Figure 1: Stripping is a quality-critical process step in conductor processing because the stripping quality itself determines the quality of an electrical connection.

Repurposing serial cabling infrastructures for Ethernet transmission

IP communications on edge devices

Learn more about

- The benefits of serial communications when compared with analog and digital I/O
- The benefits of IP communications in the field
- New physical layers for Ethernet communications
- Methodology for testing existing cabling infrastructure to be used for IP communications

Introduction

While serial protocols have been the preferred method of communications for field devices for decades, increased productivity and the need for real-time communications require higher bandwidth and the lower latency enabled by IP communications. And while solutions for Ethernet all the way to the field continue to become popular, repurposing serial cabling for IP communications could be a viable option in some applications.

Serial communications in field devices

For decades, serial communication protocols in the form of fieldbuses have been the bridge between automation and the devices in the field. These fieldbuses connect sensors, actuators, valves, and other devices located in remote locations to the higher levels of the communication pyramid, such as PLCs in process industries and factory applications and BASs in building applications.

Serial protocols such as RS-485 (2-wire) utilize a pair of twisted cables to reach far distances, making them a strong communication backbone for many fieldbus technologies. Using differential signaling allows noise immunity and long-distance communication.

Serial protocols or fieldbuses can accommodate multiple analog and digital signals in a single communication channel. Fieldbuses can also achieve moderate to long distances at moderate speeds, which facilitates real-time control in automation, process, and building environments. Figure 1 shows the different levels in the automation pyramid and how the sensor/actuator level relies mostly on fieldbuses to share information with the control level.

Contents

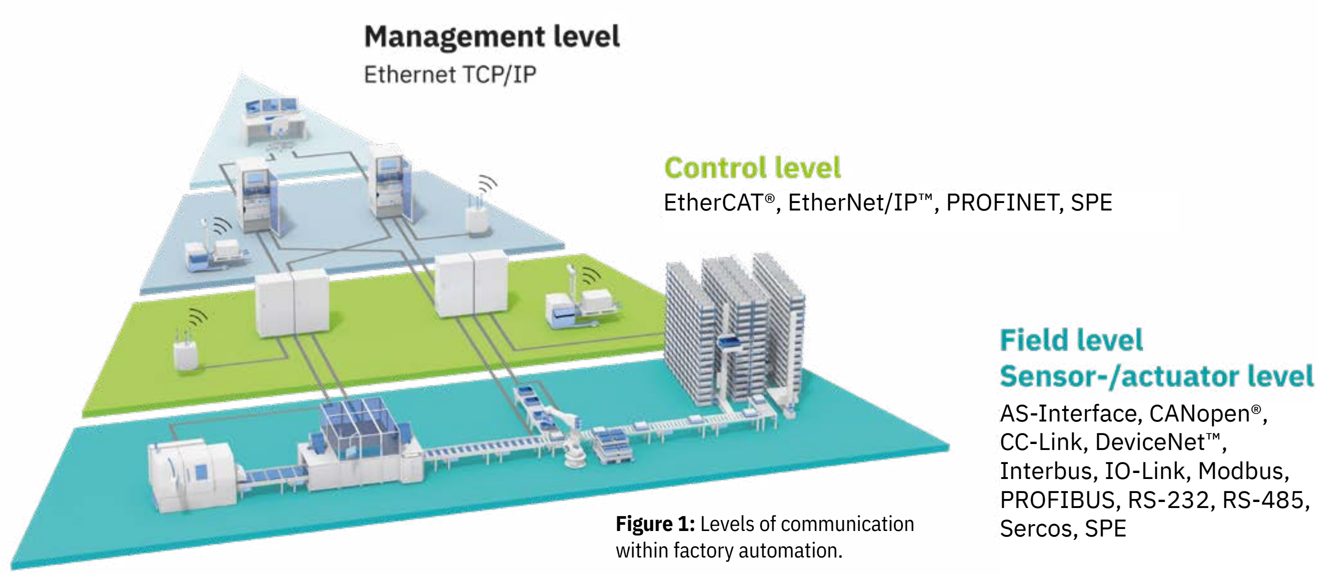

Figure 1: Levels of communication within factory automation.

Serial communications in field devices **continued** →

Despite the many benefits of fieldbuses when compared with analog and digital I/O signals, there are shortcomings related to bandwidth and latency when compared to IP communications. The transmission speed of fieldbuses is limited to Kilobit-per-second speeds on most protocols, and latencies of a few milliseconds, compared to Industrial Ethernet speeds between 100 and 1000 megabits-per-second (Mbps) and latencies as low as 1 millisecond (ms). Table 1[2] shows an example of the speed and distances achieved with various fieldbuses used in process automation, factory automation, and building automation, and the recommended cable diameter for deployment. Some serial protocols can perform at megabit per second speeds, but the deployment distances at these higher speeds are limited to 100 m or less.

Another disadvantage of serial-based communications is that they incur a bandwidth penalty, as it is typically half-duplex. This means only one device can communicate at a time. Further complicating matters is the fact that the entire bus is one collision zone, so even in a large multidrop bus network, only one device can communicate at a time.

Other limitations include support for only properly terminated bus topologies, which adds both a lack of scalability and reliability.

When considering Ethernet-enabled devices in the field, the cabling infrastructure requirements of different applications are very important. Factory and building applications may use copper Category cable. Process automation plants, which may contain hazardous environments and require intrinsically safe components, may use fiber-optic infrastructure for intrinsically safe communications in some hazardous zones.

