

Extending Industrial Ethernet Benefits to the Field Level with Single Pair Ethernet (SPE)

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Industrial Ethernet, Single Pair Ethernet (SPE), Advanced Physical Layer (APL), Industrial Network Infrastructure

Summary

Industrial customers are looking to automation and digitalization not only to improve production performance, but also to enable sustainability, regulatory compliance, and supply chain capacity monitoring while simultaneously addressing the increasing cost of labor and capital. These efforts are leading to ongoing escalation in the need for secure, reliable

Single Pair Ethernet (SPE) extends digitalization to the field level, leveraging the benefits of IT/OT convergence and data transparency from sensor to enterprise.

connectivity from the sensor to enterprise. Driven by increased reliance on analytics, machine vision, and other high bandwidth applications.

Sustainability, electrification, regulatory compliance, and performance initiatives inherently require connectivity to monitor and control a variety of core performance variables, such as efficient equipment operation, power consumption, and CO2 and other emissions. Mission-critical industrial networks are likewise relied upon to provide the communication and control infrastructure necessary to enable the operational scalability, flexibility, and timely responsiveness to compete in today's markets.

The IEEE 802.3cg 10BASE-T1L Single Pair Ethernet (SPE) standard and accompanying Advanced Physical Layer (APL) for hazardous process environments can assist manufacturers, factory operators, machine builders, and system integrators with meeting these escalating connectivity demands by enabling extension of IP-based Ethernet infrastructure down to the sensor level. Extending Ethernet into the realm of legacy dedicated or proprietary field networks significantly increases the number of communication and

control options available when used with connected assets, processes, and other data sources.

This paper highlights the value proposition for SPE and APL deployment at the field level of industrial automation networks. The objective is to educate and inform industrial manufacturers, factory operators, machine builders, system integrators, and potential SPE ecosystem participants as to the operational benefits and criteria for success when implementing these latest additions to the industrial Ethernet portfolio.

Industrial Digital Transformation Data Requirements Drive Escalating Demands on Industrial Networks

Digital transformation in the form of industrial Internet of Things (Industrial IoT), Industry 4.0, and other initiatives is a primary response to the numerous challenges faced in the production environment. Manufacturers are implementing digital transformation in a variety of forms, including reliance on cloud-based applications, analytics, digital twins, and sensor-to-cloud data transparency. These technology enablers are charged with meeting not only the core objective of reduced downtime by enabling predictive maintenance capabilities, but also new requirements in the areas of sustainability, regulatory compliance, and cybersecurity.

Traditional 4-wire Ethernet continues to descend in the network hierarchy, but its price and form factor are not suitable for use with low-cost sensors and actuators.

and cybersecurity.

Industrial network infrastructure is a core architectural enabler to these ends, providing secure data availability for enhancing uptime, compliance, analytics, and other crucial capabilities. Fast Ethernet (100BASE-TX) continues to descend in the industrial automation hierarchy as the wireline network of choice, but its current form factor and configuration are cost prohibitive at the sensor and I/O level and not easily incorporated into smaller equipment. Traditional Multi-Pair 100BASE-TX and 1000Base-T are defined only up to 100-meter segment lengths, while SPE's 10BASE-T1L defines segment lengths of up to 1,000 meters, enabling connectivity to remote sensors. These longer segment lengths will especially appeal to process industry customers interested in the APL that combines 10BASE-T1L and intrinsic safety.

Legacy dedicated proprietary, serial, or analog networks, on the other hand, are difficult to integrate into digitized architectures. Attempts to this end reveal their constrained data pipelines and visibility, reliance on protocol conversion and gateways for interfacing to higher levels of the architecture,

and overall lack of convergence between IT and OT operational and management environments.

Miniaturization Addresses Field Level Space Constraints, Flexibility Requirements

SPE likewise meets field network functional requirements in areas such as component and infrastructure miniaturization and deployment simplicity.

Belden's SPE passive infrastructure component offerings include the DataTuff® line of SPE Cables with variants for 10 Mbps/1.000 meter and 1 Gbps/40 meters, as well as SPE connectors that conform to IEC 63171-6 and are available with either IP20 ratings for clean-area connections or IP65/IP67 for field device connection cables.

