We get technical

The engineer's guide to RF cable assembly selection and use

Connector, gland, and grip options for industrial-automation cabling

Understanding and applying the new standard connectors for indoor & outdoor LED-based lighting

Connectivity – the backbone of sustainable automation

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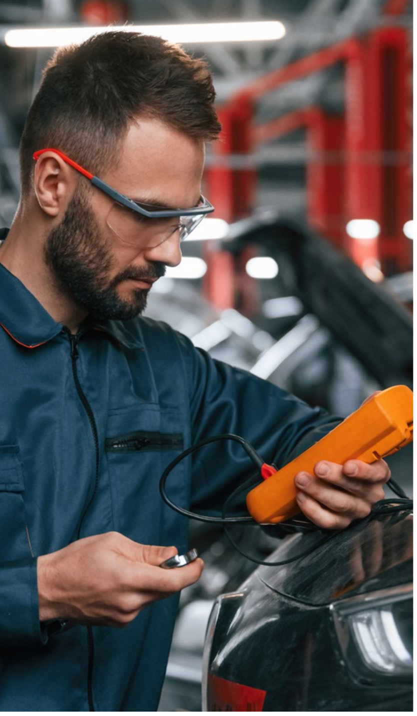
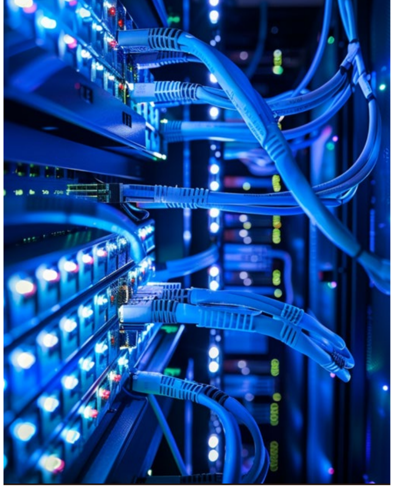
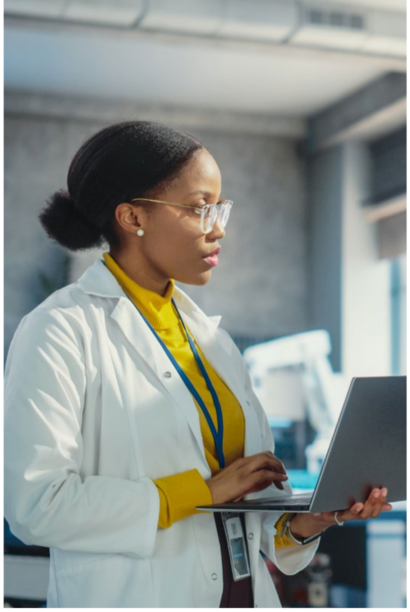


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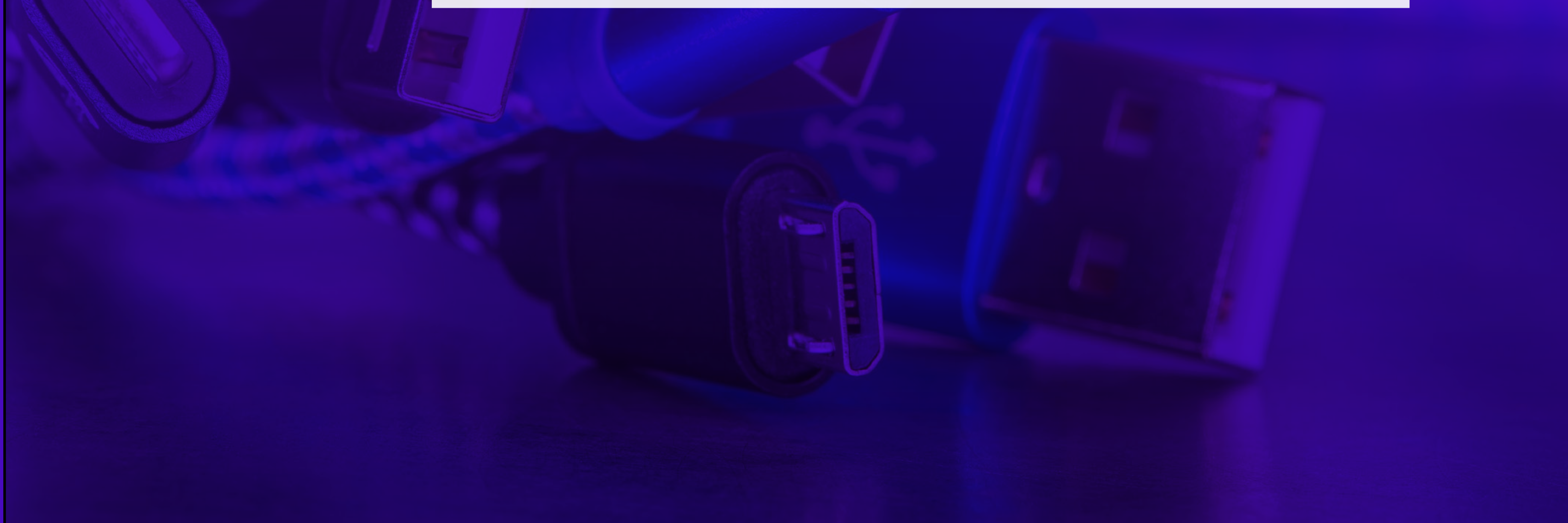
Editor's note

In this issue, we dive into the essential elements that drive today's most sophisticated electronic systems. As engineers and designers, you know that choosing the right connectors, cables, and assemblies isn't just about functionality—it's about enhancing performance, reliability, and efficiency across all applications.

We've compiled an expert guide to help you navigate the complex world of RF cable assemblies, GHz coaxial connectors, and USB specifications. Whether your project involves high-frequency applications or rugged outdoor conditions, our articles offer technical insights and practical tips on selecting components that meet the highest standards. You'll find in-depth articles on medium-voltage connectors, critical for applications that demand robust power delivery and safety, as well as circular and heavy-duty industrial connectors designed for environments where reliability and resilience are paramount. We'll also take a closer look at outdoor LED lighting connectors, an essential element for urban and industrial lighting systems.

With so many options and specifications to consider, we hope this issue serves as a valuable reference for making informed choices and staying at the forefront of connector technology. Enjoy the read, and as always, we welcome your feedback and insights.



The engineer's guide to RF cable assembly selection and use

By Kenton Williston
Contributed By DigiKey's
North American Editors

RF cable assemblies are used in a wide range of applications, from well-established domains like aerospace and communications, to newer use cases like automotive, industrial, and the Internet of Things (IoT). This expanding list of applications has prompted the development of new types of RF cable assemblies, giving engineers further opportunities to optimize their RF system designs.

However, all this growth is complicating the design process. With so many assemblies on the market, it is difficult to identify the best choice for a particular application. Also, the use of RF cabling in new applications is putting unfamiliar technology in front of more designers, installers, and maintenance technicians. Along with space and environmental considerations, those groups must now become familiar with frequency compatibility, impedance matching, voltage standing wave ratio (VSWR), magnetic coupling, and shielding.

To ensure the performance and reliability of RF systems, engineers need an attentive approach and a clear roadmap of the options and potential pitfalls that await them.

Beginning with a brief overview of RF applications including their electrical characteristics, physical construction, and typical use cases, this article serves as a guide to the complex task of choosing, installing, and maintaining RF cable assemblies. Examples from Molex are introduced to illustrate key selection and usage criteria.

The expanding use cases of RF cable assemblies

RF technologies span a multitude of sectors, each with its unique challenges. Frequencies range from hundreds of hertz (Hz) to tens of gigahertz (GHz). Some applications require ruggedization. Others have extremely confined physical footprints. To illustrate the diversity of use cases, consider these common applications:

- **Aerospace and defense:** Radar systems, communication channels, and GPS
- **Automotive and transportation:** Infotainment systems, navigation, and vehicular communication networks
- **Telecommunications and broadcast:** 8K video signals over Wi-Fi, LTE, and 5G networks
- **Industrial:** IoT sensors, automated assembly lines, and telemetry
- **Medical:** Remote patient monitoring systems, advanced diagnostic machinery, and robotic surgery units
- **Test and measurement:** Bench measurements, field tests, and quality assurance in manufacturing setups

Due to the growing use of RF, more engineers and designers are engaging with high-frequency circuits, many without a background in this technology. Faced with tight deadlines and budgets, they need solutions that simplify their tasks while ensuring their systems perform reliably.

That is where RF cable assemblies come in. These assemblies consist of pre-assembled connectors and cables that meet the specified performance requirements while reducing the engineering effort. Using premade RF cable assemblies can save time and cost during design and prototyping, and improve the quality and efficiency of production.

Frequency compatibility, impedance matching, and VSWR

Choosing the appropriate cable assembly requires careful consideration of multiple factors. First, the assembly must be able to accommodate the frequency range of the RF signal. These can vary from a few hundred hertz to the super high frequency (SHF) band of 3 to 30 GHz or higher (Figure 1).

To achieve the desired performance, a cable assembly must handle the appropriate frequency range without significant signal loss or distortion. For example, the Society of Motion Picture and Television Engineers (SMPTE) sets stringent signal quality requirements under their 2082-1 guidelines, which limits loss to 40 decibels (dB) at half the clock frequency.

One way to meet these demands is with the Molex BNC Mini RF Cable Assemblies, which deliver high return-loss performance at frequencies of up to 12 GHz. This performance exceeds the requirements for serial transmission of 8K high-definition TV (HDTV) video, allowing for future bandwidth expansion without hardware changes.

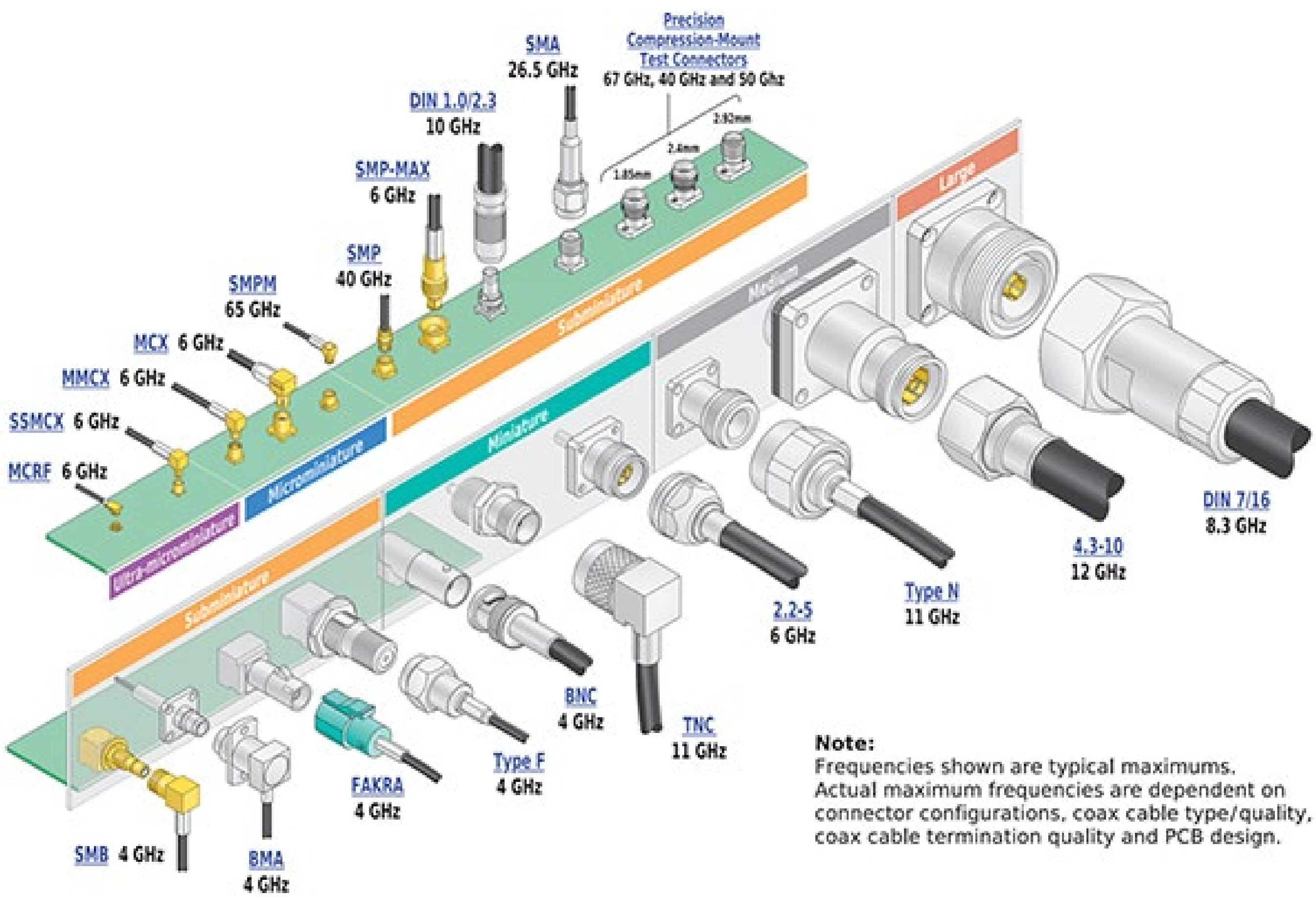


Figure 1: RF cable assemblies come in a wide variety of designs, which can be categorized by the size of the connector and their maximum supported frequency, among other factors. (Image source: Molex)

ORDER NO.	CONNECTOR-TO -CONNECTOR	CABLE LENGTH	LENGTH	VOLTAGE STANDING WAVE RATIO VSWR)	LENGTH
89762-1540	2.92 mm ST plug to 2.92 mm ST plug	086 low-loss	152.40 mm / 6.00"	1.50 max to 40 GHz	1.00 dB
89762-1541			228.60 mm / 9.00"		1.43 dB
89762-1542			304.80 mm / 12.00"		1.85 dB
89762-1543			381.00 mm / 15.00"		2.15 dB
89762-1544			457.20 mm / 18.00"		2.85 dB
98762-1580		047 low-loss	152.40 mm / 6.00"	1.55 max to 40 GHz	1.65 dB
89762-1581			228.60 mm / 9.00"		2.30 dB
89762-1582			304.80 mm / 12.00"		2.90 dB
89762-1583			831.00 mm / 15.00"		3.60 dB
89762-1584			457.20 mm / 18.00"		4.20 dB

Figure 2: Shown are examples of VSWR and insertion loss figures for efficient, low-loss, microwave-frequency cables. (Image source: Molex)

Impedance matching is another key parameter. RF signals are susceptible to interference from incident and reflected waves caused by an impedance mismatch along the signal line. To minimize signal loss, the cable assembly should have the same impedance as the connected load, typically either 50 or 75 ohms (Ω). It is good practice to design the connectors and cables together to achieve the best match.

A real-world example of this practice is the 0897629290 assembly that pairs Molex BNC connectors with a Belden 4794R cable for high-end 75 Ω applications.

For particularly demanding applications like test and measurement, it may be necessary to carefully consider additional parameters like VSWR and insertion loss. VSWR is the ratio of an incident signal to the reflected signal that provides a measure of how efficiently RF signals are carried from source to load. Insertion loss is the amount of energy that a signal loses as it travels along a connector and cable. Figure 2 illustrates some examples of each.

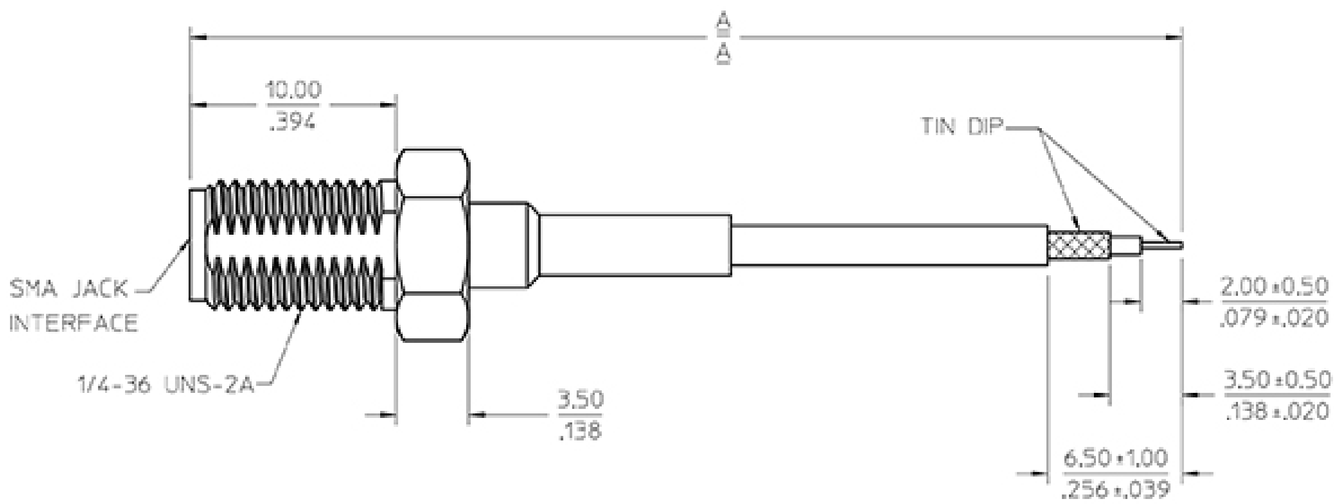


Figure 3: Shown is a typical shielded cable. Starting from the inside of the cable are the core conductor, a dielectric material that separates the core from the shield, a woven metal shield, and the cable jacket. (Image source: Molex)

Shielding, magnetic coupling, and other considerations

Shielding is another important consideration. Any cable carrying RF signals can act like an antenna and broadcast or receive signals, creating interference. To minimize this interference, cables need to be shielded by a grounded metallic housing (Figure 3).

Shielding material choice is influenced by a range of factors, including performance requirements, environmental conditions, and budget constraints. For example, copper is highly effective across most frequencies but also relatively heavy and costly, while aluminum is light and inexpensive but less effective and more prone to corrosion.

There is also the form of shielding to consider. Metallic braids like those on the 0897616761 MCX assembly with RG-136 cables offer excellent mechanical strength and physical protection. In contrast, foil shields are typically made of aluminum laminated to a polyester or polypropylene film for a lightweight, inexpensive, and flexible alternative. There are other types, such as spiral, tape, and combinations, which vary in terms of percentage of frequency coverage, flexibility, lifespan, mechanical strength, cost, and ease of termination.

