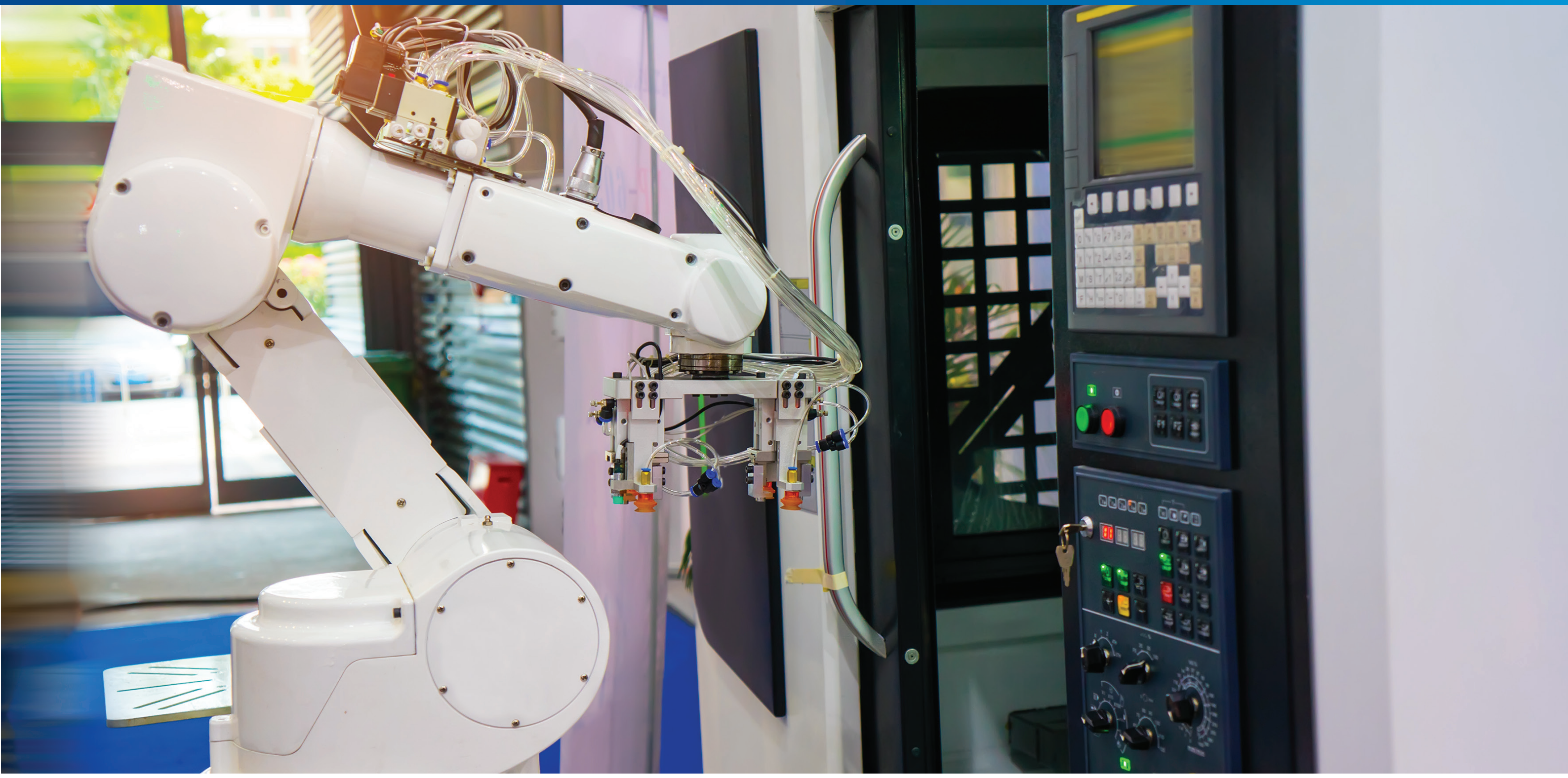
BELDEN
SENDING ALL THE RIGHT SIGNALS

White Paper



Bonded-Pair Cable

Driving the Future of Automation

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Executive Summary

"Connected" is the word that best describes today's industrial automation world. Advancements in sensors, actuators, switches and active components strive to keep up with the insatiable demand for increased output and productivity in the manufacturing industry. At the center of this transformation is the rapid migration to Ethernet-based (IP) communication protocols that enable signal transmissions to connect with a network through an integrated digital sensor.

