system cost reductions by reducing the number of PHYs and cabling needed in the network. Up to at least 8 devices (PHYs) can be supported over the shared 10 Mbps bus of up to at least 25 m in length.

10BASE-T1S is also deterministic by inherently avoiding collisions from devices simultaneously trying to transmit on the bus, through a method known as PLCA (Physical Layer Collision Avoidance).
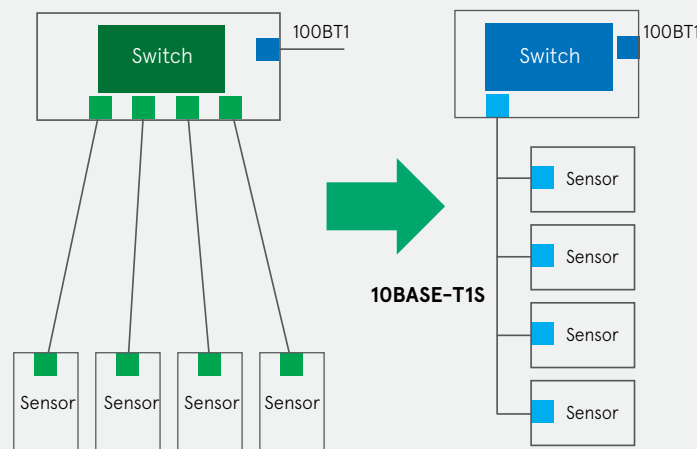

Figure 6 –Analog Devices ADIN1110 ultra-low power single port 10BASE-T1L transceiver

Figure 7 –Würth Elektronik tiny Ethernet and LAN transformer

Figure 8 –WEIDMÜLLER 2725850010 Ethernet Cable, SPE Jack to SPE Jack, STP (Shielded Twisted Pair), Black, 1 m,3.3 ft

Figure 9 – HARTING SPE Jack, 1 x 1 (Port), 2P2C, IP20, Through Hole Mount – part of the HARTING T1 Industrial Series of connectors

Analog Devices' ADIN1110 is an ultra-low power, single port, 10BASE-T1L transceiver design for industrial Ethernet applications and is compliant with the IEEE® 802.3cg-2019™ Ethernet standard for long reach, 10 Mbps single pair Ethernet (SPE). Featuring an integrated media access control (MAC) interface, it enables direct connectivity with a variety of host controllers via a 4-wire serial peripheral interface (SPI).

This SPI enables the use of lower power processors without an integrated MAC, which provides for the lowest overall system level power consumption. The SPI can be configured to use the Open Alliance SPI protocol or a generic SPI protocol. The programmable transmit levels, external termination resistors, and independent receive and transmit pins make the device suitable for intrinsic safety applications. It is used in applications such as field instruments, building automation and fire safety, factory automation, edge sensors and actuators, condition monitoring, and machine connectivity.

Würth Elektronik Single Pair Ethernet Signal Transformers feature the super small WE-STST series with transformers that measure only 4.7mm x 3.22mm x 2.9mm (L x W x H). These devices are machine-manufactured and offer 1.5 kV isolation voltage and 350 µH open-circuit inductance (OCL) as per IEEE 802.3. They have an operating temperature range of -40°C to +105°C. Typical applications for Würth Elektronik WE-STST transformers include Ethernet 10/100/1000 Base-T, Ethernet 2.5/5G and 10G Base-T, single pair Ethernet, ultrasonic sensors, and G.fast.

The WE-STST provides a discrete solution for Ethernet designs. This can save over 50 % of PCB space compared with individual transformer solutions using ring cores, while still providing the possibility of high transmission rates. Its innovative automated production reduces electrical deviation and increases reliability as well as quality .

Weidmüller IP20 and IP67 patch cables, also used for free field coupling, support Power over Data Line (PoDL). These cables can contribute to SPE installations, allowing uniform Ethernet-based communication from the sensor to the cloud. They can be used across applications thanks to ranges of up to 1,000 m and transmission properties of up to 1 Gbit/s

Fig. 8 below shows an example of one of these patch cables, offered with the description: Plug acc. to IEC 63171-2, SPE plug (IEC 63171-2) - IP20 female straight, Plug acc. to IEC 63171-2, SPE plug (IEC 63171-2) - IP20 female straight, T1-B, PVC, 1 m.

The **HARTING T1 Industrial Series of connectors** feature an Internationally standardised mating face according to IEC 63171-6. They can be used to construct future-proof and standardised Single Pair Ethernet (SPE) communication networks with standardised cabling according to ISO / IEC 11801 and TIA 42.

Designed for industrial applications up to M3I3C3E3 environmental conditions (See under 'SPE Standardisation' above for a definition of MICE), they meet all IEEE 802.3 requirements for SPE. They have a robust industrial design with 360° shielding, locking lever protection and high mating cycles.

A SECURE AND CO-ORDINATED FUTURE FOR SINGLE PAIR INTERNET

The future of SPE is being managed by the SPE Industrial Partner Network, which provides the assurance of quality for uniform and coordinated infrastructure that meets set standards. The seven brands HARTING, TE Connectivity, HIROSE, Würth Elektronik, LEONI, Murrelektronik, and Softing IT Networks form the founding members of the SPE Industrial Partner Network.

They describe themselves by saying: "Our strong partner network is unanimous in its support of the T1 Industrial interface according to IEC 63171-6 as a uniform Media Depended Interface (MDI) as defined by the ISO/IEC JTC 1/SC 25/WG 3 and TIA42 in 2018.

"To ensure the reliable establishment of the entire future SPE ecosystem, standards for transmission protocols, cabling and device components are also jointly supported. Therefore, all members of the partner program, as well as ISO/IEC JTC 1/SC 25/WG 3, are in close exchange and intensive cooperation with IEEE 802.3 and IEC SC46C for uniform transmission standards and copper data cables."

CLICK HERE

Figure 5 – 10BASE-T1S architecture

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