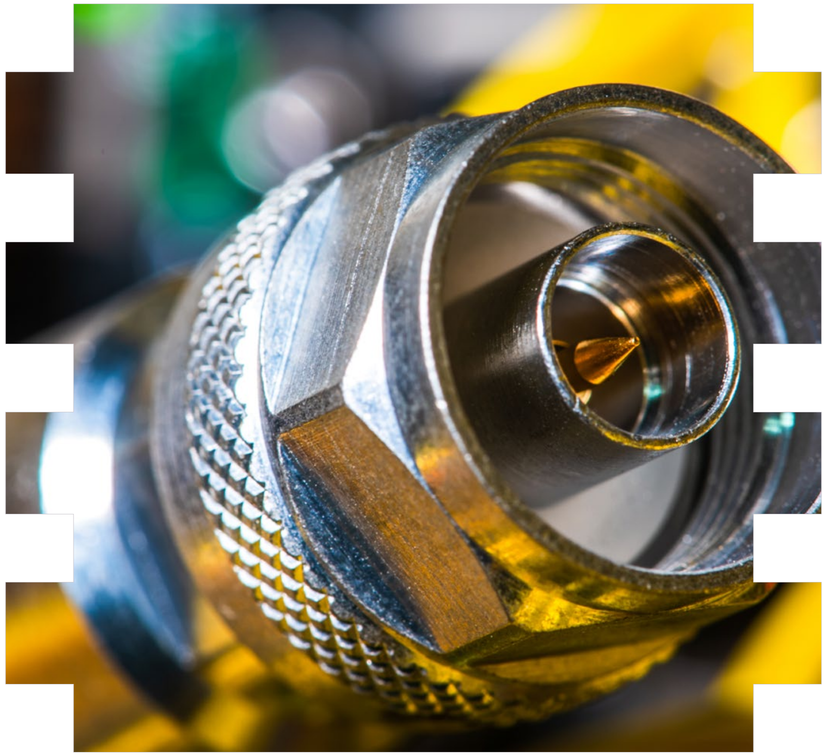
There may also be unique application requirements to consider. For example, medical applications often involve sensors that can be affected by magnetic fields. Here, a solution like the 0897616791 MMCX cable assembly is a viable choice, as these assemblies are available in non-magnetic coupling versions for better design compatibility.

Space constraints, environmental hazards, and maintenance

When considering physical parameters, limitations on space and routing are often the main obstacles. Consider defense applications, which are notoriously cramped. Here, a solution like the 0897611760 SSMCX cable assembly is practical. SSMCX connectors are some of the smallest on the market and are available with vertical and right-angle orientations to accommodate challenging space and routing constraints.

Designers also need to consider the minimum bend radius when selecting an assembly. Due to their complex construction, RF cables tend to be rather stiff. For situations that require tight turns, look for solutions like the flexible microwave assemblies from Molex (Figure 4). These cables are specifically designed for a smaller static bend radius.

Temperature extremes can also be an issue, particularly for outdoor applications like those in the telecom sector. For such applications, the thermoplastic jackets common on RF cable assemblies are not suitable.



<table>
<tr><th>CABLE PART NO.</th><th>IMPEDANCE</th><th>VOP</th><th>CAPACITANCE</th><th>STATIC BEND RADIUS (MIN.)</th><th>CENTER CONDUCTOR</th><th>INSULATION</th><th>JACKET</th><th>OUTSIDE DIAMETER</th><th>CUTOFF FREQUENCY</th></tr>
<tr><td>100067-1047</td><td rowspan="8">50±1 Ohms</td><td rowspan="3">70%</td><td rowspan="3">29 pF/ft</td><td>0.20"</td><td>0.0113"</td><td rowspan="8">PFA</td><td rowspan="8">FEP</td><td>0.061"</td><td>112 GHz</td></tr>
<tr><td>100067-1086</td><td>0.30"</td><td>0.0201"</td><td>0.101"</td><td>62 GHz</td></tr>
<tr><td>100067-1141</td><td>0.50"</td><td>0.036"</td><td>0.158"</td><td>41 GHz</td></tr>
<tr><td>100054-0007</td><td rowspan="5">87%</td><td>23.0 pF/ft</td><td>0.30"</td><td>0.0126"</td><td>0.056"</td><td>143 GHz</td></tr>
<tr><td>100054-0006</td><td>23.4 pF/ft</td><td>0.38"</td><td>0.0253</td><td>0.158"</td><td>42 GHz</td></tr>
<tr><td>100054-0008</td><td rowspan="3">23.3 pF/ft</td><td>0.75"</td><td>0.0453"</td><td>0.158"</td><td>42 GHz</td></tr>
<tr><td>100054-0027</td><td>1.00"</td><td>0.0571"</td><td>0.210"</td><td>31 GHz</td></tr>
<tr><td>100054-0028</td><td>1.60"</td><td>0.0907"</td><td>0.310"</td><td>19 GHz</td></tr>
</table>

Figure 4: Shown is a sampling of RF cables with a small static bend radius. (Image source: Molex)

Instead, more durable materials are required. For example, the flexible microwave assemblies mentioned earlier use Temp-Flex fluorinated ethylene propylene (FEP) material for the jacket, which is a tough material similar to Teflon.

Vibration and shock can compromise a design, particularly in applications like aviation. To ensure reliable operation, the RF cable assemblies used must have extraordinarily secure connections. A good example is Molex's 0732306110 cable assembly, which utilizes I-PEX's patented MHF® LK connector locking mechanism (Figure 5).

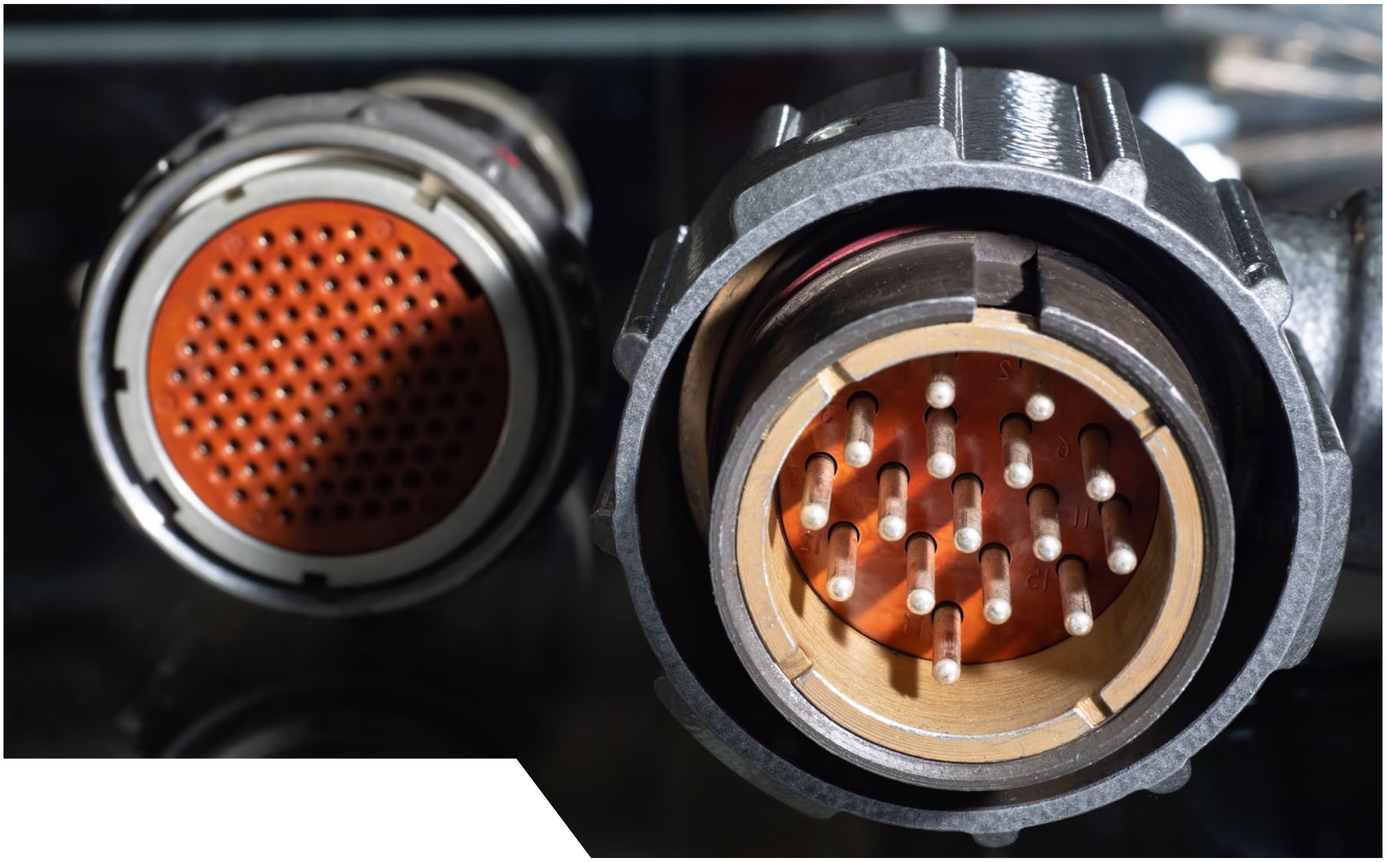
Maintenance must be considered as part of the design process. It is important to look at the mean time between failure (MTBF) for cable assemblies and consider how to arrange a design for ease of maintenance and repair with reasonable access to those subassemblies and connections that might need the most care.

Designers should also consider creating inspection schedules for normal maintenance, and user checklists for signs that a cable assembly might need repair or replacement to proactively manage complications.

Common maintenance steps include checking assemblies for wear, as well as cleaning cables and connectors to remove contaminants that could penetrate connections and degrade performance.

Finally, it's important to evaluate the cable assembly manufacturer. Criteria include appropriate certifications, experience in producing the relevant assemblies, sufficient product options to support design flexibility, and quality assurance processes to avoid performance issues. For example, Molex has been a leading developer of cable and connector technologies with innovation supported by more than 8,100 patents and a strong reputation for quality and technical support, including a custom cable creator tool.

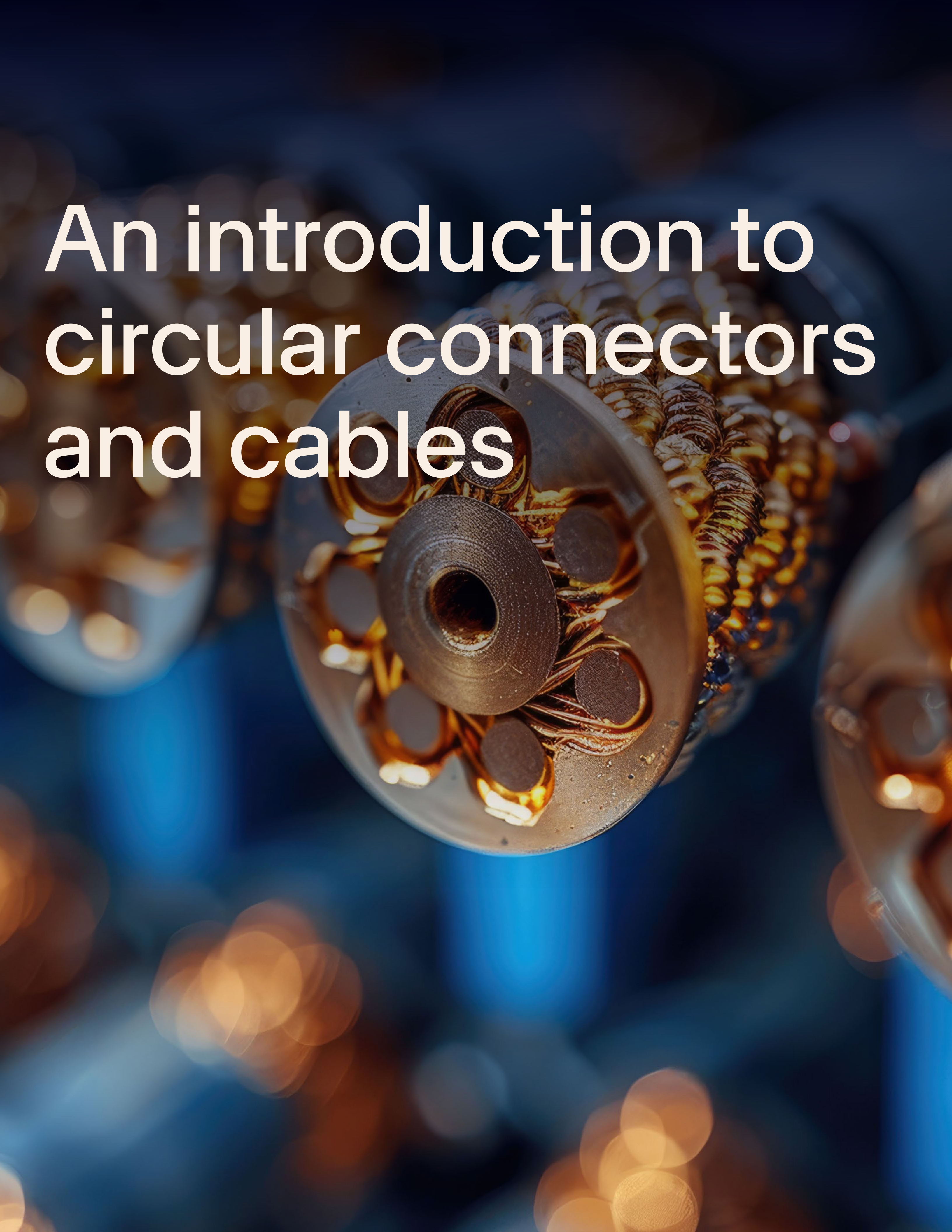
Figure 5: The MHF LK connector system from I-PEX uses a patented locking mechanism to ensure a secure connection. (Image source: Molex)

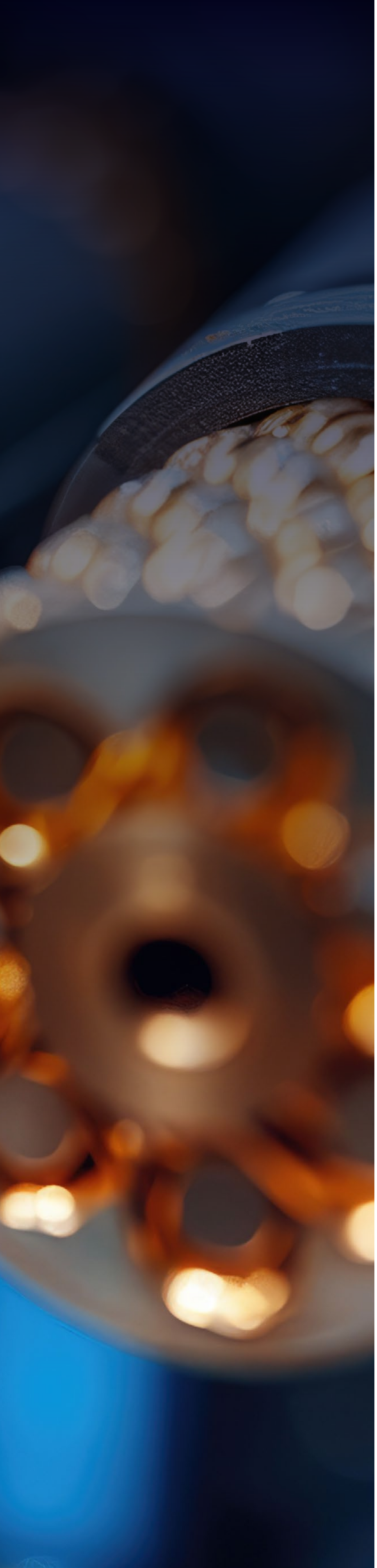


Conclusion

Selecting the right RF cable assembly is challenging as it requires an understanding and careful consideration of factors such as frequency compatibility, shielding, environmental conditions, space constraints, and maintenance. As shown, collaborating with a seasoned manufacturer that brings expertise, quality assurance, and innovation to the table can be the key to navigating these challenges, particularly for engineers and designers who are new to RF. Such a partner can guide the process of selecting, installing, and maintaining these cables to ensure that devices and systems reliably operate at their peak.

An introduction to circular connectors and cables





By Jeff Smoot, VP of Apps Engineering and Motion Control at Same Sky

Housing multiple pins or contacts for transferring electrical power, signals, or data, circular connectors are cylindrical electrical devices of varying sizes that are designed to withstand a range of harsh environments. Also referred to as circular interconnects, their circular construction affords them additional ruggedness and resistance to vibration and impact damage, outside signals or interference, incursion from environmental contaminants, and pressure or temperature extremes.

Due to their high performance in these extreme conditions, circular connectors and cables find broad uses in industrial and factory automation applications, medical devices, security and defense systems, aerospace, and more. Circular connectors encompass a wide array of product offerings from standard circular connectors to DIN, Metric, Hermetic, Push-Pull, Keyed, Mixed Signal, and Micro or Nano versions. Hybrid options are also available that combine power, signal, and data into a single device. This article will primarily focus on standard circular connectors and cables, including their basic construction, designations and codes, selection criteria, and more.

Circular connector construction

Thanks to their cylindrical shape, circular connectors have a higher strength-to-weight ratio than any other connector shape. As already mentioned, this enhanced strength gives them added resistance to impact damage, outside elements, and decoupling, while giving them durability in applications with frequent mating cycles.

The number of internal contacts as well as the layout of those contacts varies by connector and application type to ensure correct alignment and insertion into a compatible mating device. Circular connector shells are often constructed with threads to allow for more secure screw-in connections where vibration or other factors would potentially cause unwanted decoupling. Other types of connection systems include bayonet locking, push/pull locking, and snap lock.