Aside from wiring, IP-enabled field devices require additional electronics, including a chipset or PHY to enable Ethernet communications, as well as magnetics to isolate high-speed electrical signals. The tradeoff of this increased component count and design complexity on the device side is that the IP-enabled device can be directly integrated into the network (LAN, etc.) without the need for a gateway to convert serial signals. This direct integration simplifies cabinet design, adds additional reliability, and reduces system complexity.

Once integrated into the network, the device can have an IP address and full visibility within the system. This enables real-time communications without a gateway, lower latency through switched, full-duplex operation, and significantly higher available bandwidth compared to traditional RS-485-based fieldbus systems. Unlike half-duplex serial networks that rely on polling mechanisms and shared media, Ethernet provides deterministic performance through collision-free full-duplex communication and the use of Time-Sensitive Networking (TSN). TSN mechanisms such as time synchronization, traffic scheduling, and bounded latency allow critical control traffic to coexist with standard IT data while maintaining predictable behavior.

In addition to improved performance and determinism, Ethernet enables the use of managed network infrastructures that significantly increase system reliability. Redundancy protocols such as Rapid Spanning Tree Protocol (RSTP) and Media Redundancy Protocol (MRP) allow Ethernet networks to tolerate cable breaks, device failures, or topology changes while maintaining network availability. These capabilities are difficult or costly to achieve in traditional RS-485 multidrop architectures. Managed Ethernet devices also provide advanced diagnostics, including link status, traffic statistics, and error monitoring, which enable faster troubleshooting and predictive maintenance.

Security is another key advantage of IP-based field communications. Ethernet networks can leverage established IT security mechanisms such as authentication, encryption, VLANs, and network segmentation to protect devices and data. These capabilities are largely absent from classic serial fieldbus systems, which were designed in an era when cybersecurity was not a primary concern.

One barrier to implementing Ethernet networks at the field level is the large installed base of serial communication infrastructure already in buildings, factories, and process plants. In many applications, the bandwidth requirements of low-level sensors and simple actuators do not inherently justify a complete rewiring with Category cable or fiber.

	FF	PB PA	PB DP	Modbus	BACnet	CAN Bus	DeviceNet
Impedance (Ω)	100	100	150	115±15	115	120	120
Speed (bps)	31.25 Kbps	31.25 Kbps	<12 Mbps	<1.5 Mbps	500 Kbps	1 Mbps	125-500 Kbps
Max link (m)/ speed (bps)	1900 m	1900 m	100 m(12 Mbps), 1.2 Km (93 Kbps)	1000 m (100 Kbps)	1200 m (100 Kbps)	40 m (1 Mbps), 500 m (125 Kbps)	100 m (500 Kbps), 500 m (125 Kbps)
Conductor Ø	18 AWG	18 AWG	22 AWG	>24 AWG	>24 AWG	22AWG	>24 AWG

Table 1[2]

Serial communications in field devices **continued** →

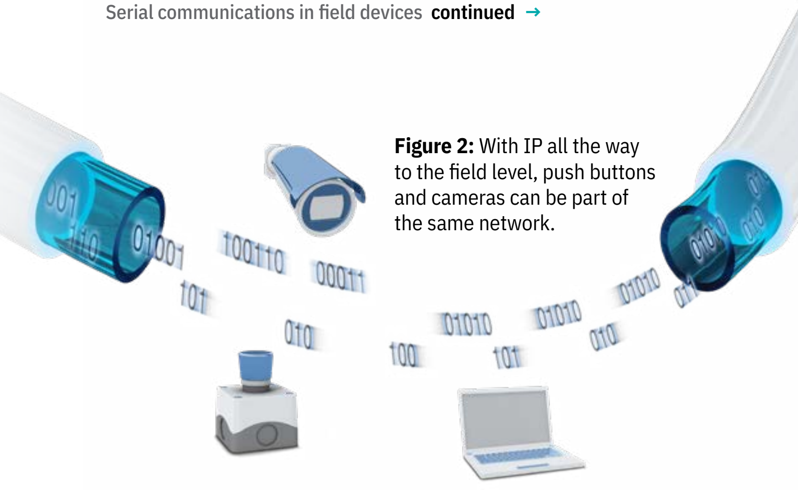

Figure 2: With IP all the way to the field level, push buttons and cameras can be part of the same network.

Additionally, industrial Ethernet over copper using traditional Category cable is limited to a reach of 100 meters, which is often insufficient for devices located in remote areas of factory floors, buildings, or large process plants.

Extending Ethernet to these locations may require repeaters, additional switches, or fiber-optic infrastructure, increasing cost and installation complexity and introducing components that may perform poorly in harsh environments with tight bend radii, high temperatures, or vibration. As a result, the transition from RS-485-based communications to Ethernet at the field level has historically involved a careful tradeoff between performance, cost, and infrastructure reuse—even as Ethernet continues to offer clear advantages in determinism, reliability, diagnostics, scalability, and long-term digital integration. ■

Using serial cabling for IP communications

New physical layers for Ethernet communications over copper aim to extend the reach of copper infrastructure to accommodate devices in remote locations. Now part of IEEE 802.3 [1], a standard that encompasses all physical layers for Ethernet deployment, Single Pair Ethernet (SPE) physical layers cover different speeds and configurations for full-duplex and half-duplex communications over a single pair of wires (Figure 3).

Initially designed for the automotive industry to reduce cabling when implementing smart devices within the vehicle, SPE branched out into other physical layers more suitable for devices within factory automation, process plants, and building applications. With a minimum reach of 1,000 m over shielded single twisted-pair copper cable, SPE standards such as 10Base-T1L are ideal for devices in remote locations that require speeds up to 10 Mbps and lower latencies than previously achieved with fieldbuses. Additionally, these physical layers are protocol agnostic, meaning they are compatible with industrial Ethernet protocols for factory, process, and building automation.