Along with the faster data rates, multiple segment lengths, optional remote power, and single network architecture, miniaturized SPE cables, connectors, and infrastructure overcome space constraints in both electrical cabinets and at the sensor level. Industrial SPE infrastructure is also able to meet the flexibility and tight bending requirements of applications such as robotic end-of-arm, cranes, gantries, and other complex machinery. Small SPE cables and connectors and the

inherent reduction in raw materials result in reduced cost, weight, and environmental impact while providing two-wire fieldbus-like ease of installation by OT personnel.

SPE Extends Digital Transparency to the Field Level

Availability of the SPE standard provides the opportunity to overcome current field network limitations due to its ability to extend data transparency throughout a single Ethernet-based architecture that spans from sensors to cloud-based applications. With all sensors accessible, protective measures need to be considered to ensure the security of the network. Well-proven Ethernet security mechanisms can also be applied to SPE, with network management tools with dedicated OT configuration capabilities required to provide the suitable security features.

SPE offers full duplex point-to-point data transmission over a single twisted pair with data rates ranging from 10 Mbps to 1 Gbps. Multidrop or bus topologies can be implemented over a shared single pair using half-duplex operation or by embedding switch technology in end devices. Optional auto-negotiation is also available for full duplex data transmission.

Like the serial CANbus networks before it, the SPE physical layer was originally conceived for use in automotive in-car applications under IEEE

802.3bw. Targeted use for in-vehicle wiring harness applications resulted in an initial project focused on 100 Mbps operation for network lengths up to 15 meters. The potential for SPE use in other applications, including industrial and transportation, resulted in standardization of IEEE 802.3bp for incremental dedicated segment lengths of up to 40m and 1 Gbps bandwidth.

IEEE 802.3bu Power over Data Line (PoDL) is a remote powering scheme comparable to PoE for multi-pair Ethernet. This first version of PoDL encompassed ten different classes representing different currents and voltages that can be used to power both industrial sensors and increasingly important vision installations. IEEE 802.3cg adds an additional 6 classes.

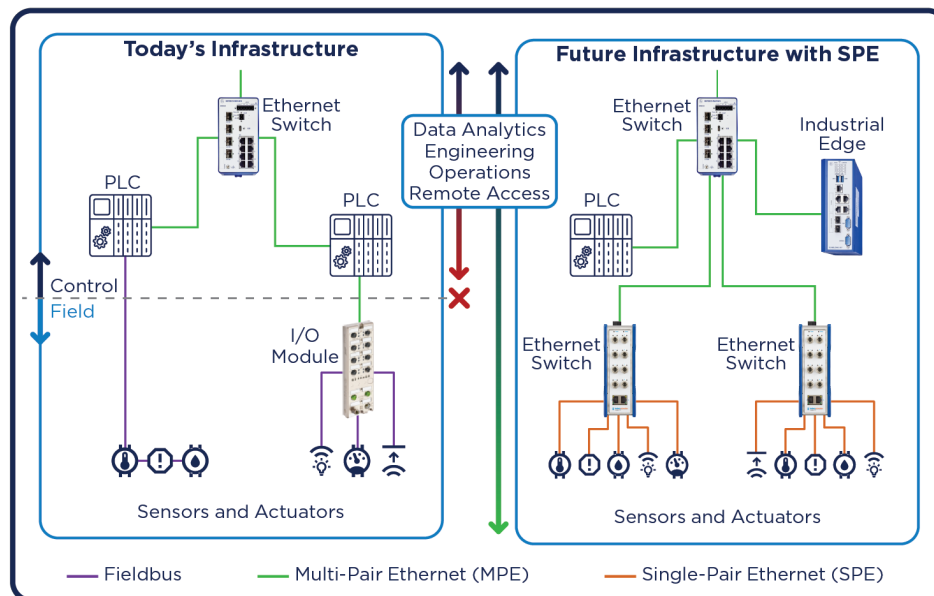
MAU	Bandwidth	Length	Remote Power	Standard/Project	Status
100BASE-T1	100 Mbps	15 meters	Per IEEE 802.3bu	IEEE 802.3bw	Released; in-vehicle
1000BASE-T1	1 Gbps	15 meters via Unshielded Twisted Pair (UTP) 40 meters via Shielded Twisted Pair (STP)	Per IEEE 802.3bu	IEEE 802.3bp	Released; in-vehicle, industrial, transportation
Power over Data Line (PoDL); Used together with 802.3bw and 802.3bp			10 classes for different currents and voltages	IEEE 802.3bu	Released; in-vehicle, industrial, transportation
10BASE-T1L, 10BASE-T1S	10 Mbps	15 meters point-to-point (UTP); 25 meters multi-drop (UTP); 1000 meters (STP)	6 additional PoDL classes	IEEE 802.3cg	Released; industrial, transportation
10BASE-T1S	10 Mbps	50 meters multi-drop	Optional	IEEE 802.3da	Mid 2025
100BASE-T1	100 Mbps	500 meters	Yes	IEEE 802.3dg	Mid 2025