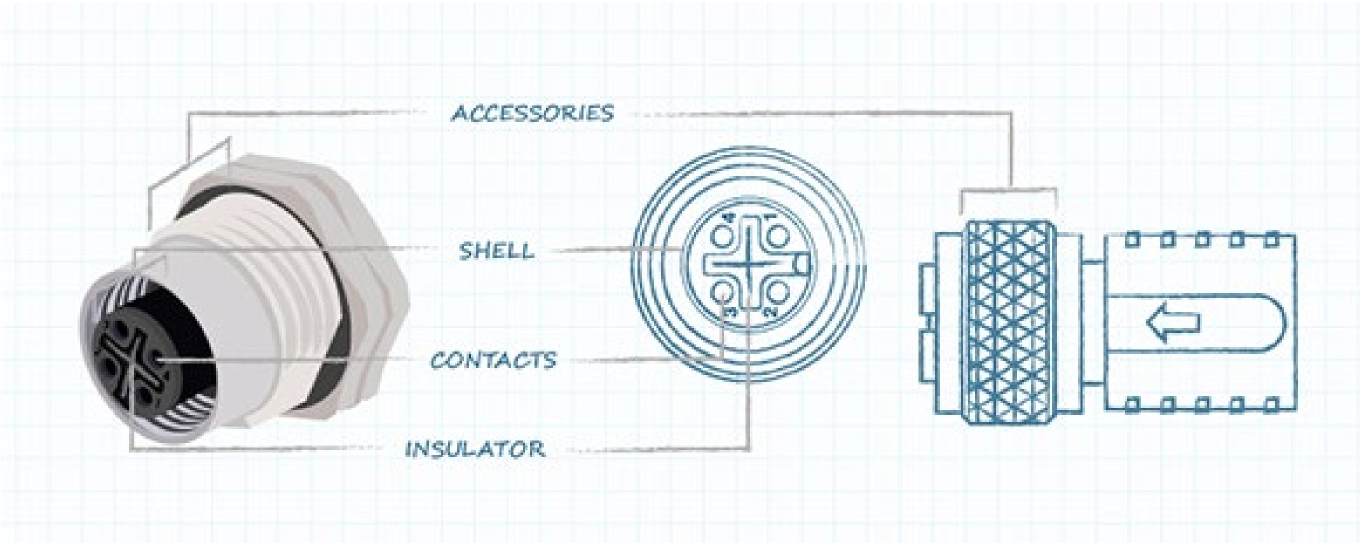


Figure 1: Basic construction of a female circular connector. (Image source: Same Sky)

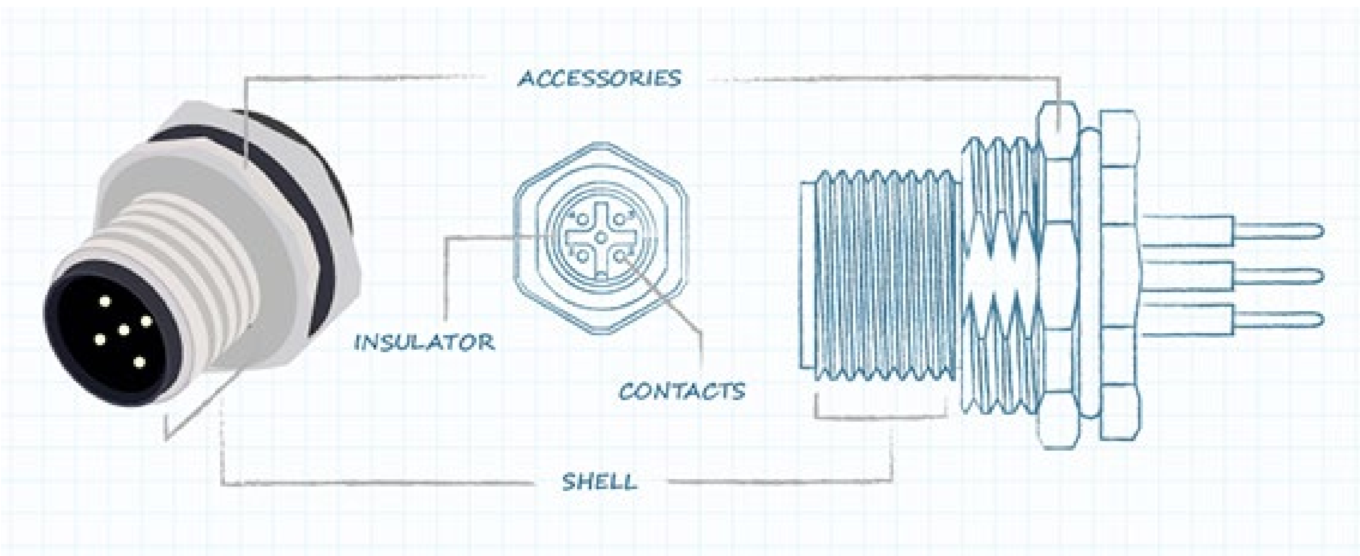


Figure 2: Basic construction of a male circular connector. (Image source: Same Sky)

From a high level, each circular connector consists of four main areas (Figures 1 and 2):

1. **Contacts:** The internal pins and sockets housed in the connector used to form the electrical connection. A mated pair consists of male contacts and female sockets.
2. **Insulator:** This component encapsulates the contacts and insulates them from each other and the connector shell. It also provides proper spacing of the contacts and holds them in the correct position.
3. **Shell:** As the outer cover of the connector, the shell protects the contacts and insulator while providing the alignment and connection mechanism for pairing two connector halves.
4. **Accessories:** These can include pins, keys, rings, clamps, gaskets, and additional components utilized to guide, secure, position, and seal parts of the connector.

Common circular connector designations and codes

Perhaps the most well-recognized type of circular connector is the M-style standard utilized for connecting sensors and actuators in industrial network applications.

"M" simply calls out the size of the metric thread on the coupling nuts and mating receptacles, which gives us the common M5 (5 mm diameter fasteners), M8 (8 mm), and M12 (12 mm) connector types. M12 circular connectors and cables are arguably the most common type found as they are a global standard for the automotive industry.

As a whole, M-style connectors are further divided into several categories that define the keying and shape of the contact body to ensure properly mated connections. These designations and codes are defined as follows (Figure 3):

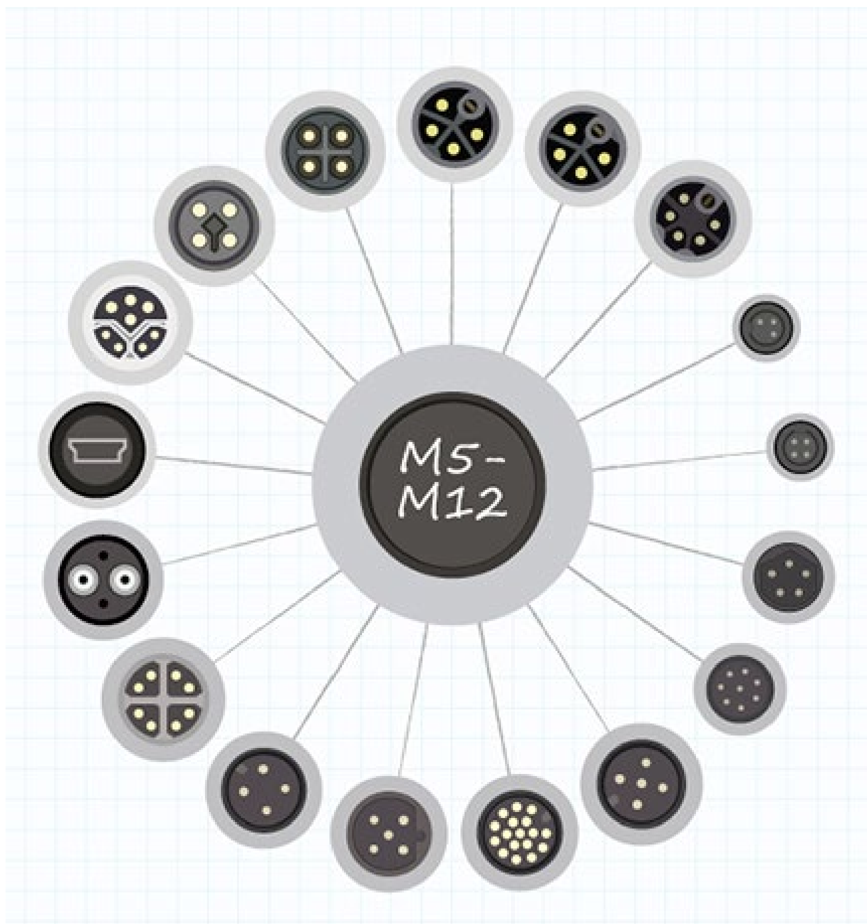


Figure 3: A general overview of the various interface options for M-style connectors. (Image source: Same Sky)

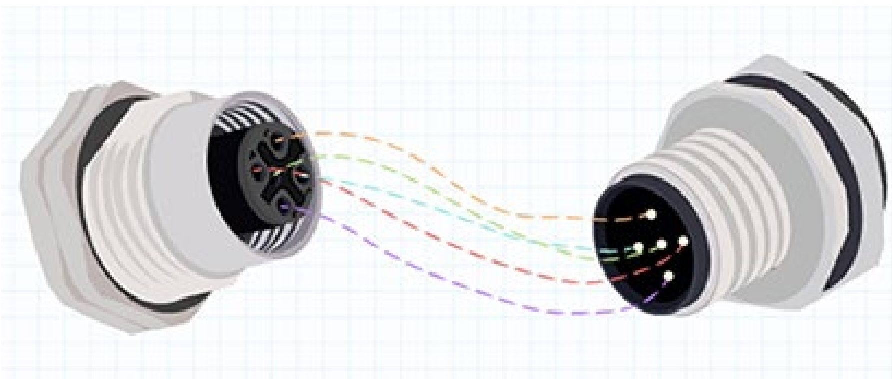


Figure 4: Mating of a male and female circular connector pair. (Image source: Same Sky)

Figure 5: How to designate jacks and plugs of different genders. (Image source: Same Sky)

A – connectors for sensors, dc power and 1 Gbit Ethernet (protocol for connecting computer systems to form a network).

B – connectors for Fieldbus (industrial computer network for distributed control) and Profibus (digital network standard providing communication between field sensors and a control system).

C – connectors with a dual keyway for added security, used for ac power for sensors and actuators.

D – connectors for 100 Mbit Ethernet and Profinet (protocol for data exchange between controllers and devices) systems.

X – connectors for 10 Gbit Ethernet high speed applications as well as power over Ethernet (PoE).

S – connectors for ac power (replacement for C – coded parts).

T – connectors for dc power (replacement for A – coded parts).

Circular connector selection criteria

There is a nearly endless list of specifications and considerations to take into account when selecting circular connectors and/or cables for a design. Outside of deciding whether a circular plastic connector (CPC) or circular metal-shell connector

(CMC) is the better fit, here is a relatively comprehensive list of parameters to consider:

- **Gender (Male/Female):** The male end incorporates the contact pins that plug into the female sockets (Figures 4 and 5). Most plugs and receptacles are designed to mate within their own brand or manufacturer. Connectors from different manufacturers typically do not interconnect, so in general, connectors will be sourced as a mated pair.
- **Number of Contacts:** The number of conductive pins in the connector required to carry the signals, data, or power. This number can range from 1 into the hundreds.
- **Termination:** How the wire or cable will mate with the conductive contacts in the connector, including solder, wire wrap, lugs, or crimping.
- **Contact Size:** The diameter of the individual contacts or gauge of wire that can mate with each contact.
- **Voltage & Current Rating:** The maximum voltage, expressed as volts (V), or current, expressed as amps (A), that the connector is designed to carry.
- **Insertion Frequency:** How often the connector will be connected and disconnected. Also known as mating cycles, the frequency of connection may require a more robust connector or cable protection accessory.
- **Mounting Style:** Common mounting options include cable mount, panel mount, or surface mount.
- **Coupling or Locking Style:** Offers secure mating of the connector and can include bayonet, latch, push-pull, threaded, and quick-disconnect.
- **Backshell Type:** Threaded onto the cable side of a circular connector to offer secure cable support, backshell types include straight, right angle, braid tail, spring, strain relief, sealed, and crimped.
- **Materials Used:** Common materials used for the connector body are stainless steel, aluminum, plastic, composite, or brass, depending on design requirements and budget.
- **Ingress Protection:** IP ratings are defined by the IEC 60529 standard that covers protection against solids and liquids entering the body of the connector. ANSI 60529 covers IP in the United States and EN 60529 covers it in Europe.
- **Plugs & Sockets:** There is no standard naming convention so different manufacturers may use alternate terms, but typically sockets and jacks are associated with panel mounted circular connectors, while plugs relate to circular connector cable assemblies.

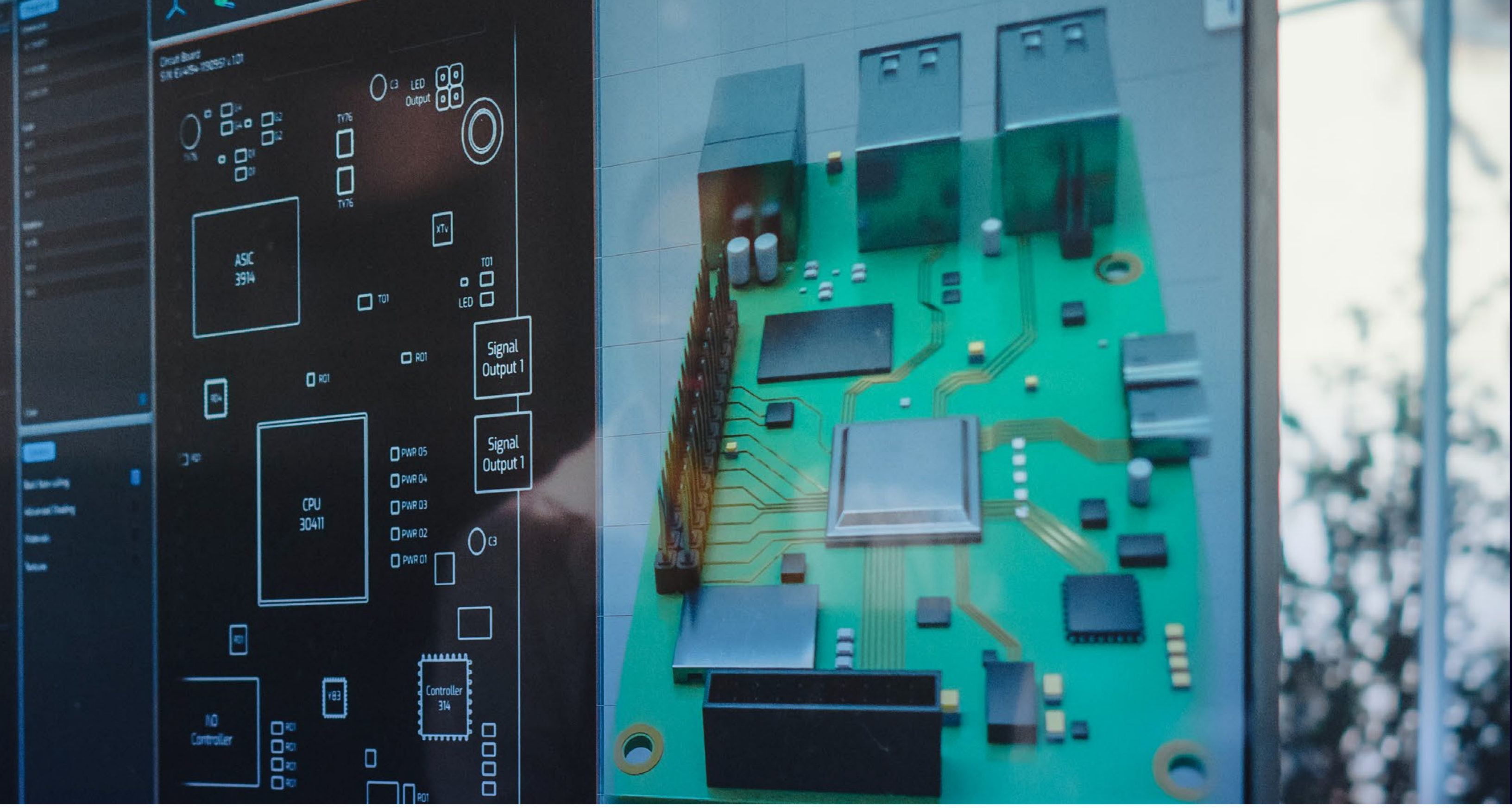
Conclusion

Will the connector be exposed to environmental contaminants or subject to immersion? Does the connector require protection from EMI or RFI signals? Will the connector be subject to excessive vibration or frequent impacts? The answers to each of these will help determine the quality, features, and accessories needed, but regardless, circular connectors have proven to be a reliable and rugged interconnect solution when dealing with harsh application conditions. Same Sky offers a diverse range of circular connectors and circular cable assemblies that can meet these design challenges head on.

Thermodynamics backgrounder

By Mark Hughes

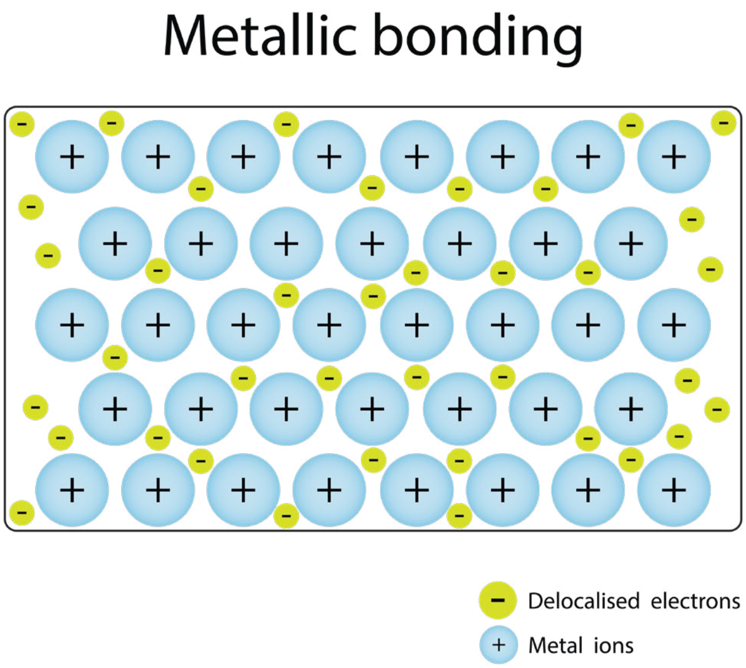
Electronics engineers only have to study thermodynamics for a few short weeks in college, and in that time, it is common for confusion and forgetfulness to overcome deep and meaningful learning. What follows is a brief refresher on the physics of resistance and heat and how it applies to printed circuit board and component failures.



Mental metal mayhem

Metals are collections of atoms arranged in an orderly crystalline lattice with one or more free electrons. This arrangement allows the outermost electrons to move freely from atom to atom.

If the atoms were stuck rigidly in place, electrons could travel from atom to atom without much interruption. However, the quantum world is awash with wiggles, waggles, and wonder. Unless an object's temperature is absolute zero, atoms are never completely still -- they translate, rotate, and vibrate. The macroscopic products of this microscopic movement is the basis for study of thermodynamics.

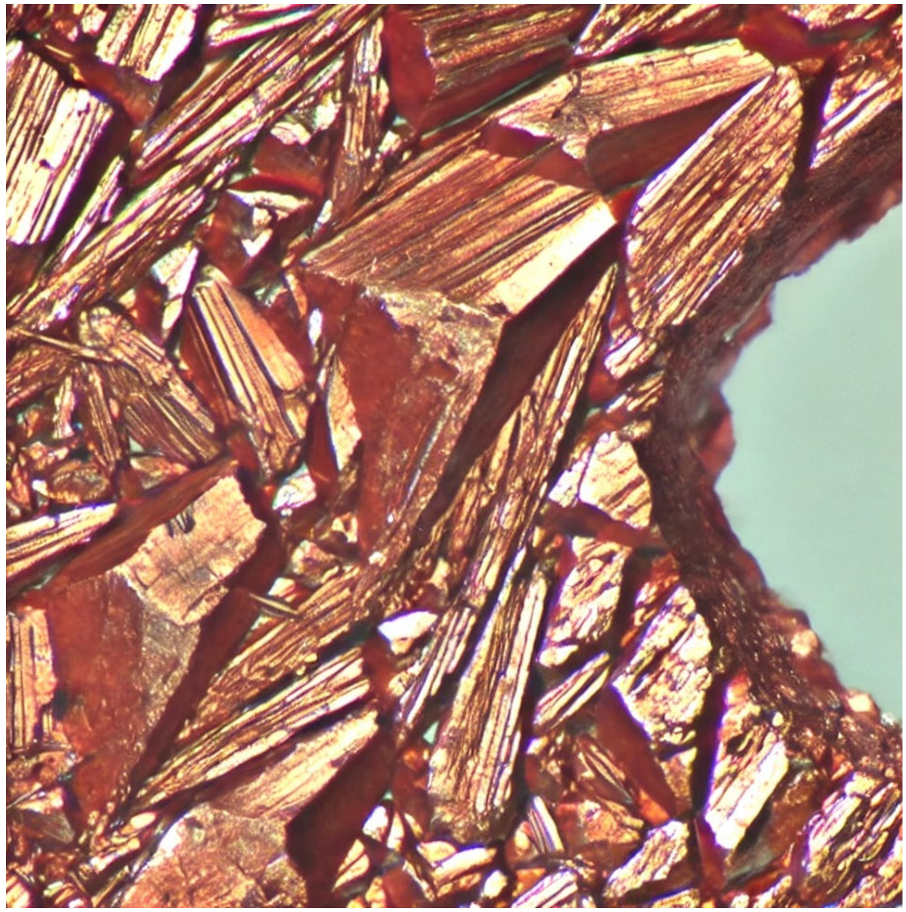


Metals are orderly collections of atoms that are able to easily share their outermost electron(s) with neighboring atoms.