Ethernet networks were first put to use in the office environment long before the advent of carrying data to and from equipment in the harsher industrial environment of the factory floor. Perhaps that's one reason why so many organizations, when building their connected manufacturing networks, automatically specified what they knew—the same familiar cable that served them well on their enterprise side—without taking into account the added challenges of the industrial environment.

That's unfortunate, because there is a long list of threats that just aren't evident in the climate controlled, carpeted comfort of the office—things like oil and solvent exposure; crushing forces; cutting forces; water immersion; high temperatures; low temperatures; twisting, bending and pulling in use and more. Any of these threats can and do wreak havoc on the performance of Ethernet cabling, causing incomplete or otherwise compromised data to reach vital equipment.

Fortunately, advances in the design of Ethernet cable can mitigate these damaging conditions and help prevent the majority of network failures occurring in the physical layer of the network.

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Be certain. Belden.

Every Signal is Mission-Critical

More than ever before, network failure is unacceptable. Downtime could mean security systems that fail, machines that don't work, fire alarms that can't alert building management to a problem or quality control issues. On top of all that risk, the cost of unplanned downtime can run into the millions for production facilities.

Statistics show the number of connected devices (Internet of Things; IoT) worldwide will dramatically escalate from 2015 to 2025. By 2020, the installed base of Internet of Things devices is forecast to grow to almost 31 billion worldwide[1].

This is a monumental shift for our networks. We've gone from considering only certain businesses and industries to be "mission-critical" (financial institutions, for example) to viewing every IoT signal transmission as indispensable.

Cable Innovations Reduce Risk

First, let's look at the conductors inside the jacket of Ethernet cable. Twisted pair cable is the basis for almost all Ethernet cable today. As its name suggests, this construction makes use of an innovative design technique in which the two copper wires forming each circuit are twisted together throughout their length (see Figure 1).

The twisted pair concept was patented in 1881 by Alexander Graham Bell in response to the observation that constant proximity of the wires in relation to each other helped to reduce the detrimental impact of electromagnetic noise interference generated by the surrounding environment. It was a significant improvement over existing parallel wired cable, but, as Bell himself warned[2], twisting the pairs only enables noise cancellation to the extent that the individual conductors stay together.

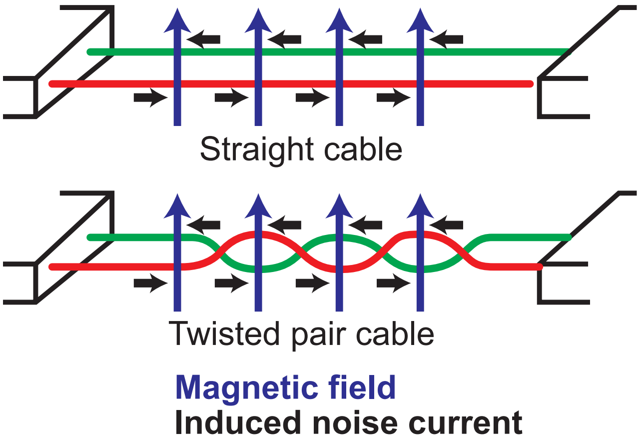

Figure 1 Twisting conductors together offered the first significant improvement in cable transmission performance, as proven by Alexander Graham Bell in the late 19th century.

In other words, a conventional twisted pair is like an antenna; as the gap between the wires widens, the pair receives more noise into the circuit from the surrounding environment (see Figure 2). Bell's twisted pair concept was developed and perfected for the relatively static application of acting as a telephone wire and was effective in use in these applications for more than a century. It is only more recently that Bell's insightful predictions about the limitations of the twisted pair innovation began to become more evident and problematic.