SPE physical layers specify either a shielded differential pair of conductors or an unshielded pair (automotive applications), which is compatible with the construction of some of the cabling used for communications using traditional fieldbuses, such as RS-485, CAN, Foundation

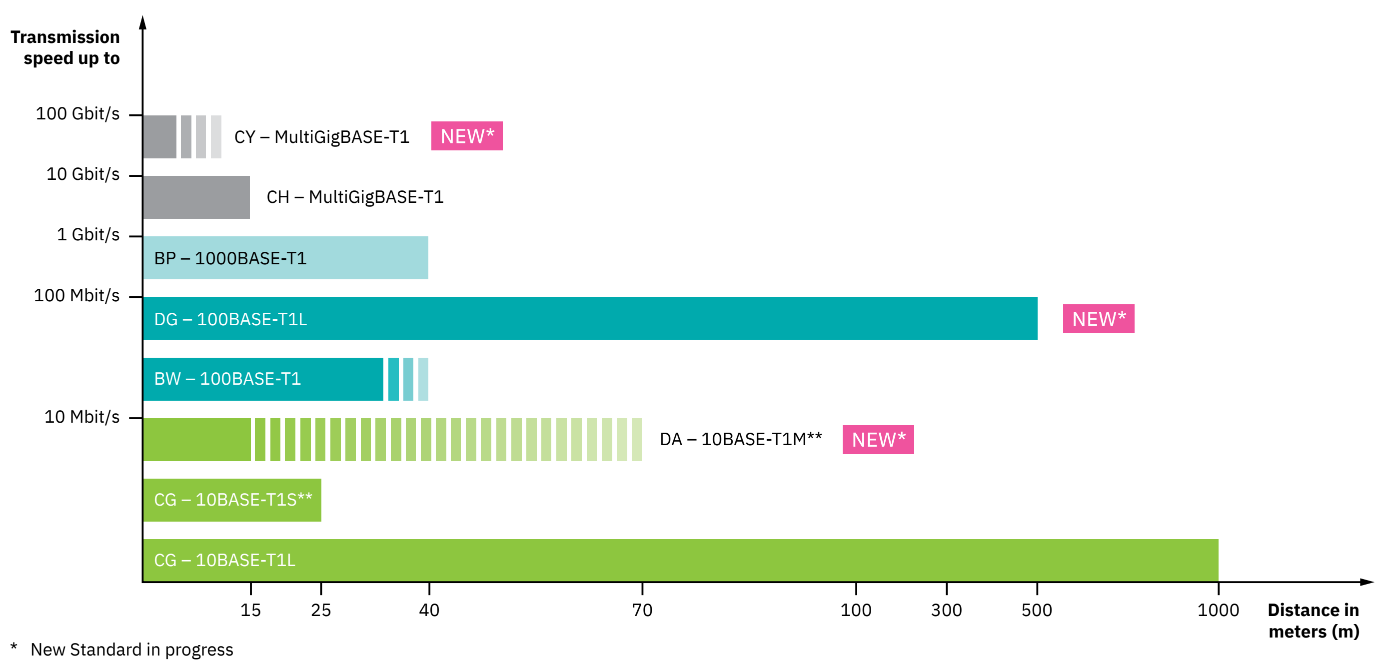

Figure 3: IEEE 802.3 standards for SPE and working groups.

Using serial cabling for IP communications continued →

Fieldbus, Profibus PA, BACnet, and others. SPE physical layers specify a balanced pair with 100 Ω impedance, whereas each fieldbus specification requires a specific impedance. And while the IEEE specification for the 10Base-T1L physical layer specifies the impedance of the cables, it does not go as far as calling out specific cables. Instead, the specification has requirements for insertion loss (IL), return loss (RL), and transverse conversion loss (TCL) over a range of frequencies. These requirements allow for wires other than those constructed specifically for Single Pair Ethernet to be considered when deploying an SPE field device.

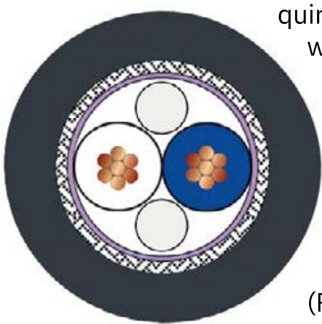

Figure 4: Shielded twisted-pair cable construction.

The Single Pair Ethernet physical layer for factory, building, and process automation is currently being designed in by numerous field device manufacturers to integrate smart sensors into IP networks and is expected to become the industrial communication medium of the future. The infrastructure for deploying these devices is already available, with manufacturers continuing to release connectors and PHYs. Switches are also available, including devices that support the Advanced Physical Layer (Ethernet-APL) for process automation and switches for 10Base-T1L communications that support Power over Data Line (PoDL), enabling simultaneous data transmission up to 10 Mbps and power to the field device. SPE infrastructure availability also includes optimized cabling that can be deployed over distances of 1,000 m with 10Base-T1L.