Visualization

Even with perfect eyesight and the best optical microscope, observing the movements of atoms and molecules is impossible. The movement occurs on the scale of picometers and at frequencies measured in terahertz. At the atomic level, those constant and slight movements will disrupt any uninterrupted path an electron might try to take through the lattice, causing a collision with another electron, and a significant change in direction of movement. These disruptions are the basis for resistance.

Consider a game of pool or billiards: imagine taking a shot while all of the balls, the pockets, the bumpers, and even the table move and vibrate in every direction. In this analogy, the pool balls are electrons, and the pool table is the crystalline lattice structure of the metal. Just as the balls in the games wouldn't follow predictable paths, electrons will not either.



This AI imagined view of the copper grains that might exist in copper metal. Electrons experience a bit more resistance at grain boundaries.

Unlike the sixteen pool balls on the table, there are far more electrons in one pool ball than there are pool balls in the world (perhaps). So the pool table we need to visualize has a zillion balls on the table. The ball you strike with a cue will cause bulk motion in the direction of your pool cue, but the first ball you strike won't go very far before a collision with another ball. Similarly, electrons suffer so many collisions per second that even in high speed circuits, an individual electron moves along a copper trace approximately as fast as your fingernails grow.

Electron movement and resistance

As electrons travel through a crystalline lattice in the presence of an electric field, there is no predictable path for any single electron. This randomness causes collisions. The Coulombic attraction between Electrons and Protons means that these collisions transfer energy from electrons to lattice nuclei and back to electrons. The increase in energy is predominantly due to translational oscillations. These collective oscillations define the object's Temperature.

The more the atoms oscillate, the greater the likelihood that future collisions will occur, which leads to higher amplitude oscillations, and this feedback loop creates a condition known as Thermal Runaway. Thermal runaway continues until the temperature of the object rises so high that materials decompose into magic smoke and a variety of carcinogens.

Thermal runaway occurs when the heat entering a circuit is greater than the heat leaving a circuit. The temperature increases which leads to increased resistance. Resistance increases due to increasing temperature. This feedback loop eventually leads to temperatures high enough melt or sublimate the conductor and break the circuit.

The only way to stop this cyclic effect is to allow the lattice to transfer their energy somewhere else through some combination of three processes: conduction, convection, and radiation.

Common language

Temperature is the measure of the total kinetic energy of a group of molecules. Heat is the transfer of that energy from high-temperature (high energy) objects to low-temperature (low energy) objects. In everyday language, we call objects "hot" if when we touch them, energy transfers out of the object into our hands, and we call objects "cold" if when we touch them, energy transfers out of our hands into the objects.

Heat generation

Every common conductor is subject to Joule's law of heating: , where P is "Power", or the rate of heating, I is current, measured in Amperes, and R is the resistance, measured in Ohms. This is true of conductors that obey Ohm's law, and PN junctions that don't. If you want current to flow in your circuit, as electronic engineers are wont to do, your design will generate heat and the temperature of the PCB will rise until the rate of heat energy into the circuit matches the rate of heat energy out of your circuit or until something fails.

Limit heat generation when you can, and when you can't limit it, expel it from your design into the environment.

Heat dissipation

There are three passive methods of heat transport: Conduction, Convection, and Radiation.

Conduction

Conduction happens when objects are in direct contact. Heat energy transfers from the high temperature object to the lower temperature object.

Convection

Natural convection occurs when a high temperature object transfers heat to a surrounding lower temperature fluid, causing the fluid to expand, and in the presence of gravity, denser and colder fluid comes in and replaces the less-dense and warmer fluid in a cyclic process.

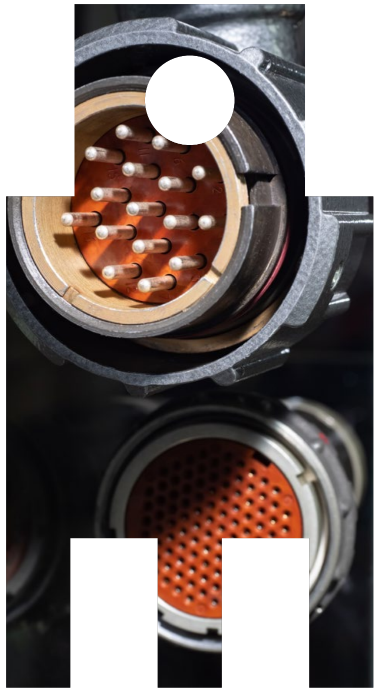
Radiation

Radiation occurs as atoms emit photons. The photon's frequency depends on the temperature of the object. As photons leave the object, the parent atoms lose energy and temperature decreases. For better or worse, energetic photons from the environment can arrive at the object and raise the temperature of the object.

Other Methods
Engineers have developed methods to improve these three natural passive methods. For example, thermoelectric coolers take advantage of the Peltier effect to provide localized cooling at the expense of heat generation somewhere else. Heat Pipes absorb energy in one location in a liquid to gas phase change, and then transfer the energy back to the environment elsewhere when the gas changes back to liquid. Perflourinatedpolyethers (PTFE) use bulk liquid→gas phase changes and the subsequent convection to transfer heat from a circuit at the bottom of a tank up to the surface, where the gas quickly returns to liquid form.

Application to electronic circuits

Joule heating applies to ohmic ($Q=I^2R$) and non-ohmic devices ($Q=IV$). If the generated heat exceeds the dissipated heat, the part will eventually reach a temperature that allows for the thermal decomposition of the material. Molecules will leave the material and enter the environment



-- often as “magic smoke” that is generated when silicon dies and their bonding wires reach a sufficient temperature to vaporize the epoxy die packages. The high temperatures then permanently damage the bonding wires and silicon fractions of a second later.

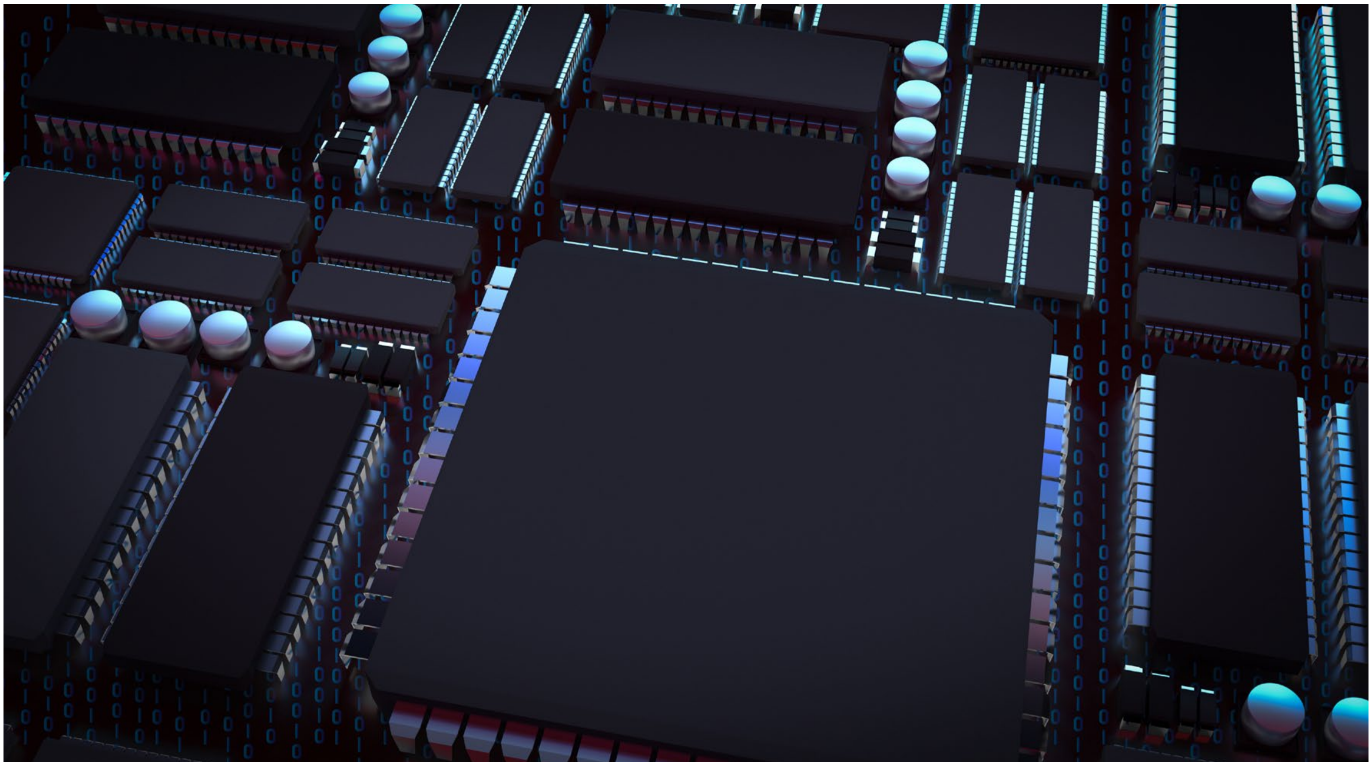
To keep your PCB from turning into a flaming ball of carcinogens, you have to balance the heat generated in the traces and components with the heat dissipated into the environment.

The trouble with high temperatures

High temperatures accelerate the rate of failure for PCB and components, sometimes in exciting ways. When possible, it’s always best to keep your PCB as close to room temperature as possible. But in the real world it’s not possible, so knowing the failure modes and designing mitigations can save your next design!

Failure modes

Mechanical Failure of PCB and Components
The most recognized PCB substrate material is called FR-4 - a NEMA designation for fire-resistant (FR) fiberglass reinforced epoxy resin (4). FR4 is an entire class of woven-fiberglass materials made with different weave patterns, epoxies, and thicknesses.
Many materials fall under the FR4 umbrella, but they all have characteristics important to the discussion of thermal failures: the in-plane-of-weave coefficient-of-thermal-expansion (CTE) and the much greater out-of-plane CTE are both significantly greater than the CTE for copper. That means when the temperature of a PCB increases, FR-4 expands more than the copper. The differential CTE places stresses on the PCB



components and interconnects eventually leading to mechanical failures: via barrel wall cracking in PCBs and solder metal fatigue and failure in the attached components.

Remember, FR4 is an entire class of materials. And there are other classes of materials that don't have fiberglass inside them. If high temperature use or multiple temperature fluctuations are expected in your use case, choose a material with an isotropic CTE closer to that of copper.

Component Failure

Chemists predict reaction rates using the Arrhenius equation. Electronics engineers adopted that equation to predict the lifespan of components. When used correctly, the equation allows the prediction of mean-time-to-failure with some degree of accuracy. When used incorrectly by an unsupervised junior engineer, the predicted lifespans are often expressed in geological timescales. But if you've ever wondered how engineers determine that LEDs will last for 40 years without waiting 40 years for a failure, they accelerate failure in heated chambers and use the modified Arrhenius equation to work backwards to room-temperature failures.

Summary

Heat at Temperature are different things, and a decent understanding of how both topics relate to resistance will help you improve your next high-reliability PCB Design. To learn more about designing "Heavy-Copper" PCBs, read another article in this issue titled "You Want to Put How Much Current in Your PCB?"

Connector, gland, and grip options for industrial-automation cabling

By Lisa Eitel
Contributed By DigiKey's
North American Editors

Connector, gland, and grip options for industrial-automation cabling

There are various connectors to join cables and components used in industrial automation. These connectors must transmit all power and data-signal streams carried over the cables while terminating the line in a way that keeps the conductors tightly connected and protected. The challenge is that equipment associated with industrial automation is often located in dirty, hot, mobile, and electrically noisy settings … so industrial cable connectors require a level of robustness and reliability not necessary for other application

First, consider some industrial-connector basics: Connectors include the components classified as couplers (which join two cables) as well as systems that include both the plug and socket (or receptacle) halves of a connector assembly. In some contexts, the term connectors can also refer to cable glands — terminations that pass through enclosures … often with a free-spinning subcomponent that acts to compress an O-ring seal around the cable end to close it off from chemicals, flames, dirt, and extraneous currents.

IED 60529 INGRESS (or more properly) INTERNATIONAL PROTECTION (IP) RATINGS

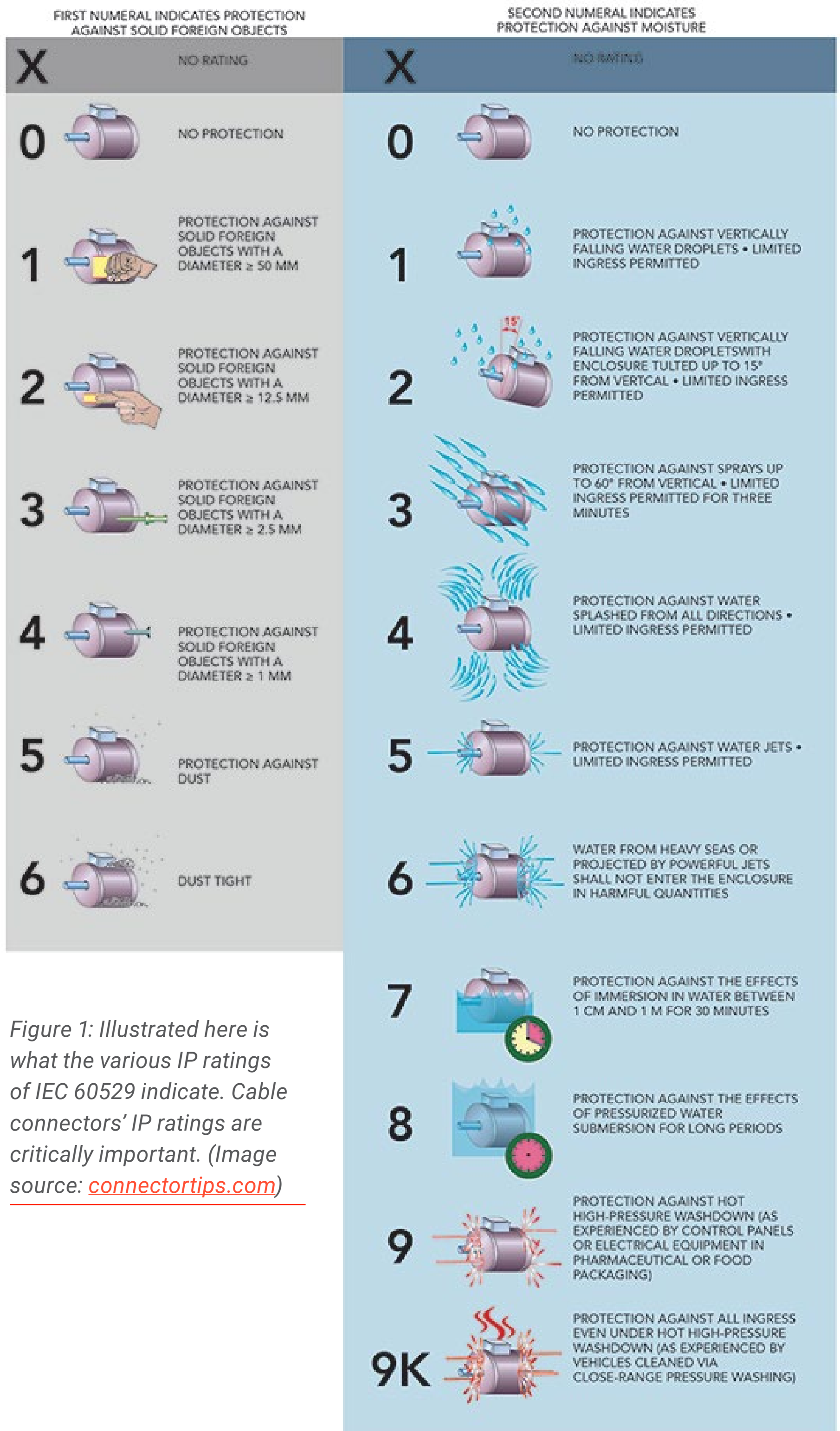


Figure 1: Illustrated here is what the various IP ratings of IEC 60529 indicate. Cable connectors' IP ratings are critically important. (Image source: connectortips.com)

Industrial cable connectors join cables (more commonly) at front and rear-mount equipment receptacles. All connectors and cable glands have ingress protection (IP) ratings as defined by IEC 60529 that quantify their resistance to dirt and moisture. These ratings are the same as those used to describe the ruggedness of component housings as well as industrial equipment enclosures. An IP code has two digits, with higher values indicating a higher level of protection for both.

The first IP-rating digit specifies the level of protection from solid objects such as dust — ranging from 0 for no protection to 6 for dust-tight sealing.

The second IP-rating digit specifies the level of protection against fluids — ranging from 0 for no protection to 8 for continuous protection from water at a depth of 1 m.

Comparing RJ and M12 ethernet connectors for automation

Ethernet defined by IEEE 802.3 remains the most widely used local area network (LAN) technology anywhere. Ethernet-based communications standards for industrial automation include ModbusTCP/IP, EtherCAT, Ethernet/IP, and Profinet. The connectors commonly associated with Ethernet cables are the ubiquitous registered jack (RJ) connectors. Most RJ connectors include a plug having a simple plastic tab that clicks into mating geometry on an RJ socket to securely hold the two together.

Figure 2: This is a TL2253-ND hand crimper tool that allows in-field RJ-plug termination of four, six, and eight-wire Ethernet cable cut to length. With one squeeze the tool's blades strip flat or round Cat5e and Cat6 and secure the connector body. (Image source: Tripp Lite)

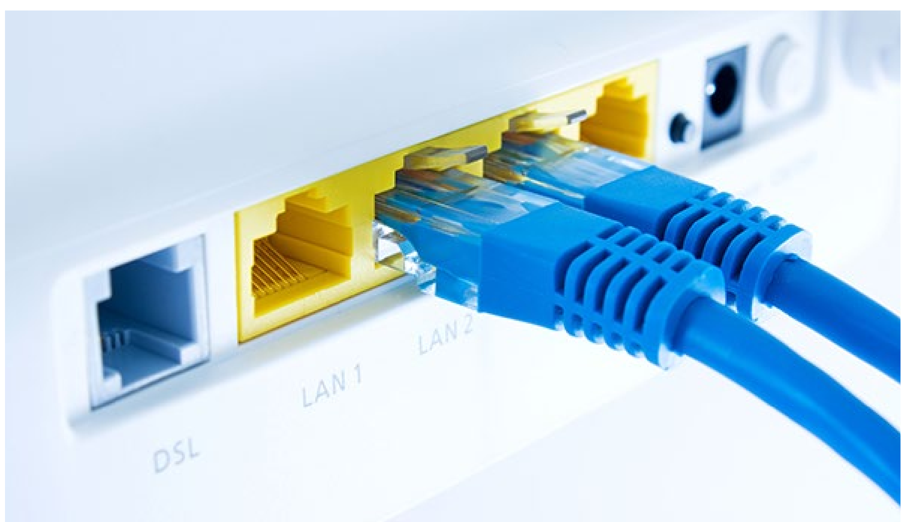


Figure 3: RJ connectors such as the ones shown here are the most common on Ethernet cables. That said, there are other connector types available for use on Ethernet cable. (Image source: Getty Images)

The plugs and sockets easily fit to cables — and installation personnel can simultaneously clamp them and make the electrical contacts using a special-purpose crimping tool. Crimping terminators allow for the construction of custom-cut cables (fitted onsite) that are reasonably reliable. Plug subcomponents designed for such onsite installation often have clear bodies to let installation personnel inspect all internal contacts before putting them into service. That said, the reliability of factory-assembled cables is unbeatable.