IEEE 802.3 SPE Projects and Standards

The IEEE 802.3cg project, focused on 10 Mbps operation for 15-meter point-to-point, 25-meter multi-drop, and 1000-meter segments, plus 6 additional PoDL classes, brings the SPE standard more in line with industrial automation requirements. The IEEE 802.3da project likewise targets 10BASE-T1S multidrop operation with optional remote powering, while 802.3dg is

intended to define a 500-meter segment operating at 100 Mbps with remote power.

Greenfield installations will be the primary initial targets for SPE implementation, due in large part to the legacy industrial customer's reticence to rip and replace. Brownfield installations can also benefit, for example by deploying an SPE compatible IO-Link Master that provides IO-Link downloads and SPE uplinks.



SPE Ethernet Is Transforming Industrial Network Infrastructures

Source: Belden Inc.

Challenges to SPE Adoption

Many of the enabling SPE standards are ready now for implementation, with the first cables, connectors, and PHYs available and associated ecosystems established. Initial pilots and technology evaluations for use in industrial automation and transportation applications are also underway with the first product offerings now being introduced.

This initial activity has identified several challenges to SPE implementation in industrial automation and transportation that need to be addressed as the technology continues to evolve. For example, the optional auto-negotiation feature is not required for in-car automotive applications, so is not always implemented in initial component offerings. Future chipsets will likely incorporate auto-negotiation as well as auto-polarity, two features critical to ensuring ease-of use in industrial applications.

Early trials are focused more on the incremental value-add the technology affords, while price points will decrease as volume increases. As with other novel technologies, the pace of adoption in the target industrial automation and transportation sectors will be critical factors to achieving the volume necessary to bring prices down. In the interim, the pace of product introductions, segment lengths below 100 meters for the individual 100 Mbps and 1 Gbps bandwidths, and initial price premiums for industrial SPE products will slow its initial promise in industrial automation.

Industrial SPE products are currently available, but mostly at the cable and connector level. The lack of multi-port PHYs and incompatible MAC interfaces for single-port PHYs and state of the art switch ASICs remain an issue for efficient switch implementation. Consequently, only a few industrial Ethernet switches, including the Belden BEETLE Lite Managed Switch, are currently available. The BEETLE DIN rail switch offers 2 Fast Ethernet uplink ports and 8 10Base-T1L downlink ports that employ IEC 63171-6 compliant M8 connectors, class 12 PoDL, and IP40 housing.

SPE Use Case: Enabling Accurate, Scalable, and Flexible Logistics

Warehouse and logistics center environments typically incorporate a set of high-bay warehouses and associated Automated Storage and Retrieval (ASRS) systems along with automated conveyor systems for separating, packaging, and distributing goods. Smart sensors and cameras are typically deployed in conveyor applications for identification purposes at the warehouse's input and output and to enable high-speed picking, sorting,

SPE enables both digitally transformed architectures and centralized management in logistics applications.

packaging, and distribution with low error rates. Warehouse operations typically rely on simple low-cost sensors and associated networks to properly position goods in high-bay warehouses, with redundancy implemented to reduce failure rates.

Automation of high-speed warehouse and logistics operations is a primary means of achieving the flexibility and scalability necessary to meet escalating supply chain challenges in today's commercial environment. Migrating existing legacy sensor interfaces to SPE networks allows use of smart sensors and cameras to extend to high-bay warehouse applications, eliminating the need for redundant implementations while adding incremental predictive maintenance capabilities and the resulting increased uptime. Availability of

predictive maintenance and smart sensor remote status add further benefits given the difficulty of accessing the high warehouse bays. SPE's PoDL capabilities can also be used to provide remote power for field sensors and actuators. Conveyor applications can likewise benefit from SPE's thin, flexible cable construct that can be used to connect small conveyor lines or small segments of a larger conveyor, while multidrop capabilities can be used to connect multiple smart sensors and cameras.