The question of cable reuse has always been present in the context of Single Pair Ethernet. The guidelines for

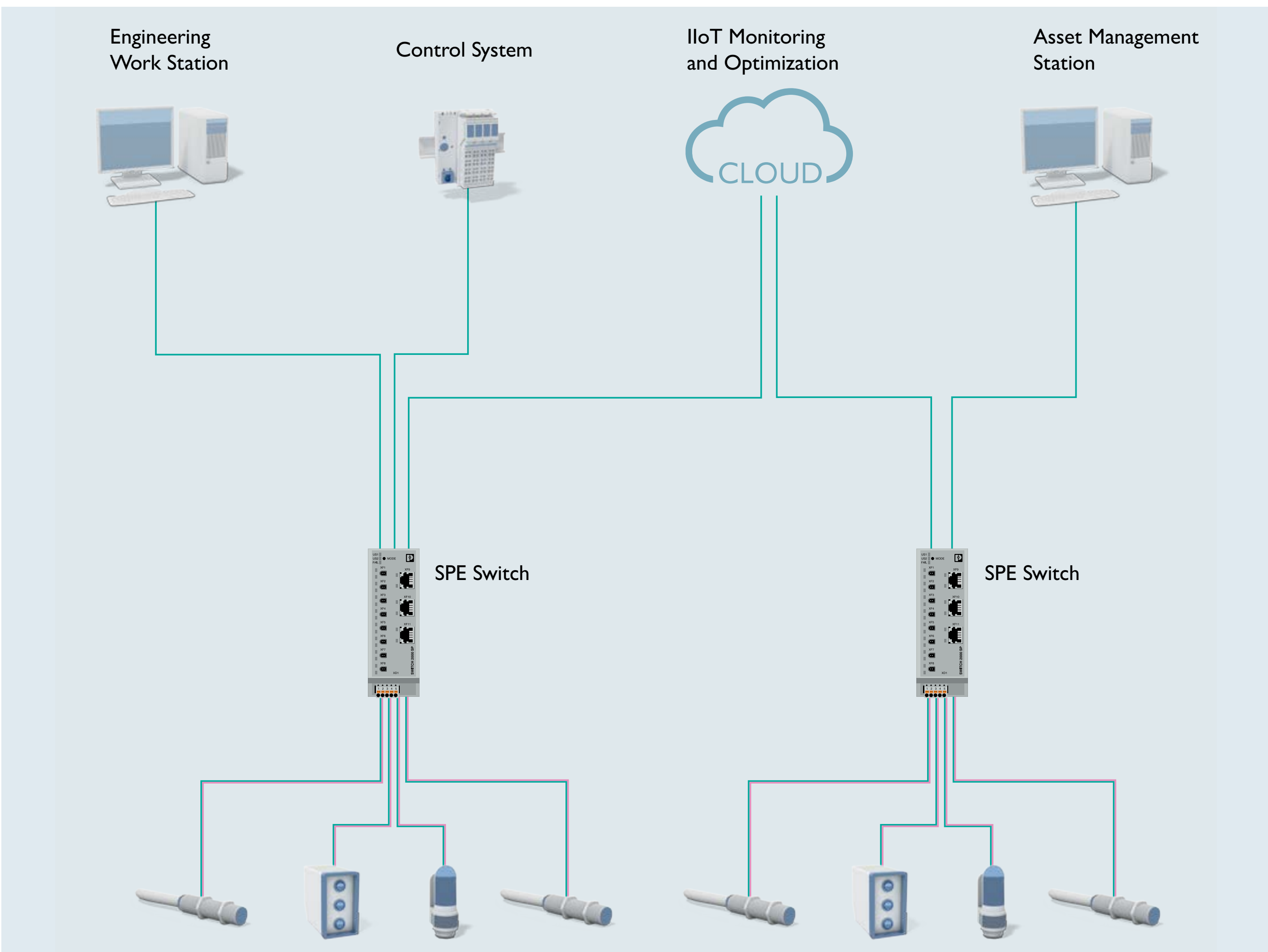

Figure 5: SPE sensors and field devices can be connected to control systems, asset management stations, engineering workstations, and the cloud.

Guidelines for the reuse of serial cabling for IP communications over a Single Pair Ethernet physical layer **continued** →

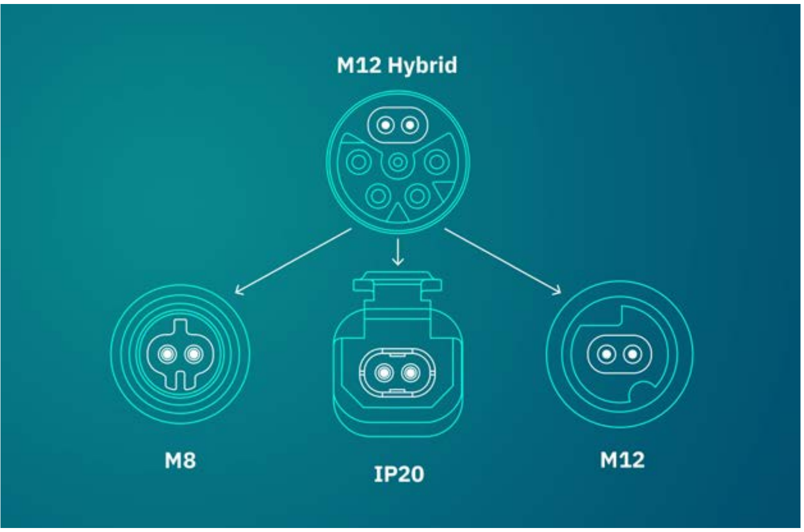

Figure 6: IEC-63171-7: New family of connectors to connect various SPE flavors.

deploying 10 Mbps Single Pair Ethernet with intrinsic safety for hazardous areas, or Ethernet APL in process automation, have cable requirements that include Foundation Fieldbus and Profibus PA. These guidelines were part of a collaboration between standards organizations and process instruments and infrastructure manufacturers with recommended cabling between 26 AWG and 14 AWG, typically used for serial communications within process automation. This makes it possible to reuse cable in brownfield applications, provided the cables are subjected to mandatory testing and meet the requirements for trunk-and-spur transmission, including RL, IL, Crosstalk, etc.