Where RJ connectors aren't rugged enough for a particular industrial environment, M12 connectors may be better. That's because M12 connectors provide a more reliable and physically robust connection — with the added advantage of protection against the ingress of dust and fluids.

Power over Ethernet (PoE) defined by IEEE 802.3 is a convenient way to obtain both data and electrical power through a single cable. PoE Alternative A (often called mode A) uses the same two twisted pairs to carry both data and power, so cables with fewer cores can be used — and bandwidth is limited to 100 Mbps (100BASE-TX). PoE Alternative B (often called mode B) uses a Cat 5 Ethernet cable with four twisted pairs — two pairs carrying data and two pairs carrying power. This reduces the bandwidth available for data — limiting the data rate to 100 Mbps even when the cables are rated for Gigabit Ethernet.

4PPoE or four-pair cable requires a cable with four twisted pairs of conductor strands and all transmitting both power and data. This means that higher data rates (Gigabit Ethernet and beyond) and currents are supported. Devices accepting power over PoE must be configured to accept mode A or mode B as it's supplied. That said, they may use fixed or alternating resistance across wire pairs to indicate compatibility and request a specific power configuration. Of course, it's PoE power supplies (the sourcing equipment or PSE) that actually determine the system's PoE mode.

Terminating both data and power cables (as well as network cabling such as industrial Ethernet, PROFINET, and Fieldbus) are M-series connectors — round mating connectors with a threaded female sleeve (to mount on a male receptacle) wrapped around an array of conducting pins. M8 (8 mm) and M12 (12 mm) threads are most common but M5, M16, and M23 are also familiar standards. The positive (screw-on) closure of M-series connectors ensures a highly reliable connection that minimizes intermittent signals even while protecting against the environmental debris so common to washdown and corrosive environments. No wonder M-series connectors are a top standard on the cables for actuators, PLCs, sensors, switches, and controls of industrial automation.

Figure 4: The connector design is largely dictated by the cable it terminates. M12 Ethernet-cable connectors such as the ones shown here are generally more robust than RJ connectors; some manufacturers color-code them to indicate compatibility with PoE modes and conductor arrangements. (Image source: Lumberg Automation)

M8 and M12 connectors may have two, three, four, five, eight, or 12 pins (also called positions). Sensors and power supplies generally require three or four pins. For M-series connectors on the ends of Ethernet and PROFINET cables, four or eight pins are needed. In contrast, those on the ends of cables carrying Fieldbus, CAN bus, and DeviceNet data usually have four or five pins. Of course, cables carrying multiple data and power streams may require termination with an M-series connector having all 12 pins.

Figure 5: This Brad Ultra-Lock 120108 right-angle connector is a proprietary adaptation of an M12 connector design to boost reliability. (Source: Molex)

In fact, one related connector-receptacle design that's quite common in the industry is the pin-array-and-socket pair — originally introduced by Molex so it is sometimes referred to as Molex interconnections in the vernacular. The proprietary Molex Brad series of connectors are based on M12 connectors but replace the threaded sleeve with a more convenient and reliable push-to-lock system. Because the locking does not depend on the operator tightening a thread, it ensures reliability and minimizes the risk of an intermittent signal. Brad connector variations include:

- Brad Micro-Push M12 connectors — a push-on and pull-off connector providing IP65 protection
- Brad MX-PTL M12 push-to-lock connectors offering IP65 protection
- Brad Micro-Change M12 threaded connectors offering IP67 protection
- Brad Ultra-Lock and Ultra-Lock EX M12 connectors with push-to-lock fittings and O-rings for full IP69K level of ingress protection.

Coaxial connectors for high-frequency signals

Coaxial cables (fitted with coaxial connectors) are also used in industrial automation for transmitting high-frequency signals — especially those supporting vibration monitoring and analog signal transmission. Standards abound.

BNC connectors have a bayonet fastening that requires a quarter turn to connect or disconnect. They can be used for frequencies of beyond 12 GHz and in some cases up to 18 GHz. DIN 0.4 to 2.5 connectors are very small push-fit connectors suitable for frequencies to 3 GHz. In contrast, DIN 1.0/2.3 connectors are small push-fit radio-frequency connectors widely used in digital telecommunications.

Modular and custom cables proliferating for automated machinery

With conventional system integration approaches, cables are "made up" — measured, cut, and terminated — onsite during the installation of the automated equipment. That usually means an onsite electrician cuts the required cables to length, strips all their conductors' delicate sheathing, and fits the cables with the connectors required to join the components at hand. Such in-field cable preparation is time-consuming and leads to variable connection quality. That's why the trend now is to source modular cable and connector systems consisting of standard cables and factory-fitted connectors. Required cable lengths are determined during design and supplied ready to install.

Some estimate that modular cables reduce onsite installation time by 60% to 70% while improving the reliability of the electrical connections.

The special case of cable glands

Cable connectors called glands are used wherever cables pass through an enclosure. Glands serve three purposes — securing the cable, preventing cable wear, and providing a seal around that cable to shield components inside the enclosure from environmental debris. The way in which cable glands secure the cable essentially prevents damage to electrical contacts from yanking or other disturbances. It also prevents the cable from scraping or rubbing against the sharp sheet-metal edge of the enclosure cutout. That's important because sheet metal can easily saw through cable sheaths and eventually cause the cable cores to short.

Less demanding applications often use lamellar glands having multiple fingers that clamp around the cable. This type of gland is less costly but requires regular retightening to maintain ingress protection. Higher quality glands use a continuous seal that clamps around the cable. This type of gland is much less likely to loosen over time.

Construction of today's industrial-power connectors

Devices used for industrial automation often require a wired power supply in addition to a data connection. The relatively new technology of PoE mentioned earlier is preferable where it's possible to use because it keeps cabling so simple. However, the vast majority of automation components and systems require traditional power cords.

Figure 6: General-purpose power cables include a variety of IEC and other standard connectors. (Image source: Getty Images)

Figure 7: Notice the color coding (adherent to IEC 60309) of this high-power cable connector. (Image source: Railway Tech)

Connectors standardized by the International Electrotechnical Commission (IEC) are common on power cables for consumer and office as well as industrial applications. The IEC defines a range of non-locking connectors in the IEC 60320 standard with voltages to 250 V and current not exceeding 16 A. Here, the C13/C14 connector is commonly used for electronic equipment — including computer power supplies. Larger C19/C20 couplers are used on the ends of cables carrying higher current — including server enclosures, for example.

For more critical or demanding applications, IEC 60309 connectors are often preferred. These plugs, sockets, and couplers are expressly intended for industrial use and can carry voltages to 1,000 V, currents to 800 A, and frequencies to 500 Hz. All of these connectors provide some level of resistance against water ingress: IP44 connectors are splash-proof, IP67 connectors are waterproof, and IP66/67 connectors can reliably prevent ingress even when subject to pressurized waterjets. Socket outlets may also be interlocked so that the socket cannot be energized unless it's mated with a plug — and the plug cannot be removed until the power is switched off.

Different sizes of IEC 60309 connectors are used for different current ratings. The connectors are also keyed and color-coded to indicate their voltage and frequency range:

- Yellow indicates carriage of 100 to 130 V at 50 to 60 Hz
- Blue indicates carriage of 200 to 250 V at 50 to 60 Hz
- Red indicates carriage of 380 to 480 V at 50 to 60 Hz — often in a three-phase configuration

Conclusion

There are many geometry and integration options when it comes to selecting connectors and glands for industrial automation. During the specification of a cable for a given automated piece of machinery, the first consideration for design engineers must be the cable core count and the cores' gauges. Ingress protection and the need for a positive lock to prevent intermittent signals are the next-most important considerations.

How to select 48 V connectors for medium-voltage automotive architectures

By Kenton Williston
Contributed By DigiKey's
North American Editors

Government mandates for lower CO_2 emissions and consumer demand for vehicle electronics have resulted in a transition from 12 V automotive systems to more efficient 48 V architectures. These mid-voltage architectures offer higher power delivery and lighter, lower-cost wiring harnesses.

The problem for designers is ensuring that the connectors meet the demanding electrical, safety, reliability, and physical requirements of 48 V systems while meeting cost and time-to-market constraints. The solution lies in developing an understanding of the

operational, regulatory, and safety requirements of mid-voltage automotive architectures before choosing from an appropriate supplier's selection.

This article reviews the benefits of 48 V architectures and outlines the challenges of selecting appropriate connectors. It then presents suitable solutions from Molex and describes how these solutions may be applied in practical scenarios.

The benefits of 48 V automotive architectures

Automakers can implement mild hybrid systems that recuperate energy during braking and coasting by moving to mid-voltage architectures. They can also deploy enhanced start-stop systems that reduce fuel consumption while city driving and in traffic jams. Additionally, because the higher voltage allows the use of lighter, smaller-gauge wires to deliver the same power at a lower current, 48 V systems reduce vehicle weight. All these factors translate to significant fuel savings, particularly in smaller vehicles.

Higher-power wiring harnesses are also needed to accommodate the electrification of components such as power steering, air conditioning, and the adoption of advanced driver assistance systems (ADAS), such as adaptive cruise control and lane-keeping assist. Transitioning to a 48 V architecture meets this need without the costs and complexities associated with the high-voltage systems (i.e., 400 V and beyond) used in full hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs).

The 48 V architecture also serves as a bridge to greater vehicle electrification, allowing gradual integration of hybrid technologies without a complete electrical overhaul. These mid-voltage systems will remain valuable even in fully electric vehicles, as evidenced by their incorporation into designs like the Cybertruck.

Cost considerations for 48 V connectors

The question of which electrical connection system should be used for 48 V architectures can be answered by looking at the technical challenges arising from the increased voltage.

Adopting the high-voltage connectors developed for use in electric and hybrid vehicles is technically feasible, but cost and package-space considerations make it inadvisable. In contrast, adapting 12 V connectors for mid-voltage architectures is an attractive cost and size proposition.

It is worth noting that not all vehicle systems will switch to 48 V. Some smaller devices that consume less power will stay at 12 V. Therefore, it is useful to have consistent connectors across 12 V and 48 V systems to simplify tooling and technician training.

Molex's MX150 Mid-Voltage Connector System (Figure

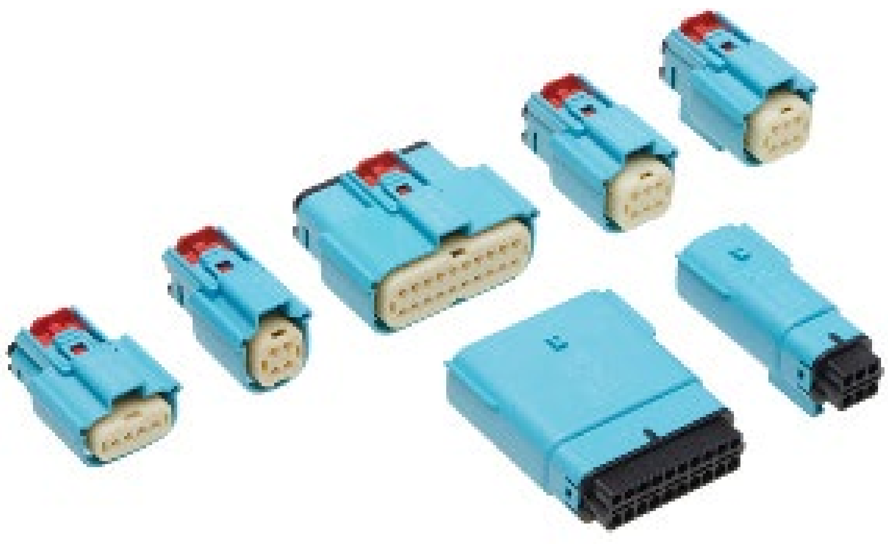


Figure 1: Connectors from the MX150 Mid-Voltage Connector System share their form factors with the field-proven, low-voltage MX150 connectors. (Image source: Molex)

1) exemplifies these design principles. These connectors share their form factors with the field-proven, low-voltage MX150 connectors. By using the same package size and housing design as the 12 V connector system, the MX150 Mid-Voltage Connectors provide a straightforward upgrade to 48 V wiring architecture with minimal design engineering.

The MX150 Mid-Voltage Connector System currently encompasses five different configurations, as detailed in Table 1. These include the dual-row 33482 blade connectors and the corresponding dual-row 300361 receptacles, as well as the single-row 300363.

Safety considerations for 48 V connectors

Although 12 V is a good starting point for mid-voltage connectors, the challenges in moving to 48 V are not trivial. Arcing is of particular concern.

In 12 V systems, small arcs typically extinguish quickly when circuits are broken. However, at 48 V, arcs can persist longer, potentially causing severe damage to the terminals and housings. To mitigate this risk, terminals must be spaced adequately to meet creepage distance and clearance requirements as outlined in DIN EN 60664-1, which governs insulation coordination for equipment within low-voltage systems.

Creepage refers to the shortest path between two conductive points along an insulating surface, while clearance denotes the shortest air path between conductors. These specifications are crucial to ensure

Table 1: Key specifications of the MX150 Mid-Voltage Connector System. (Table source: Molex, modified by Kenton Williston)

TECHNICAL SPECIFICATIONS	DETAILS
Circuit sizes	Single row: 4 Double row: 4, 6, 20
Voltage (max)	60 V
Current (max)	22.0 A
Contact resistance	8 mΩ
Industry compliances	USCAR-2, USCAR-21, GMW3191
Operating temperatures	-40°C to +125°C
Sealing	IP67 and USCAR-2 Sealing Class 2

protection up to 60 V, the upper limit of the overvoltage range.

Effective terminal secondary locking is also essential to prevent terminal push outs (TPOs), which can cause slow or intermittent power disconnects. Such disconnects may initiate micro-arcing, damaging the plating or compromising the terminal base metal, leading to high resistance or a welded connection.

Connector sealing also merits careful attention. Exposure of a 48 V connector to an electrolyte such as salt water can trigger an aggressive electrochemical reaction, more so than at 12 V. To prevent such damage and short circuits, it is crucial to use connectors that meet the appropriate pollution degree, typically USCAR-2 Sealing Class 2 or higher.

Figure 2 illustrates how these design principles are implemented in the 3003610011, a dual-row, mid-voltage female receptacle with twenty circuits. The corresponding male connector is the 0334822423.

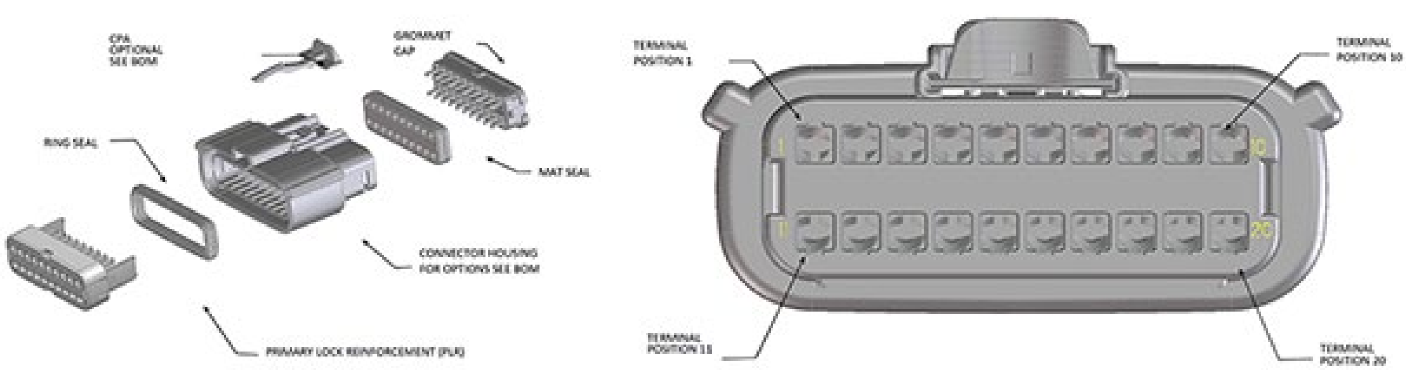
The MX150 connectors are pre-assembled with connector housings, seals, and Terminal Position Assurance (TPA) components in place, streamlining installation and maintenance. Key features of the connector illustrated in Figure 2 include:

- A TPA that securely locks terminals into their housings, preventing dislodgment
- A secondary Connector Position Assurance (CPA) lock that ensures a secure connection and prevents accidental disengagement under severe vibration or shock
- Integral mat and ring seals that ensure safe performance even when submerged, eliminating the need for individual cable seals
- A grommet cap that enhances the protection of the mat seal and ensures the correct alignment of terminals, maintaining the integrity of connections

Mixed-voltage design considerations

Special precautions are essential in mixed-voltage systems to prevent current from flowing between mid-voltage and low-voltage circuits. The most effective strategy is to use

Figure 2: The MX150 Mid-Voltage Connector System incorporates several features to ensure a safe and reliable connection. Shown is the 3003610011 dual-row female receptacle with 20 circuits. (Image source: Molex)



separate connectors for each voltage level, avoiding the integration of both voltages within the same connector. Additionally, the automotive industry has adopted light blue color coding for 48 V connectors to clearly differentiate them from 12 V connectors.

The origin of this color coding dates back to electric forklifts, which have long used batteries of varying voltages. Color guidelines were established to prevent errors, leading to the widespread adoption of blue for 48 V connectors across various industries.

This system works in tandem with the established use of orange connectors and wiring, which signify high-voltage systems. This color coding clearly indicates components that require specific safety precautions, ensuring that they are not handled without appropriate safety training and personal protective equipment (PPE).

Manufacture and serviceability considerations

The risk of arcing in mid-voltage connectors necessitates that they be designed for reliable manufacturing and servicing. This requirement is addressed by USCAR-21, which stipulates the test methods and criteria for cable-to-terminal electrical crimps in automotive applications.

A key aspect of USCAR-21 is pull testing, which involves applying a consistent pull rate to a crimped connection to assess its tensile strength. This testing ensures the crimp can endure the mechanical stresses it will face during its service life. The specification also highlights the necessity of using precise tooling and process settings during crimping.

Additionally, it is advisable to seek connectors certified to GMW3191, a comprehensive standard formulated by General Motors. This standard outlines the testing and validation requirements for automotive electrical connectors, confirming their reliability and durability in demanding conditions.