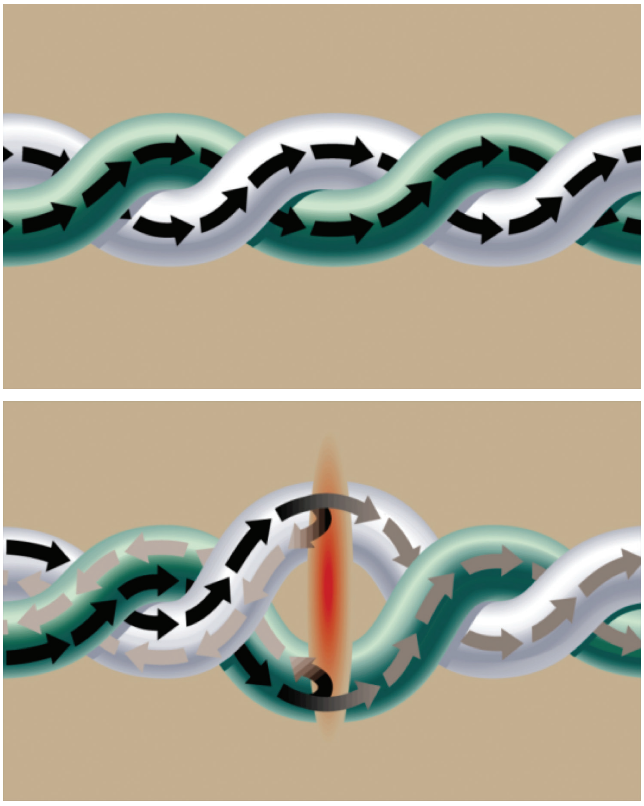

Figure 2 While twisted pair technology improved signal quality and reliability, over time gaps would develop. This spacing allows more noise interference and eventually leads to signal failure.

In today's more stringent industrial and data-intensive applications, for example, although it may perform fine "out of the box," it is nearly impossible for conventional twisted pair wires to maintain equal distance as the cable is pulled, flexed, coiled or otherwise manipulated during installation. Things get worse in the industrial environment, where frequent or continuous cable motion gets coupled with actively moving or vibrating equipment.

In fact, even the simple act of simulating a service loop for a few seconds by bending a conventional twisted pair in a figure eight with mild force can cause it to fail. Extrapolate to an industrial environment subject to extreme continuous rugged pulling and wear and tear and it is clear how the wires can be pulled apart again and again. This leads to electrical issues that can quickly become a frequent and, ultimately, permanent and continually escalating issue.

Evolution to Bonded Twisted Pair

As Alexander Graham Bell recognized in his original patent, any deviation from the pairs being equidistant leads to poor twisted pair performance. These conductors were never intended to separate from each other, whether that be during manufacturing, installation or use in flex applications common in industrial environments.

In fact, the TIA 568-B[3] standard advises that failures during termination occur after just ¼-inch of untwist. This can be summarized by the phrase "physical equals electrical" – any time you physically alter a twisted pair, you have permanently changed the relationship of the pairs, leading to significant degradation of the cable.

To overcome this weakness, Belden invented a new bonded-pair technology to improve on the original twisted-pair patent. The underlying principle of this patented technology is to add another level of physical robustness to eliminate performance-robbing gaps. By bonding the individual conductors along their longitudinal axis, a solution was born to do something that Alexander Graham Bell never could – guarantee extremely uniform spacing within each twisted pair, as demonstrated in Figure 3. Regardless of physical alteration, these cable pairs maintain consistent distance.