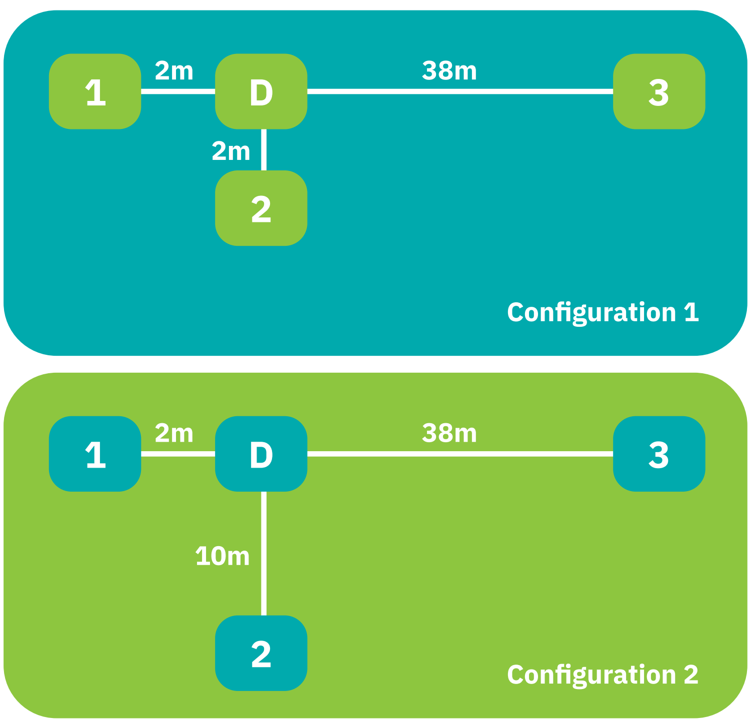

Figure 7: Realistic cable configurations for evaluating potential cable reuse.

Factory and building automation markets have yet to come up with specific guidelines for implementing SPE. And while the IEEE specification for the SPE physical layer applies to both markets, questions remain about the extent to which serial communication cables can be reused for long-reach IP communications. As a manufacturer, Phoenix Contact has set out to answer that question by testing various cables to determine the maximum length through which they could enable IP communications when used as an SPE physical layer. The results are promising, but guidelines must be followed to ensure optimal performance. ■

Guidelines for the reuse of serial cabling for IP communications over a Single Pair Ethernet physical layer

Methodology

By evaluating existing cable structures upfront, reliable performance can be confidently achieved when reusing cabling. 10Base-T1L, for example, enables communication over 1000 m at 10 Mbps in full-duplex mode using a balanced pair with an impedance of 100 Ω. IL, RL, TCL, and crosstalk values are given to ensure performance over the frequency of operation (100 kHz to 20 MHz). Any cable to be considered for reuse should be tested to ensure it meets these parameters if attempting to deploy the total length specified in the standard (1000 m) or tested to determine the maximum length it can achieve. Additionally, the age and physical integrity of the cable should be considered to avoid discontinuities. As such, we proceed to investigate the extent to which some serial communication cables can be used for SPE by testing three cables used for serial communications.

For this investigation, three different serial communication cables were tested using a Fluke field tester (Fluke DSX 8000) and comparing the results to those obtained with VNA (Vector Network Analyzer). The field tester was paired with a prototype adapter for SPE cables that uses SPE interface IEC 63171-2. The serial cables were terminated using a field-wirable SPE T1 CIM SF connector (Figure 6). For the impedance measurements, a TDR (Time Domain Reflectometer) was used. The cable characteristics were as follows:

1) Cable type YV 2x0.8/1.4, switching wire, also known as bell wire, unshielded, and used for point-to-point connections for low-speed communications and low power.

Guidelines for the reuse of serial cabling for IP communications over a Single Pair Ethernet physical layer **continued** →

2) Cable type J-Y(ST)Y 2x2x0.8, shielded, used to transmit KNX signals in buildings, and are also suitable for measurement data, used for HVAC applications with Modbus or BACnet protocols via RS-485 interfaces.

3) BACnet twisted pair Plenum Rated EIA-485 communication cable, shielded, also used in HVAC applications.

These cables had not undergone high-speed data performance testing during design and validation, as they were not meant for high-speed applications. As such, their specification sheets did not provide frequency of operation, IL, RL, or TCL data. These cables had a nominal impedance of 90 Ω, 75 Ω, and 115 Ω, respectively, with cables 1 and 3 within the tolerance allowed for SPE (100Ω ± 20 Ω) and cable 2 slightly out of the tolerance.

Findings: Evaluating branch lines for realistic cabling configurations

One part of the testing process involved identifying a method to account for realistic cabling arrangements, as some cable deployments may branch out into different areas. These branches could be open or unterminated. Two configurations were considered for testing: one configuration featured a length of 40 meters (trunk line) with a 2-meter branch 2 meters into the start of the link segment. The second configuration had a 10-meter branch starting 2 meters from the start of the link segment (Figure 7). These configurations were tested in open and terminated positions for both the trunk and branch lines to determine the influence of terminating the lines in the performance of the link length.