Molex MX150 assembly and service considerations

To complete a connector assembly, the wiring must first be terminated. With the MX150 male connector assembly, for example, the wire harness must be terminated into a 330000001 blade. Similarly, the wiring must be terminated into a 33001 or 33012 series rectangular connector contact for the female receptacle.

In either case, the terminated wires must be pushed into the connecter until they are secured. If a circuit position must be left empty, the gap should be filled on the male side with the 343450001 cavity plug.

To aid in this termination process, Molex offers the 0638115900 manual crimping tool (Figure 3). This device ensures a secure connection between the wire and blade or rectangular contact.

Figure 3: The 0638115900 manual crimping tool ensures a secure connection between the wire and blade or rectangular contact. (Image source: Molex)

Figure 4: The 0638131500 extraction tool allows the removal of any wire from a connector without disturbing the rest of the assembly. (Image source: Molex)

Specialized equipment is also available to service a connector. The 0638131500 extraction tool (Figure 4) allows technicians to remove wires from a connector without disturbing the rest of the assembly.

Conclusion

When transitioning to a mid-voltage architecture, automakers and their suppliers can benefit from using components based on low-voltage technology. The move to 48 V presents new safety and reliability concerns, but these concerns can be readily addressed by careful attention to standards and choosing a connector system incorporating robust locking and sealing mechanisms. When selecting a 48 V connector system, it is advisable to seek a vendor with a comprehensive portfolio, proven experience, and associated tooling.

Genius and tragedy

By David Ray
Cyber City Circuits

The Siege of the Bastille

Young Ampère as he was in the late 1790s

André-Marie Ampère

André-Marie Ampère is an important visionary of the past. Not unlike Newton and Lord Kelvin, Ampère influenced many different fields of science and natural philosophy. In the late 18th and early 19th centuries, most of the significant scientific advances came from Italy, France, and modern-day Germany. Ampère's story is marked with tragedy along with professional achievement.

Early life (1775–1793)

The son of a merchant

Andre Marie Ampère was born on January 20th, 1775, in Lyon, France, during the peak of the French 'Age of Enlightenment.' His father, Jean-Jacques Ampère, was a successful silk dealer who imported silk from Persia and Italy. His father kept an extensive personal library, and he encouraged his son to study everything. In Ampère 's own words, his father 'knew how to inspire in him a desire to know.'

As a child, his favorite book was 'Buffon's Natural History,' but he also studied Euler, Newton, Rousseau, and more. He could swiftly learn things and quickly develop his own methods and theories in mathematics and science. By the age of 13, he had read the whole Encyclopedia. While still only 13 years old, he submitted a paper on mathematics to the Académie de Lyon, never having them accepted or published.

As a wealthy merchant, his father assumed the role of 'Justice of the Peace,' essentially maintaining the local government. In July 1789, many French citizens mobbed together in revolution to attack a military post, the *Bastille*, formally beginning the French Revolution.

The Jacobins are at the gate

The new National Army moved into Lyon in May 1793, during the 'Reign of Terror.' After some months of local conflict, the 'Committee for Public Safety' entered the newly conquered Lyon and had the justice of the peace sent to prison.

This short period of French history was bloodied by teams of revolutionaries who went from town to town and arrested anyone who might be loyal to the French monarchy. Through this time, an estimated 40,000 people were executed, many by the blade of a guillotine. The executions were widely attended, and people from all over the country would gather to watch.

In a letter from his prison cell, waiting for his execution, Jean-Jacques Ampère wrote his final will. In it, he tells his wife how to manage his current financial affairs to ensure the people he owed money to were paid. He laments that he is far from leaving his family rich. He begs that she doesn't blame this on his bad conduct, but explains that his greatest expense has been the purchase of books and geometrical instruments for young Andre-Marie's education, ending with *'even this expense was a wise economy since he has never had any other master than himself.'*

Then, on November 23, 1793, young Ampère 's life, as he knew it, came to an end. Much of the family's wealth was seized. The homes they had were lost, and the family retreated to the house his mother grew up in about six miles outside Lyon in a town named Polémieux.

Middle years (1793 – 1820)

Young Ampère was eighteen when this tragedy struck him, and the shock caused his excitement for knowledge to leave him. His fantastic mind was a wreck. Hollow and critically depressed, he mourned his father's death for over a year. This was until he found Rousseau's 'Letters on the Elements of Botany.' With this, he found a new fascination with flowers, then poetry, and soon he met his future wife, Julie Carron.

'Her blue eyes wear the serenity of an angelic soul;

a smile animates every feature;

all her movements are marked by grace;

candor gleams on her brow,

and colors her cheeks with a light tint of rose.'

-Young Ampère describing Julie Carron, 1796

With renewed enthusiasm, he started tutoring mathematics privately while working on his own studies. In 1799, he married Julie and soon fathered his only child, Jean-Jacques Ampère, his father's namesake.

Throughout his early years as a teenager, he submitted papers to journals and academies, trying to be published. All of them were rejected, often without a return letter. This may have deterred a lesser man, but he was able to publish 'The Mathematical Theory of Games' in 1802. It covered new thoughts on probability and gambling, finally catching the attention of someone at the École Polytechnique in Paris and gaining him a position as a professor of mathematics in 1803.

This elation soon turned to grief when, in July of the same year, his wife Julie died from tuberculosis, less than ten years after his father's execution. He would carry this grief with him, and it would characterize him for the remainder of his life. While utterly brilliant, he could only work in short sprints followed by ever-lengthening periods of deep apathy and emptiness. He suffered from crippling anxiety and would fall into long bouts of existential dread regularly. There are stories from students of him breaking down in tears for no apparent reason in the middle of class. This did not take away from his compulsion for study and discovery.

Miserable and depressed, he continued his work at the academy in Paris. From there, he influenced all types of contemporary mathematics, physics, and chemistry. The story goes that he even named the element Fluorine in 1811, seventy-five years before it was isolated in a lab. This notoriety got him elected to the Institut National des Sciences in 1814, developing theories on molecule theory.

A Middle Aged Ampère

Later career (1820 – 1836)

Meeting Hans Christian Oested

When he could muster the energy, he would attend conferences and lectures. In 1820, Danish scientist Hans Christen Ørsted gave a demonstration of a new phenomenon he had discovered. He found that whenever an electric current in a wire was switched on, he could affect a compass by moving the wire near it. He spent months trying to explain the science behind this interaction but could not.

Unknown discovery

Excited by the challenge of new discovery, Ampère took it upon himself to solve it. He conjectured that if current in a wire created a magnetic force that could move a compass, perhaps two wires with current would also interact. After many inventive experiments, his work would culminate in 1827 with his treatise 'Mathematical Theory Of Electrodynamic Phenomena, Uniquely Derived From Experiments,' formally tying electricity and magnetism together into the new study of electrodynamics.

Happy at last

While 1827 marked the pinnacle of his illustrious career, Ampère continued his teaching and pursued further studies in physics and chemistry. For the remaining years of his life, he devoted considerable time to reflecting on philosophy and religion.

> 'It is perfect in form, and unassailable in accuracy, and it is summed up in a formula from which all the phenomena may be deduced, and which must always remain the cardinal formula of electro-dynamics.'
>
> – James Clerk Maxwell concerning the 'Mathematical Theory Of Electrodynamic Phenomena.'

> "Doubt is the greatest torture man can endure on earth"
>
> - Andre-Marie Ampère

In 1834 he coined the term 'cybernetics' (cybernetique), originally referring to the science of government and the regulation of society. The term was later adopted by scientist Norbert Weiner. Weiner's cybernetics explored how systems, whether social or mechanical, can use closed-loop feedback and information to regulate themselves to find homeostasis.

An Older Ampère

Ampère developed many health issues, but he was able to watch his son become independently accomplished in writing and linguistics, following his own father's success as a professor of language and history. On his deathbed at the age of 61, he ordered that his tomb have the epitaph 'Tandem Felix' (Happy at Last). He is one of seventy-two scientists, mathematicians, and engineers whose names are honored and engraved into the Eiffel Tower.

Impact and legacy

His work on electromagnetics is foundational to all modern electrical theory and is credited with influencing Georg Ohm's work and Maxwell's equations on electromagnetism. In 1881, at the First International Electrical Exhibition of Paris, Dr. Helmholtz of Germany proposed that the unit of electrical measure of current should be named after Ampère in recognition of his scientific contributions. More on the naming of these units can be found in the previous Retro-Electro article on the 'Ohm'. (https://emedia.digikey.com/view/639112496/20-21/)

Even though he uncovered some of the universe's most fundamental hidden truths, he was known for bringing misery into whatever room he occupied. Despite his tragedies and bouts of chronic depression, André-Marie Ampère's relentless pursuit of knowledge left an everlasting mark on this world. His pioneering work in electromagnetism laid the foundation for modern electrical engineering, influencing generations of scientists and shaping the future. While he struggled with inner demons, his legacy as a brilliant thinker and visionary endures.

Ampère's Tomb in Paris

1775

André-Marie Ampère is born in Lyon, France.

1789

The French Revolution begins.

1793

Ampère's father, Jean-Jacques Ampère, is executed.

1799

Ampère Marries Julie Carron.

1880

Ampère's son, Jean-Jacques Ampère is born.

1802

Ampère publishes ' The Mathematical Theory of Games'.

1803

Ampère is appointed professor at the École Polytechnique in Paris.

Ampère's wife dies of Tuberculosis.

1820

Inspired by Hans Christian Ørsted's demonstration, Ampère begins work in electrodynamics.

Ampère publishes Ampère's Law, which mathematically describes the relationship between electric currents and the magnetic fields they generate.

1827

Ampère publishes 'Mathematical Theory Of Electrodynamic Phenomena, Uniquely Derived From Experiments'

1834

Ampère coins the term "cybernetics" (cybernétique) in his work on the classification of the sciences, using it to refer to the science of government and social regulation.

1836

June 10: André-Marie Ampère passes away in Marseille, France.

1881

The International Electrical Congress names the unit of electric current, the "ampere."

Understanding and applying the new standard connectors for indoor & outdoor LED-based lighting

By Bill Schweber
Contributed By DigiKey's North American Editors

Light-emitting diodes (LEDs) have revolutionized indoor and outdoor lighting. The efficiency, controllability, color spectrum, thermal performance, and unique form factors of this solid-state lighting (SSL) technology have helped sideline the venerable Edison incandescent bulb (as well as the fluorescent, metal halide, or sodium vapor lamps). Now, for most indoor and outdoor new designs, as well as existing upgrades, LEDs are given first consideration. Still, designers need to be careful. Along with rapid innovation come pitfalls such as non-standard connections and mismatched end-user solutions, all contributing to a negative customer experience.

It is not just the light source itself that is radically changing. For example, LED-based lighting is also changing the design and form factor of the connectors—a necessary part of any lighting system—as well as its fixtures (called luminaires). These connectors do not carry AC line voltage; instead, they carry lower voltage DC at currents typically in the 3 amperes (A) to 7 A range. Further, an LED-based lighting system is often part of a control network supporting the Digital Addressable Lighting Interface (DALI) and Zhaga industry standards, yielding smart, energy-saving, high-performance lighting as part of an intelligent home or office.

As a result, before proceeding with an LED-based lighting system design, it's incumbent upon engineers to become familiar with the standards and how they're reflected in real-world connectors as new designs are emerging rapidly.

This article briefly reviews why LEDs have become so pervasive, and then introduces and describes the two connection standards that ensure interoperability, rapid development, and easy deployment of smart LED-based designs. Connectors from Amphenol ICC are introduced, and their use is outlined as real-world embodiments of the relevant standards and their application.

Why LEDs are so pervasive

The growth of LEDs as a lighting source is due to many factors:

- Lower costs driving higher volumes, which in turn drives even lower costs and ever higher volumes
- Enhancements in the basic reliability and longevity of LEDs as light sources
- Improvements in the circuitry, primarily the power supplies that drive these LEDs
- Improved ease of control of LEDs via smart controls and even networked I/O
- Improvements in the quality of optical output as characterized by color temperature (Kelvin) and color rendering index (CRI)
- Government incentives, standards, and mandates for higher efficiency lighting to save energy (estimates are that between 15% and 20% of total energy use is for lighting)
- Development of industry and government standards that ensure both interoperability among LED-based light sources as well as compatibility with smart controllers

The last point is especially important. One of the important attributes of the traditional incandescent bulb, which is being displaced by LEDs and fluorescent bulbs to a lesser extent, is the near-universal use of the "E26" 26 millimeter (mm) diameter screw-in Edison-base bulb in residential settings in the United States and many other countries (Figure 1). There are other sizes such as the E12 candelabra, but the E26 is by far the most widely used.

Figure 1: The 26 mm E26 Edison base is the most widely used lamp bulb base by far, though there are some smaller and larger ones to meet various application requirements. (Image source: LOHAS LED Ltd.)

Standardization with a single base and socket lowers costs, of course. It also encourages availability of many bulb shapes, power levels, and other attributes built around that base while reducing concerns about long-term replacement for burned-out bulbs. Early generations of LED bulbs used the E26 base for compatibility with existing sockets to get users accustomed to LED lighting. These E26 LED bulbs are still widely sold, as there are countless millions of such sockets currently in use, and that will be the situation for a very long time.

However, LEDs are quite different with respect to their current, voltage (DC), and power consumption when compared to incandescent bulbs, which are typically mains powered using 120/240 volts AC. Also, the E26 socket often has relatively large screw terminals for its wires, which are not ideal for powering LED-based sources (Figure 2). Thus, to allow LEDs to fully realize their potential from the system level down to the physical connection, new standards and types of connectors are needed.

Recognizing the need for a modern lighting interface standard, the Digital Illumination Interface Alliance (DiiA) developed the DALI standard.

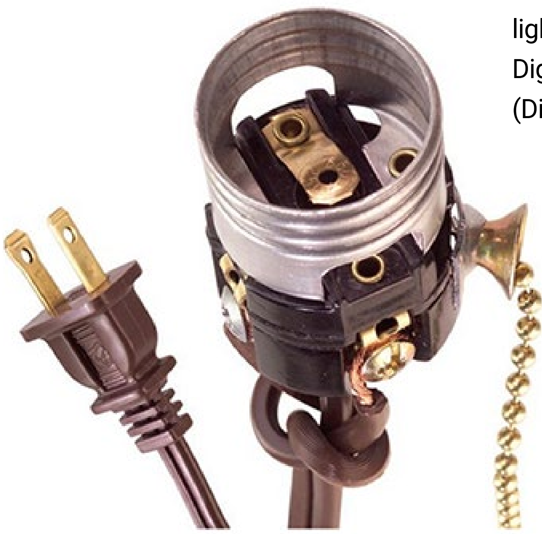


Figure 2: The large screw terminals required for wiring an E26-base socket interfere with getting the best use of the LED-based light source. (Image source: Family Handyman via Pinterest)

DALI standard redefines lighting connectivity

DALI is a dedicated protocol for digital lighting control that enables the easy installation of robust, scalable and flexible lighting networks (Figure 3). The first version, DALI-1, was better suited to digital control, configuration, and querying of fluorescent ballasts with little consideration for LEDs. It replaced the simple, one-way, broadcast-like operation of existing 0/1 to 10 volt analog control approaches.

The standard also includes a broadcast option, and, with a simple reconfiguration, each DALI device can be assigned a separate address allowing **digital control of individual devices**. In addition, DALI devices can also be programmed to **operate in groups** so the lighting systems can be **reconfigured** by software, thereby avoiding the need to change the wiring.

The growth of user expectations along with improvements in LED technology has encouraged the development of what is now the DALI-2 standard. DALI-2 is more than an industry standard—it