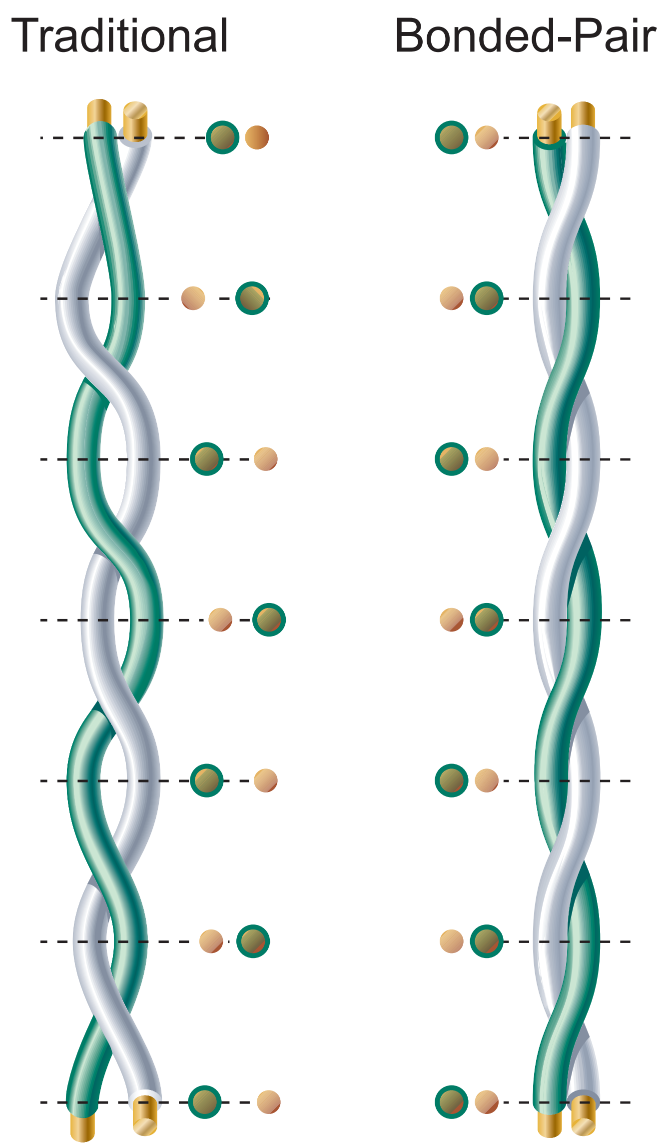

Figure 3 Installed and manipulated unbonded-pairs (left) have a tendency to gap, varying the centricity of the two conductors. Belden bonded-pairs (right) do not gap so the physical integrity of the pair is maintained.

Preventing gaps between the twisted pairs also affords additional protection against noise as well as abrasive and other hidden internal mechanical damage since the wires can no longer be made to rub against each other as the cable itself undergoes motion in use.

While shielded industrial cable can provide outstanding noise protection, non-shielded, bonded-pair industrial cable provides excellent noise protection, often at a lower cost than shielded cable. In many cases, you can eliminate the need for shielded cable altogether. For example, ODVA guidelines[4] suggest routing conventional cable at least five feet from electromagnetic sources to avoid interference. Bonded-pair cable can allow routing as close as six inches or less without issue.

From Installation Forward: Bonded-Pair Cable Acts Differently

Bonded-pair technology eliminates the potential for separations occurring between the two wires that lead to changes, potentially permanent, in electrical performance. This can happen during installation and in locations where cable is subjected to continuous or intermittent pulling, bending, twisting and other common motions.

While many manufacturers can claim 100% tested reels, a common problem occurs after the sale has been made. Laboratory testing under the parameters of TIA 568 standards demonstrates the failure of non-bonded Ethernet cables. As the cable is pulled through several twists and bends, coiled in and out of conduit and control panels and wrangled in service loops during installation, performance falters (see Figure 4). In contrast, Belden's bonded-pair cable retains its performance quality.