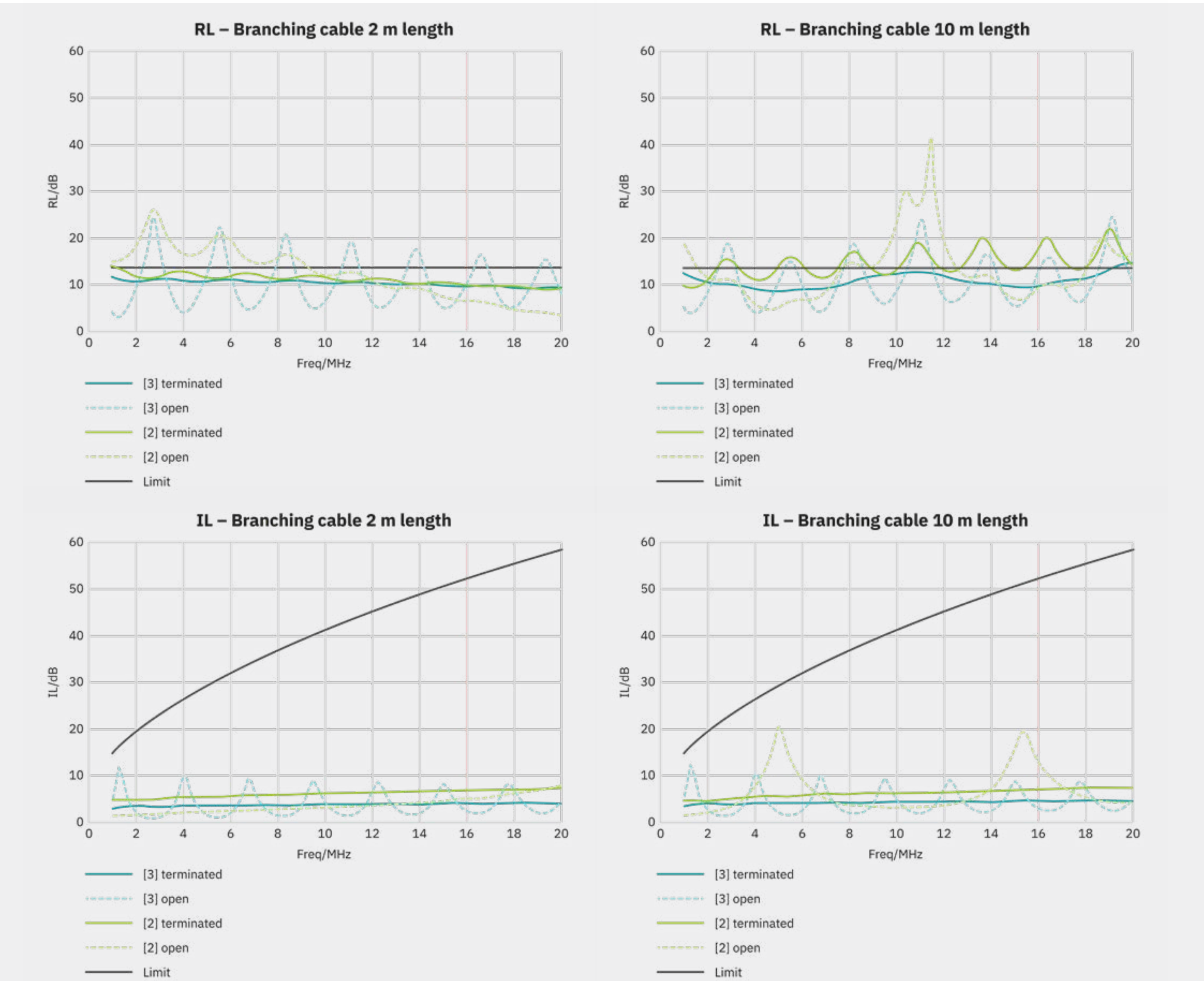

Figure 8: RL and IL results for branching configuration of BACnet cable.

Guidelines for the reuse of serial cabling for IP communications over a Single Pair Ethernet physical layer **continued** →

Measurements were taken from the start of the link to the end of the branch (2 m or 10 m) and from the start of the link to the end of the trunk line (40 m), with the branches either terminated or left open. Figure 8 shows the results of return loss and insertion loss for the branched arrangement of the BACnet cable. The criteria for meeting SPE 10Base-T1L are defined in IEEE 802.3 and are as follows [1]:

- Return loss ≥ 13 dB for frequencies between 0.5 MHz and 20 MHz.
- Insertion loss ≤ 5.9(1.23*√f + 0.01 * f + 0.2/√f) + 10 * 0.02 * √f dB, where f is the frequency from 0.1 MHz to 20 MHz.

The return loss results for both configurations show poor performance, as the values are mostly below the limit line, with the open configurations showing waveforms that are more pronounced than those of the terminated branch lines. The results from the 2-meter branch line test show RL values decreasing from 11 dB to 9 dB with a terminated trunk and increasing from 4 dB to 8 dB, with an open trunk, which amounts to maximum losses of 13% for the terminated trunk line and 40% for the open trunk line. In the case of the measurements taken along the trunk, the values decrease from 13 dB to 10 dB for the terminated branch, and from 14 dB to 5 dB for the open branch, which amounts to maximum losses of 10% for the terminated branch and 32% for the open branch. In both cases, the 2-meter branch line shows significant losses and is not recommended for SPE transmission.

The results for the RL of the 10-meter branch are comparable to those of the 2-meter branch configuration, but show more promising results as a trunk line measurement, with a terminated branch line yielding better results with enough margin to be used for SPE transmission.