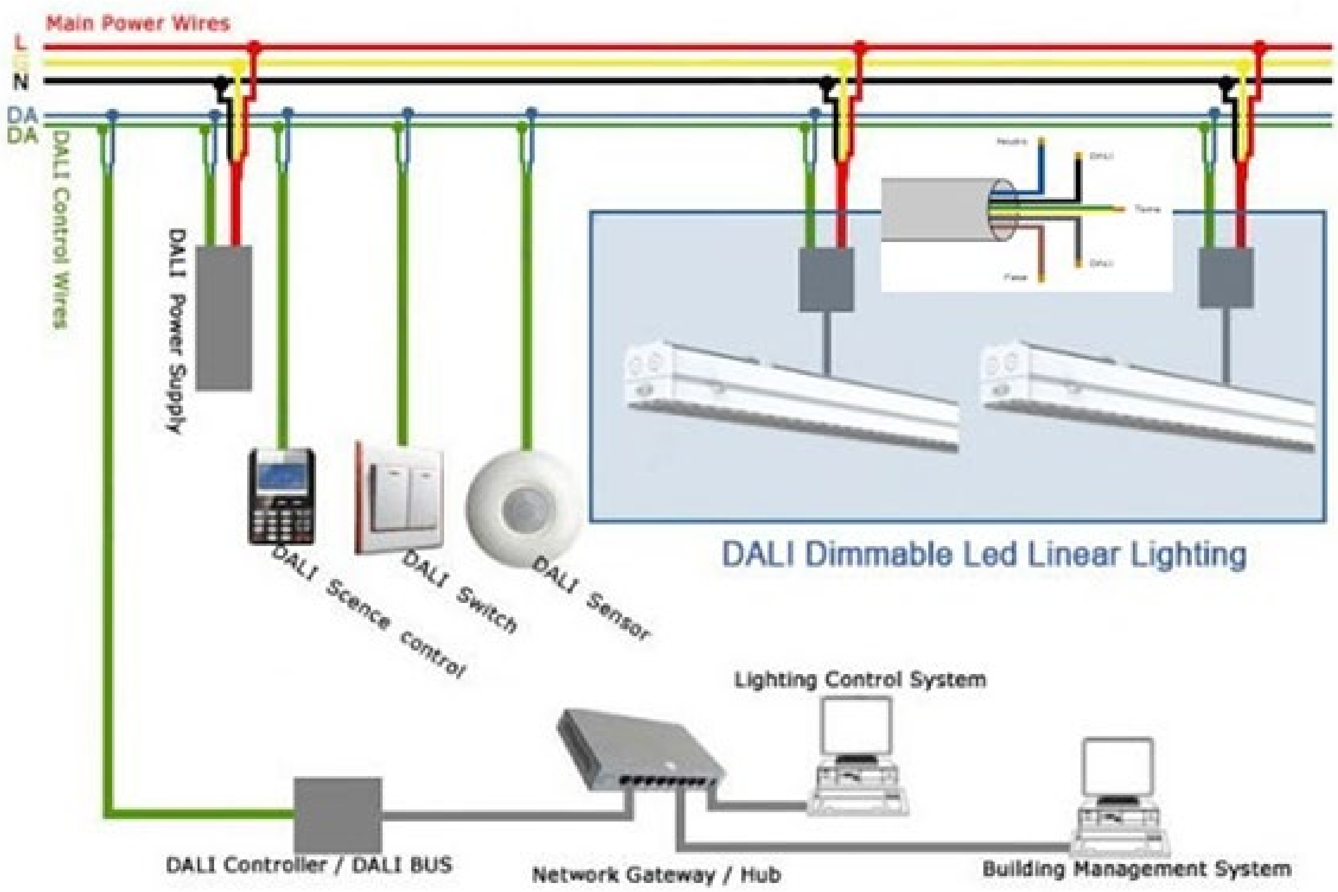


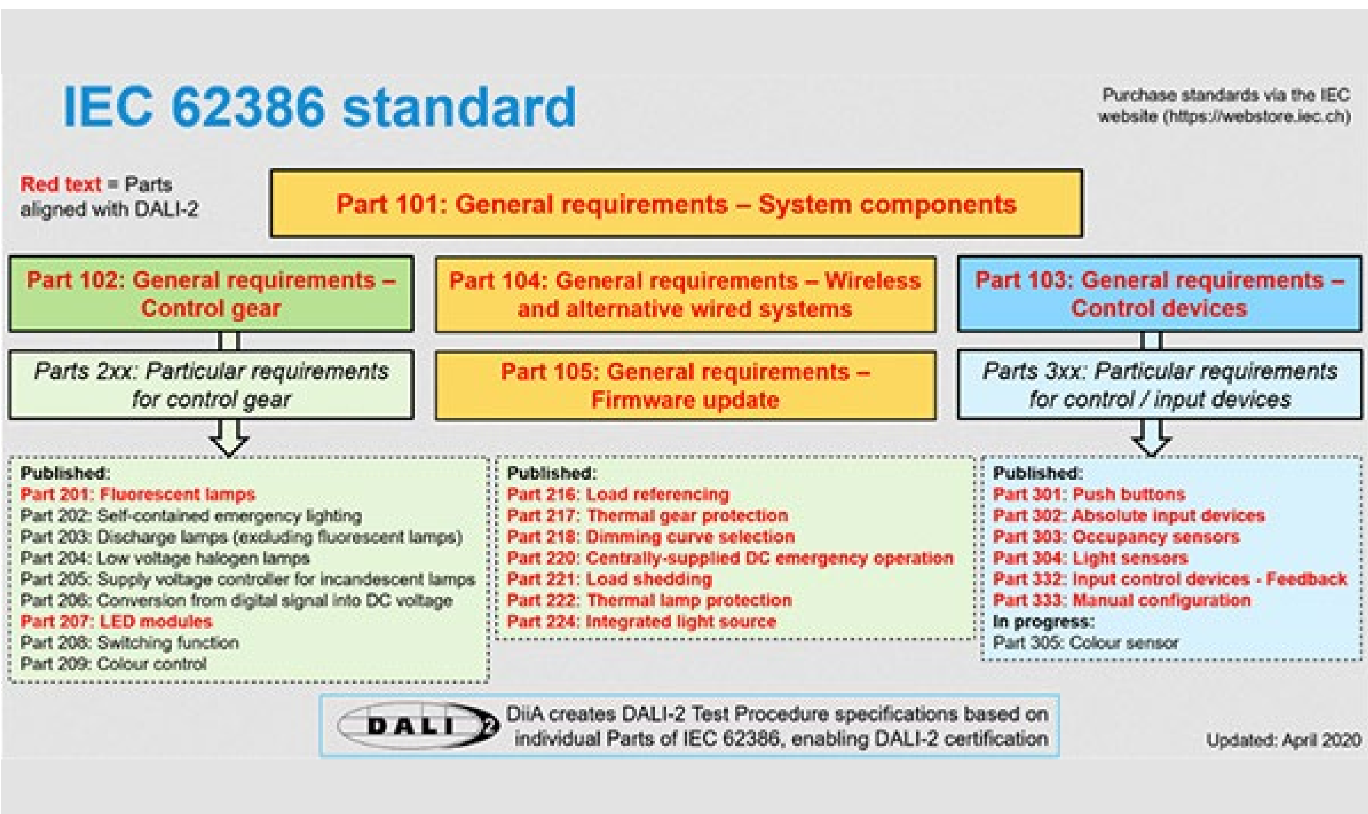
Figure 3: The first version of the DALI standard defined a control base that linked all items being powered by the parallel main AC power wires. (Image source: Omnialed)

is now also an International Electrotechnical Commission standard (IEC 62386). DALI-2 adds many new commands and features. While DALI-1 only included control modes, DALI-2 covers control devices such as application controllers and input devices (e.g., sensors), as well as bus power supplies. It is focused on the interoperability of products from different vendors and is supported by the DALI-2 certification program to confirm product compatibility with the specifications (Figure 4).

As with all comprehensive standards, DALI-2 is complicated. In brief, a single pair of wires acts as the bus, and each device on a DALI network can be addressed individually. The bus is used for both signals and power and is supported by a power supply that provides up to 250 milliamperes (mA) at 16 volts DC (typical). The standard supports devices powered by the AC line or a DC rail.

While there are various standards that define extra-low voltage (ELV), the IEC defines an ELV device or circuit as one in which the electrical potential between electrical conductor and Earth (ground) does not exceed 50 volts AC or 120 volts DC. The DALI

Figure 4: The DALI-2 standard takes the needs of LEDs into greater consideration than DALI-1 and also adds new commands and updates. (Image source: DALI Alliance)



control cable is classified as ELV potential and so requires only basic insulation from AC mains; it can be run next to those mains or within a multi-core cable that includes mains power.

Beyond DALI-2: Zhaga specification targets luminaires

Standards such as DALI-2 are important but can only go so far. It is not within their purview to define how the standard is to be linked to specific applications, such as LED lighting and luminaires. To address this issue, the international Zhaga Consortium has established industry specifications of interfaces for components used in LED luminaires. The consortium is a member program of the IEEE Industry Standards and Technology Organization and has more than 120 members as of 2019.

Now's a good time to make clear the difference between a light fixture and a luminaire. The term "luminaire" is used by the Illuminating Engineering Society (IES) Lighting Handbook, ANSI/NEMA standards, and the IEC. It was added to the National Electrical Code (NEC) handbook in 2002, with a formal definition as "a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply." A luminaire includes the lamp and all components directly associated with the distribution, positioning, and protection of the light unit, and specifically does not include support components, such as an arm, tendon, or pole; the fasteners used to secure the luminaire; control or security devices; or power supply conductors.

Luminaires take many forms and are available for a wide range of situations ranging from strictly functional outdoor street lighting to indoor office lighting, and even to "trendy" retail or home lighting.

"Fixture" is not defined by the NEC and generally refers to whatever the user has in mind and may include some or all of the following elements: the lamp (bulb), perhaps with the lamp guard, the globe, the lens or diffuser, the support, the pole or fixture fitting, and other elements.

The Zhaga specifications, which are formally called Books, address electrical, mechanical, optical, thermal, and communication interfaces, and allow the interoperability of components. By adhering to the Zhaga specifications, designers can ensure that users have components that are interoperable and can be replaced or serviced, and that an LED luminaire can be upgraded after installation when new technology becomes available.

Zhaga Book 18 and Book 20 are of special interest to designers working with LED-based luminaires; the former is focused on outdoor design while the latter is for indoor applications:

Zhaga Book 18: "Smart interface between outdoor luminaires and sensing/communication modules" specifies power and communication aspects, in addition to the mechanical fit and electrical pins for a connectivity system as defined in Edition 1.0. It simplifies the addition of application modules such as sensors and communication nodes to LED luminaires and assures plug-and-play interoperability.

Zhaga Book 20: "Smart interface between indoor luminaires and sensing/communication modules" defines a smart interface between an indoor LED luminaire and a sensing/communication node. The node connects to the LED driver and control system, and typically can provide sensory inputs or enable communication between network components. Nodes can be installed and replaced in the field.

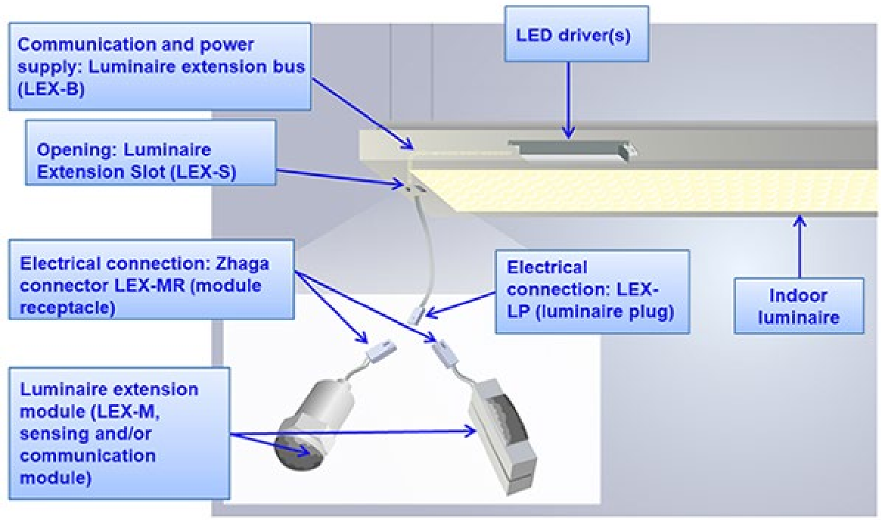


Figure 5: The DALI specification and Zhaga standard provide a complete cable and connector connectivity path for power and data from power source to illuminating LED in a variety of configurations. (Image source: Amphenol ICC)

Connectors complete the circuit

Standards are critical, of course, and compatibility and interoperability begin with the physical interface and its connector (Figure 5). The use of the DALI specification and Zhaga standards is supported by a wide choice of connectors that meet (and exceed) their requirements while providing user flexibility for operation under different scenarios.

For indoor use, Zhaga Book 20 defines a separable mating interface for sensors in intelligent building networks. The Amphenol ICC FLM Series complies with the DALI standard, and enables "plug and play" operability for indoor

LED luminaires and sensors or communication modules. In fact, the Zhaga Consortium chose the Amphenol FLM Series as the Zhaga Book 20 standard.

Two complementary members of the Amphenol ICC FLM series illustrate the Book 20 standard in practice: the FLM-P21-00 SSL two-contact connector receptacle housing for pin-contact cable/wire to cable/wire connections, and the FLM-S21-00 two-contact SSL plug housing for socket-contact cable/wire to cable/wire. Other surface mount technology (SMT) models feature right angle and vertical configurations for design-in flexibility (Figure 6).

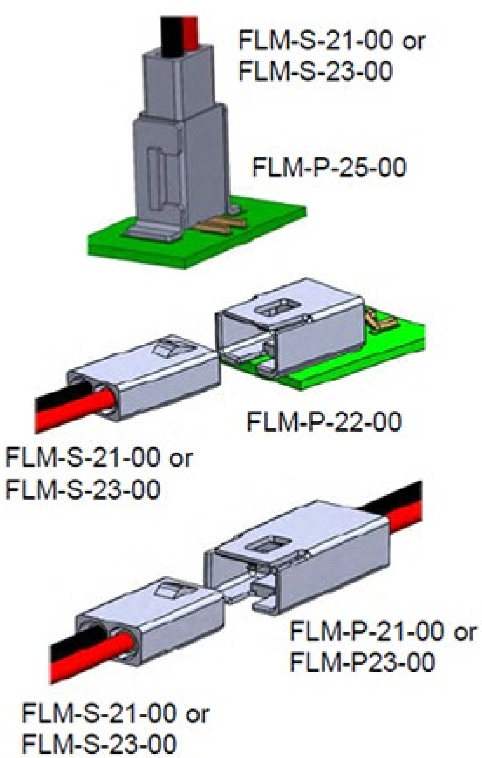


Figure 6: The FLM-P21-00 receptacle housing and mating FLM-S21-00 plug housing are basic two-wire SSL connectors. (Image source: Amphenol ICC)

Figure 7: For LEDs and other connector applications that require an IP67 rating, the FLH Series with the three-wire FLH-P31-00 rectangular housing receptacle (top left) and mating FLH-S31-00 rectangular housing plug (top right) are available, as are 2-, 3-, 4-, and 6-pin versions. (Image source: Amphenol ICC)

Among the features of this series are:

- Separable interfaces with a "poka yoke" geometry (meaning "fool-proof" or "mistake proof"), which ensures correct mating alignment
- An available plug with tool-less poke-in termination
- An integrated low-profile dimple-latch feature that provides five newtons minimum of retention force for secure mating yet with easy unmating
- A plug that is available on reel with crimp socket contacts or poke-in wire termination options to allow high-volume assembly or easy field assembly/servicing

Of course, many intended LED applications are not as benign as ordinary indoor settings. The requirements of such applications can be satisfied with the FLH Series of wire-to-wire IP67-rated (sealed and waterproof) connectors including the FLH-P31-00—a three-position rectangular housing receptacle with a pitch of 2.50 mm—and the corresponding FLH-S31-00 rectangular housing plug (Figure 7); versions with up to six contacts are also offered.

The sealed and waterproof performance of connectors in this series make them especially well-suited for harsh environments, and they can be used for lighting as well as HVAC, industrial, and smart home situations, while their compact design is also a benefit for space-saving applications. The contacts in these connectors are rated for a range of wire gauges and corresponding currents: 18 American Wire Gauge (AWG) for 8 A; 20 AWG for 5 A; down to 22 AWG for 3 A.

There's more to an installation than power connectors alone. To complete the design project, Amphenol offers other key components including the FLA-2141-30, an ANSI C136-41 compliant receptacle used to connect an outdoor luminaire in roadway, street and parking lot applications to a photocell for dimming capabilities (Figure 8). In addition to this two-contact version, there are versions with no contacts and four contacts.

For more advanced sensor integration an FLB-P base can be added in place of the photocell. This allows the addition of a pc board with sensors for a variety of other functions such as motion detection, air quality, and sound detection. The complete assembly can then be protected by adding a FLB-C dome cover. Note: These are not intended for use indoors. Amphenol also offers the FLB-C70-501-001 Dome, a NEMA ANSI C136.41 translucent cover measuring 76 mm in diameter and 130 mm high that is designed for use with the FLB-P bases.

The FLA Series of dimming receptacles can be used with ANSI C136.10 complaint photocell or cap (open circuit or short circuit). For additional sensor integration designers need:

- The FLA receptacle
- The FLB-P base
- A pc board with sensors
- The FLB-C protective dome

Finally, the FLS-SB80-02 Luminaire Extension Module (80 mm) allows lifting of the dimming assembly above the FLA Series receptacle to connect dimming and sensor modules.

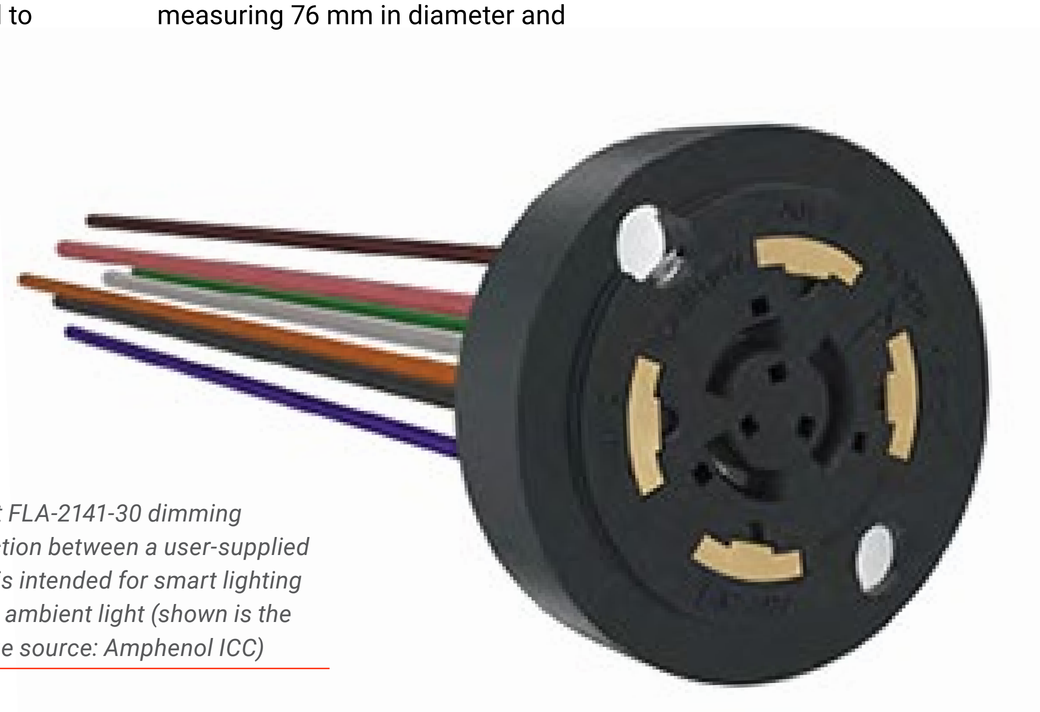


Figure 8: The ANSI-compliant FLA-2141-30 dimming receptacle provides a connection between a user-supplied dimmer and the luminaire. It is intended for smart lighting that is controlled by available ambient light (shown is the four-contact variation). (Image source: Amphenol ICC)

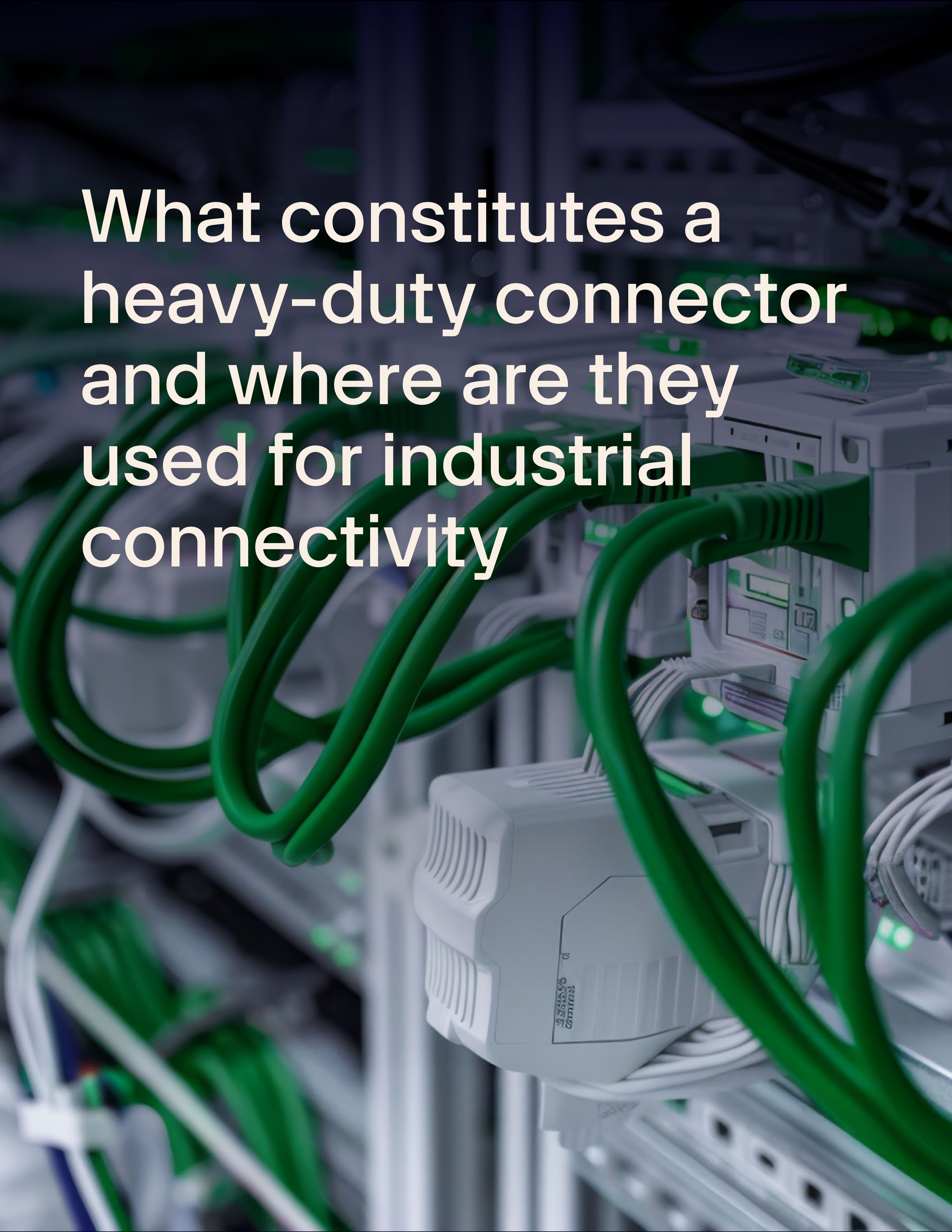
Conclusion

LED-based lighting has dramatically transformed both indoor and outdoor illumination in industrial, commercial, and residential settings. It offers a near-perfect combination of energy efficiency, long life, and flexibility in luminaire configurations. To simplify and accelerate LED design-in, the various families of connectors from Amphenol ICC meet indoor, outdoor, and IP67 requirements while also satisfying the Zhaga industry standards, thus enhancing system compatibility and interoperability.