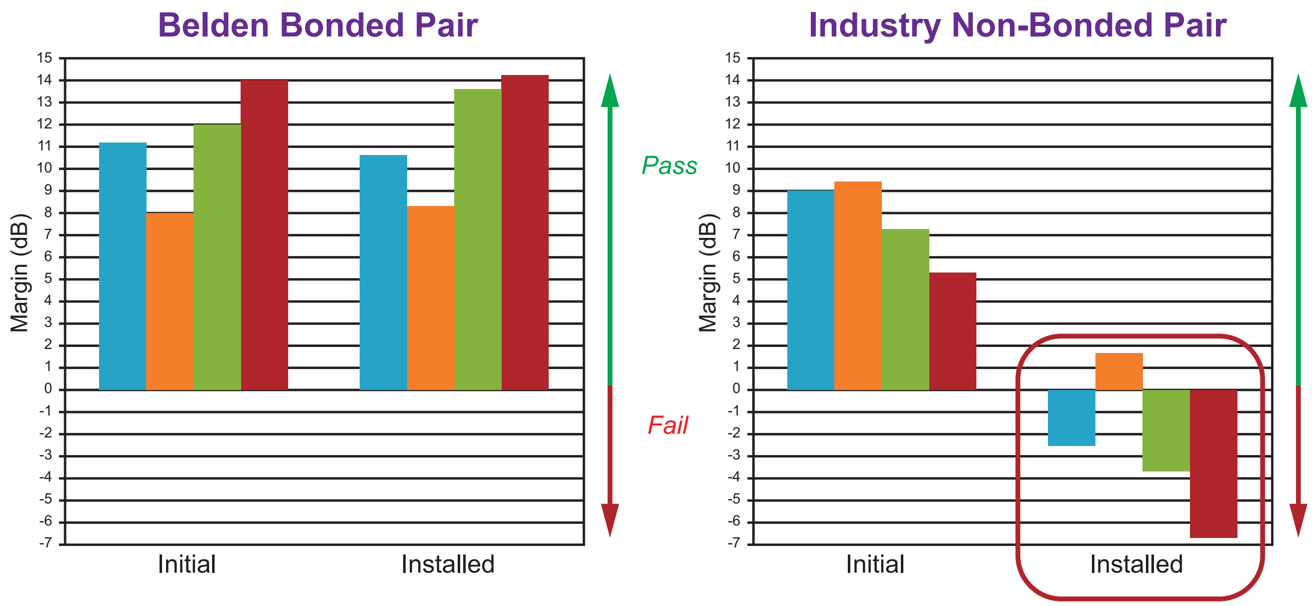

Figure 4 This chart depicts the performance of the individual data pairs (blue/yellow/green/red) before and after installation, per TIA 568 standards.

Another way to look at the difference is to compare the impedance of cables during stress testing. For these data signals, matching the input impedance of an electrical load to the output impedance of its corresponding signal source maximizes power transfer and minimizes signal reflection. In Figure 5, you can see the tight grouping of performance factors for bonded-pair cable vs. the erratic performance of non-bonded-pair cable.

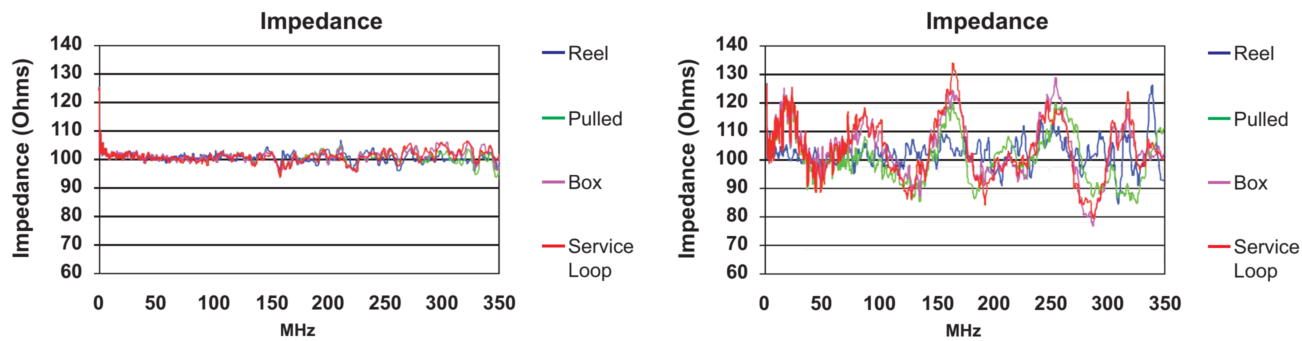

Figure 5 While bonded-pair cable (left) remains stable before and after installation, standard industrial cable (right) spikes up to 35 ohms, resulting in signal disruptions.

Mechanical Protection Against Electrical Degradation

The primary benefit of bonded-pair cable comes from its ability to maintain the ongoing electrical integrity of the cable as it is pulled, bent or twisted in installation and in ongoing use—a benefit that, like noise protection, cannot be provided by conventional cables.

Specifically, impact on the physical integrity of cable can cause related impacts on electrical integrity, leading to signal loss. Ultimately, permanent changes in physical form, not surprisingly, will lead to permanent changes in electrical performance, like a paper clip bent back and forth is altered with a permanent weak point created at the point of the bend.

Bonded-pair technology is a more elegant and effective method of maintaining contact between the twisted pairs, creating an actual bond between the two wires that eliminates any threat of separation. Even when a bonded-pair cable is forcibly bent, twisted or pulled, its conductor-to-conductor spacing – known as centricity (see Figure 6) – remains stable, providing immunity to installation stresses as well as ongoing stresses in use. In fact, the bond between the pairs has been shown to be far stronger than the wires themselves, with the wires failing in testing before the bonds between them.