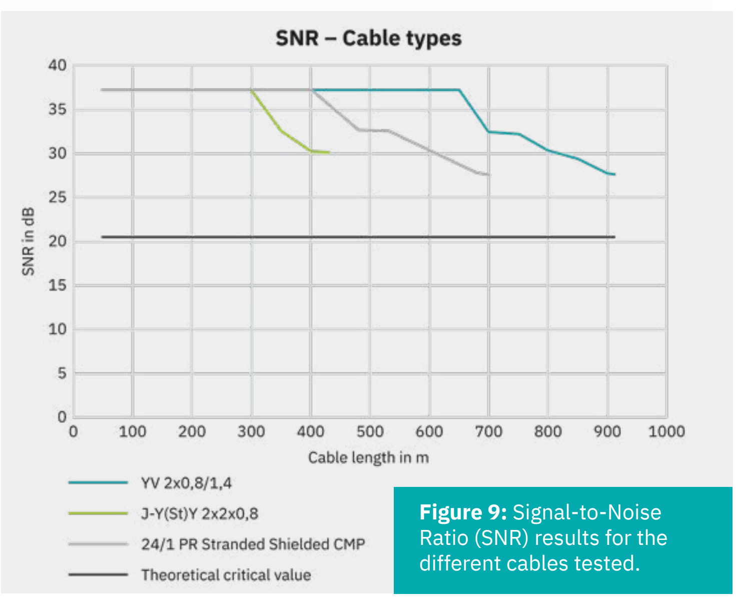

Figure 9: Signal-to-Noise Ratio (SNR) results for the different cables tested.

The waveform in question increases from 10 dB to 15 dB between 1 MHz and 3 MHz, then falls to 11 dB and continues to increase until it reaches 22 dB at 19 MHz, ending with 14 dB at 20 MHz. This amounts to a maximum power loss of 10% over the entire frequency range. The results of the insertion loss are well below the limit values for SPE 10 Mbps transmission. The RL and IL results for the other cables are explained in detail in “Single Pair Ethernet in Building Automation” [2] and are comparable with the results of the BACnet cable, with slight deviations, which can be attributed to the different impedances of the cables.

The results of these tests using branched line configurations assume realistic cabling infrastructures

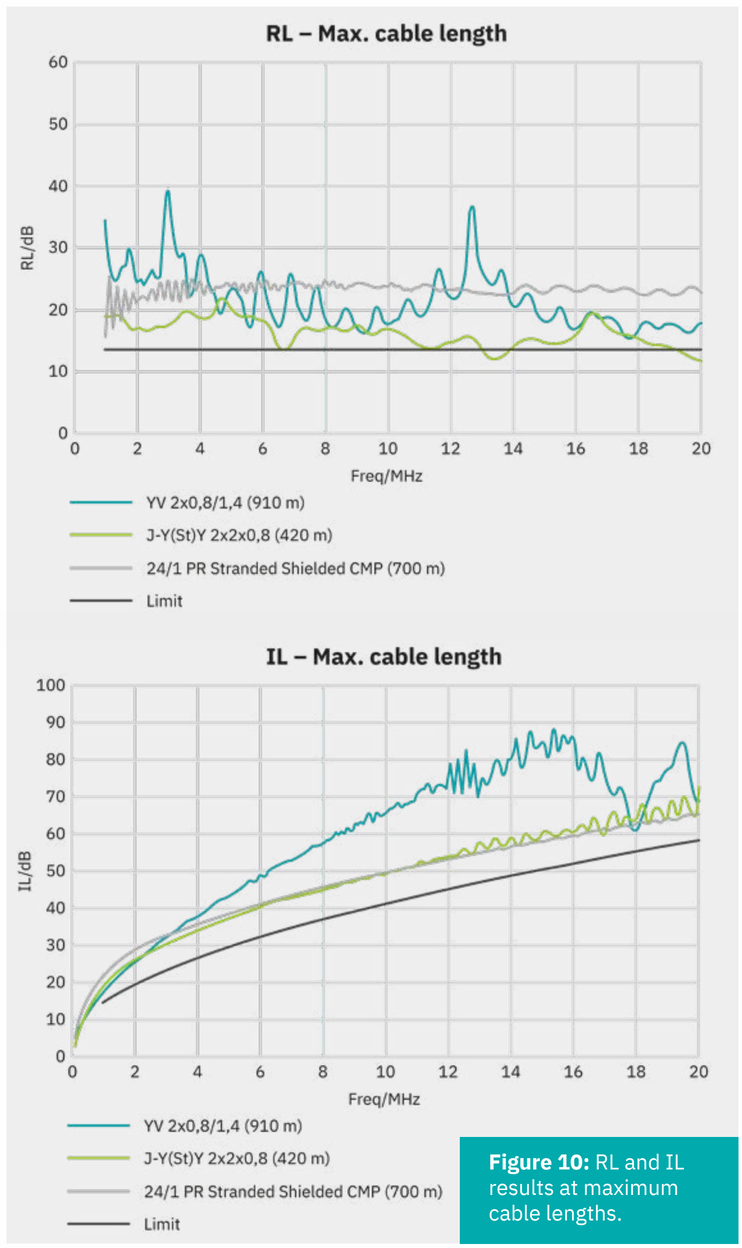

Figure 10: RL and IL results at maximum cable lengths.

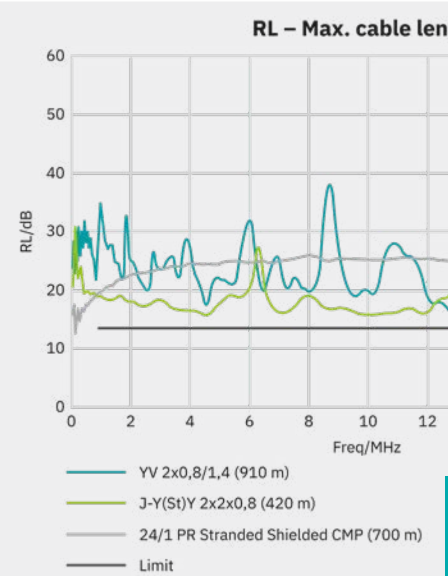

Figure 11: RL a maximum length using Fluke field tester.