SPE's advantages in these applications extend beyond improved automation infrastructure to logistics management. Data from the automated processes is made readily available at the centralized logistics level and beyond via transparent, seamless data connectivity from sensor to cloud. Continued monitoring and refinement of key logistics performance variables such as pick rate, accuracy, and uptime, as well as real-time location visibility and tracking, is now possible through Ethernet-based network transparency. This transparency likewise addresses blind spots in areas such as network management, operations, and cybersecurity through enhanced monitoring and visibility.

SPE Use Case: Improving Operational Efficiency in Food & Beverage Processing

Automation in the food and beverage industry represents a mix of time-sensitive food processing, packaging, and distribution processes and the attendant process, logic, and motion control. Operational challenges in this industry can include quality control, safe food handling, accurate tempera-

SPE can help food and beverage manufacturers optimize processing, packaging, and distribution processes.

ture and humidity control, in situ equipment cleaning, maintenance of hygienic environments, and regulatory documentation requirements.

Processing and packaging facilities in this industry typically rely on a vast number of analog or low-cost digital sensors to control processes and meet documentation requirements. Parallel serial or Ethernet-based networks are also employed to accommodate gas chromatographs and other smart sensors.

Food and beverage processors are turning to data analytics, predictive maintenance, remote control, and other processes to improve operational efficiency in their facilities. SPE mirrors the long-distance capabilities of legacy field networks while exponentially increasing bandwidth. This enables smart

sensors to seamlessly communicate over transparent networks and provides the visibility and control necessary to monitor and optimize KPIs and other operational metrics. The DIN rail IP40 BEETLE switch from Belden, for example, which can be either housed in a cabinet or placed on the line itself, can provide SPE over M8 terminals into the hygienic area.

SPE Ecosystem Central to Success

Industrial network infrastructure ecosystems bring together switches, cables, connectors, sensors, I/O, and other industrial devices, software, and services from a variety of industry participants to support interoperability and ease of integration via a common standard. Cable and connector suppliers are the leaders in bringing SPE to market and are also the primary current ecosystem leaders. Passive devices and cabling are already available from ecosystem participants, with active devices expected in 2024.

Make the Right Connections with Belden and the SPE Industrial Partner Network

Leading industrial network infrastructure supplier Belden, whose brands include Hirschmann™, ProSoft Technology™, Lumberg Automation™, NetModule™, Macmon Secure™, OTN Systems™, and others, offers an expanding portfolio of end-to-end solutions and services designed to meet the

requirements of the SPE and APL standards. Belden's SPE offerings include the DataTuff® line of SPE Cables with variants for 10 Mbps/1,000 meter and 1 Gbps/40 meters, as well as SPE connectors that conform to IEC 63171-6 and are available with either IP20 ratings for clean-area connections or IP65/IP67 for field device connection cables.



The Belden Beetle SPE Lite Managed Switch features 2 Fast Ethernet uplink ports, 8 10Base-T1L downlink ports, IEC 63171-6 compliant M8 connectors, class 12 PoDL, and IP40 housing.

Available networking devices include the BEETLE SPE Lite Managed Switch and the LioN-H SPE IO-Link Master. The BEETLE DIN rail switch offers 2 Fast Ethernet uplink ports and 8 10Base-T1L downlink ports that employ IEC 63171-6 compliant M8 connectors, class 12 PoDL, and IP40 housing. The LioN-H SPE IO-Link Master supports 10BASE-T1L as well as the IEC 63171-6 connectors.

In addition to its own end-to-end portfolio, Belden supports both its own and industry-wide ecosystems designed to promote and facilitate SPE adoption and reduce network implementation and management complexity. The Belden Ecosystem Partner programs provide end-to-end solutions that make scalable digital transformation easier and faster.

Belden is also a Premium Member in the SPE Industrial Partner Network through its Hirschmann brand and a leading member of the Single Pair Ethernet Consortium (SPEC) of the Telecommunications Industry Association (TIA), both of which are composed of technology leaders committed to accelerating the adoption of next generation OT and IoT using SPE Technologies. Manufacturers, factory operators, machine builders, and system integrators are encouraged to join the Belden ecosystems to facilitate SPE adoption in your installations.

Belden's extensive global partner network and global team of engineers and consultants ensures delivery of purpose-built, reliable, fast, secure, and flexible network infrastructure regardless of technology choice. Learn more by visiting their website: <https://www.belden.com/solutions/single-pair-ethernet-technology>

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