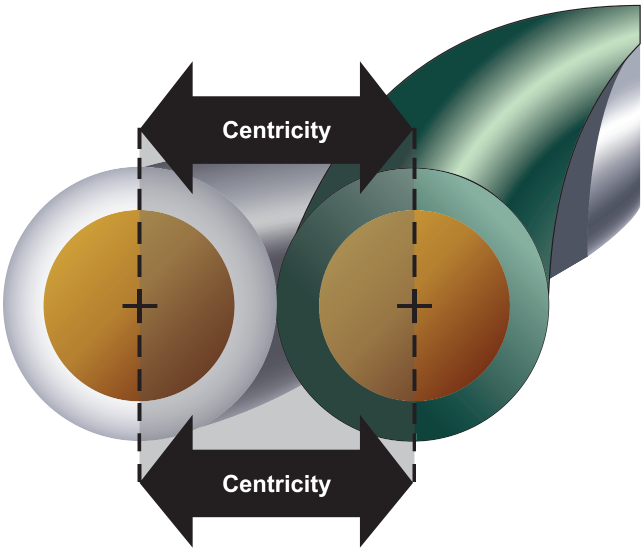

Figure 6 The center-to-center distance of the copper within the conductors of a pair is known as "centricity." Maintaining centricity protects signal reliability.

The strength of the bond in bonded-pair cabling has been effectively proven out in real-world use for decades. To further support this effectiveness claim, Belden subjected its bonded-pair cable to a series of laboratory tests.

There is no standard industry torture test for simulating flex. Indeed, some organizations have been known to create nonrealistic flex tests using very small lengths of cable or unnatural conditions to get the results they want, rather than creating a testing protocol more applicable to real-world usage conditions in mission-critical applications.

To overcome this issue, Belden built a torture test truly aligned to common industrial operating conditions, starting with a commercially available 5 H.P. C-Trak Flex Testing machine. A 15-foot length of bonded-pair cable was first subjected to a tight 3" bend, then subjected to multiaxial movement of 10 feet per second for 28,800 cycles per day. It was continually monitored for shorts, voltage drops and other issues at eight points along its length. After more than 10 million flex cycles—10,075,000 to be exact—the test was stopped due to time constraints. No physical or electrical failures were seen at any point during testing.

Damage somewhere in the network is almost unavoidable with conventional cable as installers pull, twist and bend the cable into their desired infrastructure. Cable lengths are bent forcefully around rafters and equipment corners, pulling them down elevator shafts and crawl spaces and twisting them in loops and knots to get the cable into required positioning.

Bonded-pair cable protects against this treatment. It can withstand a pulling tension of 40 lbs/foot—60% more than conventional industrial cable. And, it can withstand even a very tight, sharp bend radius of 1.1 times the outer diameter, while shielded cables can show separation at even a wide service loop of 8 times the outer diameter.

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For Industrial Success, Specify the Right Cable

In today's highly connected world, one thing is certain. You can't afford to be wrong about the cabling you choose – especially in an industrial environment. Personal safety, production output and profits are all on the line. The cost of even a single, relatively brief cable data failure at your facility can easily escalate into catastrophe.

Commercial-grade cable is fine for applications in the temperature-controlled, clean, protected environments of carpeted offices. But out on the concrete, where assembly lines rumble and moisture or chemicals combine with temperature spikes, you need something tougher and more durable. The advent of industrial-grade cable offered a significant improvement in such operating conditions. But for true reliability over the life of your connected machines, only bonded-pair cable keeps uptime at a maximum.

In summary:

Protection Against	Commercial Grade Cable	Conventional Industrial Grade Cable	Bonded-Pair Industrial Grade Cable
Abrasion	—	✓	✓
Cold Exposure	—	✓	✓
Temperature Variation	—	✓	✓
Crushing	—	✓	✓
Cutting	—	✓	✓
Oil Exposure	—	✓	✓
UV Exposure	—	✓	✓
Water Immersion	—	✓	✓
Electrical Noise	—	—	✓
Pulling/Twisting/Bending During Installation & Use	—	—	✓

To learn more about Belden's broad portfolio of Ethernet cables, visit. https://www.belden.com/products/industrial/cable.

References

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2 Bell, A.G. Telephone-Circuit. No. 244,426, United States Patent Office, 19 July 1881

3 https://www.csd.uoc.gr/~hy435/material/Cabling%20Standard%20-%20ANSI-TIA-EIA%20568%20B%20-%20Commercial%20Building%20Telecommunications%20Cabling%20Standard.pdf

4 ODVA website: https://www.odva.org/

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