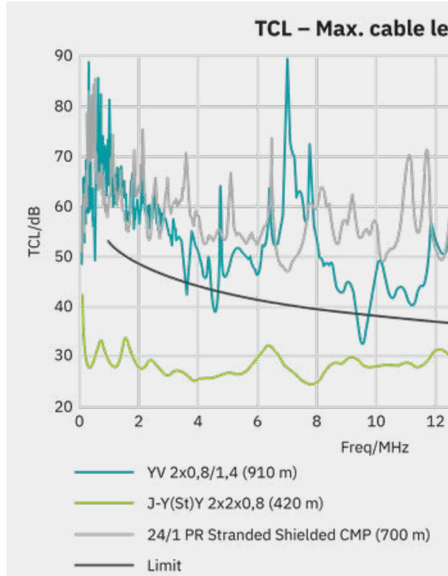

Figure 12: TCL results for maximum cable lengths.

being repurposed for Point-to-Point IP communications, using limits for 10 Mbps SPE transmission. These measurements show that at short distances of 40m, some branched configurations can perform well enough to be considered for repurposing serial cabling for IP communications, with the terminated branch performing better than open branch lines in all the measured configurations.

Findings: Evaluating maximum cable reach

The second part of the testing process was to measure the maximum distances serial cables could run SPE in a point-to-point configuration. For this measurement, two evaluation boards were connected to either end of the cables to perform Signal-to-Noise Ratio (SNR) measurements to find the point at which communication was no longer possible.

The results of the SNR tests yielded the following distances: Cable 1 (YV) can achieve a maximum range of 910 m with an SNR value of 27.6 dB. Cable 2 (J-Y(St)Y) can achieve a maximum range of 420 m, with an SNR value of 30.1 dB. Cable 3 (24/1 PR) can achieve a maximum range of 700 m with an SNR value of 27.6 dB (Figure 9).

The SNR limit for the board used to perform the test (ADIN1100) is 20.5 dB, and the board was set to auto-negotiation mode, which may have influenced the range of values obtained with this test. These measurements show that SPE transmission, while not at maximum length, can be achieved using serial communication cabling and can be an option for device upgrades in factory and building environments where serial cabling is available and deployed.

Additional measurements, such as IL and RL, were performed on the cables both with a Vector Network Analyzer (VNA) and with a Fluke DSX-8000 field tester. Return loss for all cables is above the limit line and meets requirements for SPE transmission. The insertion loss results for all the cables are above the limit line and do not meet the requirement for SPE transmission, with the unshielded cable having the worst attenuation when compared to the shielded cables tested (Figure 10). Figure 11 shows RL results obtained with the Fluke field tester. These results are comparable to those obtained using the VNA with some deviations at lower frequencies, especially for the BACnet cable. ■

Conclusion

The reuse of existing serial communication cabling for IP-based applications can be a viable and attractive option, depending on several key factors. Cable construction and characteristic impedance play especially important roles in determining overall performance. Evaluations of different cable types show that cables with an impedance close to 100 Ω tend to deliver the best results, as reduced signal reflections lead to more efficient power transmission.

Cables with impedances that deviate from the ideal value for Single Pair Ethernet (SPE) can still be successfully reused, particularly over shorter distances. In these scenarios, acceptable performance can often be achieved even without extensive testing, making cable reuse practical for many localized applications. Cable topology is also an important consideration. While open branch lines are not recommended, terminated lines can support SPE in certain branch-line configurations when properly designed.

Conclusion continued →

As a result, SPE deployments using existing cabling can benefit from straightforward optimizations such as terminating unused branch lines and validating key electrical characteristics. Performing targeted testing ensures confidence in the reused infrastructure and helps confirm that performance expectations will be met. These evaluations can be carried out using standard field testers equipped with measuring adapters, with cable ends terminated using appropriate connectors or terminal blocks.

For short-distance deployments or installations that include branch lines, return loss serves as an effective indicator of signal quality, as it reflects the level of signal reflections in the system. For longer cable runs, attenuation — or insertion loss — becomes the primary focus, since transmission distance can ultimately define system limits. Overall, this evaluation demonstrates that even when existing cables do not support the full reach defined by the 10BASE-T1L standard, reliable SPE communication can still be achieved at shorter distances — opening the door to cost-effective Ethernet adoption using installed cabling. ■

Nick Sandoval
SPE Technology Evangelist,
Phoenix Contact USA
nsandoval@phoenixcontact.com

About Phoenix Contact

Since 1923, Phoenix Contact has created products to connect, distribute, and control power and data flows. Our products are found in nearly all industrial markets. Sustainability and responsibility guide every action we take, and we are proud to collaborate with our customers to empower a smarter and better world for future generations. Together, we are creating a sustainable world based on our passion for technology and innovation.

For more information about Phoenix Contact or its products, visit **www.phoenixcontact.com**, call technical service at **800-322-3225**, or email **us-info@phoenixcontact.com**.

References

[1] IEEE Std 802.3 -2022 IEEE Standard for Ethernet

[2] Radau, M., & Chalas, G. (2024). *Single Pair Ethernet in Building Automation* [White paper]. Phoenix Contact. https://dam-mdc.phoenixcontact.com/asset/156443151564/8973abe4a7544245b-8ba223773708521/US_SinglePairEthernet_in_Building_Automation_20240227.pdf

[3] Escher, B., & Wassmuth, A. (2023). *Backward Compatible SPE Cabling: The Successful Path to IoT Infrastructures: Single Pair Ethernet (SPE)* [White paper]. Draka. https://singlepairethernet.com/wp-content/uploads/2024/01/White-Paper_SPE-Verkabelung_EN_2.pdf

Acknowledgements: *The various tests were done in collaboration with Michael Radau from Phoenix Contact GmbH, who laid the groundwork for this cable assessment and findings.*