Further reading:

1. Amphenol LED Lighting Products: Commercial / Industrial Lighting, Indoor & Outdoor
2. Zhaga Book 20 Compliant FLM Series | Datasheet Preview

What constitutes a heavy-duty connector and where are they used for industrial connectivity



By Jody Muelaner
Contributed By DigiKey's North American Editors

A wide array of connectors are used in industrial applications to take the electrical power, sensor signals, and control data on cables through their junctions out of and into automation components. What constitutes a heavy-duty connector (sometimes abbreviated *HDC* in connector product names) depends on the application … so is somewhat relative. That said, there's a distinct difference between ruggedized industrial connectors and those light-duty RJ and IEC connectors found in clean indoor automation applications involving basic Ethernet and light power.

Heavy-duty connectors can feature greater overall robustness as well as enhanced ingress protection, reduced flammability, wide operating temperature, interlocks, earth shielding, or simply more reliable connection with positive locking.

Heavy-duty cable glands versus connectors

Cable glands (sometimes called cord grips) are mostly mechanical components that encircle cables as the latter pass through the boundaries of industrial control panels as well as other enclosures, connectors, and controller bodies made of sheet metal and hard plastic. Cable glands serve three purposes. They:

- Secure the cable
- Prevent cable chafing and other wear
- Provide a seal around the cable section to protect against moisture ingress and siphoning into the enclosure

The way cable glands anchor cables prevents damage to electrical contacts should the cable be tugged or otherwise disturbed. Cable glands also prevent the sheaths of cables from rubbing against the sharp rims of holes through the enclosure as the gland bodies fill and flare out around these edges. Without cable glands, cables subject to even the slightest movement could be quickly sliced by the sharp edges of enclosure holes until their outer insulation is completely sawn through … and the cable cores short out.

In contrast with these cable glands (that encircle cables), are connectors that terminate cables — and generally allow for more convenient disconnection and reconnection as well as joining of multiple component and cable sections. Typically, heavy-duty variations of these connectors include one or more ruggedizing features.

Heavy-duty cable connectors can feature **cable-entry protection** in the form of a universal cable gland, cable clamp, or seal and anti-twist device. No matter the mechanical form, these secure the cable and prevent it from pulling out of terminals. Cable-entry protection can also prevent cable wear just as standalone cable glands do. Note that lamellar inserts (glands with multiple fingers) are common on moderately ruggedized connectors, though the inserts require regular retightening to ensure ingress protection. Glands with a continuous seal that clamps around the cable are often a more reliable choice for heavy-duty applications.

The **hood** on some heavy-duty cable connectors encloses the electrical conductors of the plug while providing insulation and ingress protection — as well as some locking or latching sleeve or lever to keep the connector halves together.

On many heavy-duty cable connectors, the **male insert** includes male pins as well as screws or crimp terminals where the conducting wire cores contact the pins. In such connectors, the **female insert** includes complementary sockets as well as receptacles or crimp terminals where the conducting wire cores contact the sockets.

The **ruggedized housings** of heavy-duty cable connectors are perhaps their most conspicuous feature — often including insulation and ingress protection. Accessories may include additional protective covers and guides for pin codes.

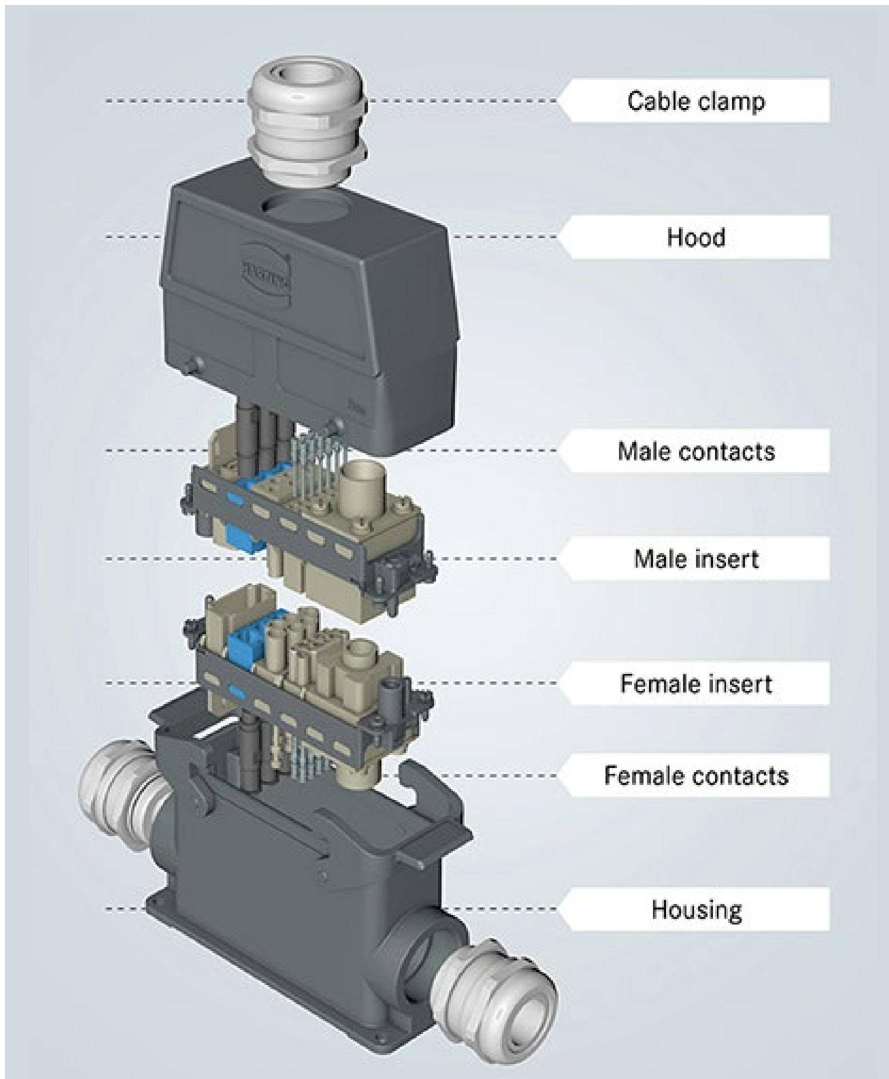


Figure 1: Han®-series connectors include several complementary features to withstand fairly brutal environmental conditions. (Image source: Harting)

IP codes for ingress protection in heavy-duty connectors

It's also fairly standard for heavy-duty connectors to provide ingress protection against fluids and solid particles. The ingress protection of connectors is rated using the same Ingress Protection (IP) codes as used for enclosures. The first digit of an IP code denotes protection from solid objects, with values ranging from 0 (indicating no protection) to 6 — indicating a fully dust-tight build. The second IP-code digit indicates protection against fluids, with values ranging from 0 (for no protection) to 8 (for continuous protection against water at a depth of 1 m) or even 9K — indicating protection against high-pressure jets. For example, an IP67-rated connector resists penetration of dust and temporary immersion in water.

Figure 2: Han-series connectors (with four and 26 pins) are somewhat of an industry standard — satisfying various data and power-connectivity requirements from 50 to 5,000 V and 3 to 200 A. Locking arrangements include a single-lever Han-Easy Lock for easy single-handed operation and a double-lever Han-Easy Lock — for more reliable locking, higher pressure tightness, and use with cable-to-cable connections. Yet another rugged option is screw locking for maximum pressure tightness and reduced risk of unauthorized use. (Image source: Harting)

Proprietary connector variations — why so common?

Due to the strong reliance of heavy-duty connectors on mechanical closure and gasketing features, many options on the market today are either proprietary designs or application-specific connector variations. For example, whole industries have standardized on the heavy-duty rectangular connectors for power and control connections from the Harting Han series. In fact, this trademarked connector brand is sometimes considered synonymous with the term *heavy-duty* connector in general.

Han-series connectors have pins arranged within a rectangular hood that mate with corresponding sockets within a rectangular housing. The connectors are generally equipped with locking levers to let installation personnel easily and securely close the connector — ensuring that it can't be pulled apart … even when considerable tension loads are applied.

Hoods (bolt-on connector cover shells) are most common on power-cable terminations; they're available in top-entry and side-entry configurations. Housings may be screw mounted, surface mounted, or bulkhead mounted to provide a connection on instrumentation or machinery. Alternatively, housings can also terminate cables for cable-to-cable connections. Hoods and housings are typically produced from die-cast alloy … but stainless steel and plastic housings are also common. Some manufacturers offer configurable connectors that can be ganged inside a single hood or housing. This can allow higher pin counts across all distinct modules. Such connectors are available under the Molex GWconnect HDC and TE Connectivity HDC brands.

The ruggedized cable connectors for data and sensor-signal cables are slightly different. Here, M-series connectors lead. They're robust connectors that serve in various data connections (including those based on Ethernet) as well as electrical power transmissions. Rugged M-series connectors are most common in industrial networking applications involving PROFINET, fieldbus, and industrial Ethernet to connect sensors, switches, and PLCs.

As covered in previous DigiKey articles, M-series connectors consist of round male and female connectors having standard metric-threaded sleeves encasing and protecting internal pins and receptacles. Standard sizes include 5-mm M5, 8-mm M8, 12-mm M12, 16-mm M16, and 23-mm M23 connectors. The threaded sleeve provides a very robust and reliable connection which cannot be easily pulled apart and which ensures a very reliable electrical connection, minimizing intermittent signals. The sleeve also gives M-series connectors a high level of ingress protection which can, in many cases, even enable use in washdown and corrosive environments. The most common sizes are M8 and M12 connectors, with two, three, four, five, eight, or 12 pins. Typically, three or four-pin M-series connectors service sensors and power supplies; four or eight-pin M-series connectors service Ethernet and PROFINET devices; and four or five-pin M-series connectors service Fieldbus, CAN bus, and DeviceNet automation devices.

Data connections used in industrial applications include Ethernet, ModbusTCP/IP, EtherCAT, Ethernet/IP, and Profinet … as well various proprietary formats. RJ connectors are the standard for all implementations of Ethernet — but don't provide ingress protection and aren't particularly robust. Although a male-side plastic tab clicks into the socket (to hold the connector halves together) it's rather delicate … and lets plugs pull from their sockets with even moderate tugging. That's why M-series connectors are a superior option if an automated installation is subject to motion and incidental abuse.

There's yet another caveat here, though. While standard M-series connectors are a suitable option

Figure 3: M-series connectors are made of high-strength aluminum and feature a ratchet screw for quick and secure cable coupling with one hand. (Image source: LEMO)

for industrial connectors, obtaining a reliable connection (and rated ingress-protection level) depends on the technician correctly tightening the connector thread. Some connector suppliers have aimed to address even this potential failure point by selling push-fit connectors that automatically lock. Perhaps the most established of these is the Molex Brad series of connectors, which are a direct replacement for standard M12 connectors. These omit the threaded sleeve for a reliable push-to-lock mechanism … so simply pressing the connector halves together ensures perfect locking and a reliable connection without risk of intermittent signals or disconnection. These connectors are available in various configurations and include push-on and pull-off connectors with IP65 protection.

When used for Ethernet applications, M-series and Molex Brad connectors can also carry power using the Power over Ethernet (PoE) standards in three configurations — Alternative A, Alternative B, and 4PPoE — to support varying levels of bandwidth and power capacity.

Figure 4: Ultra-Lock connectors are a push to lock option with O-rings to provide foolproof connections and IP69K ingress protection. (Image source: MOLEX)

IEC power connectors for high-power requirements

The International Electrotechnical Commission (IEC) defines various standards for power connectors used in domestic, commercial, and industrial applications. For example, IEC 60320 covers non-locking connectors with voltages and currents up to 250 V and 16 A respectively. These include large but nonruggedized C13/C14 as well as larger C19/C20 couplers common on electronic equipment for industrial applications — including computer power supplies and server enclosures. These couplers aren't normally considered heavy-duty connectors.

In contrast, IEC 60309 locking connectors are ruggedized — and intended for use on industrial cables that transmit voltages and currents up to 1,000 V and 800 A respectively. All IEC 60309 locking connectors provide some degree of ingress protection with standard configurations proving splashproof IP44, waterproof IP67, or jet proof and waterproof IP66/67 protection.

The standard also allows for interlocked socket outlets: Connectors with this feature don't allow energization unless mated with a plug … and the plug can't be removed until the power is switched off. The following color coding indicates the allowable voltage and frequency range for the connector.

- Yellow indicates the IEC 60309 power connector is suitable for carrying 100 to 130 V at 50 or 60 Hz.

- Blue indicates the IEC 60309 power connector is suitable for carrying 200 to 250 V at 50 or 60 Hz.
- Red indicates the IEC 60309 power connector is suitable for carrying 380 to 480 V at 50 or 60 Hz … often in a three-phase configuration.

Conclusion

Heavy-duty connectors must satisfy various requirements. Will the connector need to resist crushing from impact loads — or being pulled apart? Is ingress protection against dust or water needed? What temperatures will the connector need to withstand? Will the heavy-duty connector be installed in settings where flammability is a concern?

The number of pins and the voltage and current to be carried by each must also be considered — along with the direction of cable entry and level of cable protection. On automated machines that subject the cables and their connectors to movement, suitable glands, and cable clamps must be provided … and anti-twist devices may also be prudent.

For electrical loads that are relatively light but operating in harsh environments, M-series connectors and their derivatives are often suitable choices. For higher electrical loads, rectangular connectors may be better a better solution … especially as they can be configured to suit just about any complex requirement with various cable-entry directions, mounting options, and generally modular builds. Otherwise, for simple power connections to a single or three-phase ac supply, IEC 60309 locking industrial connectors are the leading (if not the only) choice.

Figure 5: This red color-coded heavy-duty connector satisfies the IEC 60309 standard for supplying 380 to 480 V. (Image source: Wikimedia Commons)

Understanding and choosing GHz-range coaxial connectors and cable assemblies

By Bill Schweber
Contributed By DigiKey's North American Editors

Radio frequency (RF) connectors and their completed coaxial (coax) cable assemblies provide essential signal pathways between circuit boards, subassemblies, and chassis. An appropriate connector will at least provide the required minimum electrical performance and mechanical ruggedness. However, the RF connector families which have served for many years, including the bayonet-attachment BNC connector, are no longer adequate due to their physical bulk and performance limits.

To meet the many challenges of today's designs, engineers can choose from among many specific types available in several major families, each offering some combination of higher bandwidth, less bulk, and the use of thinner coaxial cables. These connectors are available in a wide variety of pc board termination styles as well as cable termination types to meet the many classes of physical installation priorities. Designers must therefore first select the appropriate connector family to meet the design requirements and then the style within that family.

This article will look at five widely used gigahertz (GHz) range, RF connector families. It will also look at the closely related issue of complete cable assemblies terminated with the chosen connector, using components from the various families from Würth Elektronik.

The basics of RF connectors

It's important to clarify connector-related terminology. A "connector" is the metal termination which can be mated and unmated as needed, while the "cable" is the coaxial wire consisting of an inner copper conductor, spacing dielectric, outer shield, and insulation to which the connector is attached. A "cable assembly" is the combination of a cable with a connector at one or both ends. However, the term "cable" is often used in place of "cable assembly" in casual conversation, and the actual meaning is usually clear from the context. We will use these terms in their strict sense in this article.

While connectors are passive components and don't provide any signal processing or enhancement, they are essential elements in almost any product design. The "ideal" connector offers critical mechanical attributes such as convenient mating and unmating, mechanical and electrical integrity, and it should be electrically invisible with no DC ohmic resistance or RF impedance discontinuities. The challenges of designing, manufacturing, and using connectors increase with operating frequency. As their required operating frequency extends into the RF domain, into and above the gigahertz (GHz) range, their mechanical construction by necessity becomes increasingly precise, with many critical performance attributes and parameters.

Classic connectors such as the BNC (Bayonet Neil-Concelman), offered in 50 Ω and 75 Ω versions (the latter for video and TV), have been widely used since the 1950s and are still in use (Figure 1). This locking connector features a one-third turn, quick-connect/disconnect action via a "bayonet" system. Although the frequency response is formally rated to 4 GHz, the connector's losses increase to often unacceptable levels at higher frequencies. Physically, it is not a good fit for today's compact, densely packed designs due to its relatively large size and the large minimum bending radius of a complete cable assembly.

Figure 1: The BNC connector includes a bayonet body lock and has been widely used since its development in the early 1950s, but it is not a good electrical or mechanical fit for many of today's high-frequency, space-constrained applications. A male plug is usually used with cable assembles (left); a female jack (right), for use on instrument panels. (Image source: Wikipedia; Pinterest)

Newer families for new applications

Many industry-standard connector families are available which are more effective for higher frequency, more compact applications. Among the most popular are the SMA, SMB, SMP, MMX, and MMCX families, all with the standard 50 Ω RF impedance. Each offers a different combination of electrical and mechanical characteristics. In contrast to the 17 millimeter (mm) diameter of the BNC connector, these connectors have a much smaller diameter in the range of 5 mm.

This article will look at a single connector member in each of these families. However, within each family, there are many members with nearly identical electrical specifications, but very different mechanical configurations and arrangements. These include printed circuit board (pc board) versions with a right angle body or a straight body, and with surface mount, through-hole, or end launch termination; rear-mounted bulkhead types; and panel mounted versions with solder cup, flat tab, or round post connection. There are also different arrangements for mating connectors that go on the end of the cable, such as straight and right angle variations.

Having so many options within a given connector type is good for designers as it increases

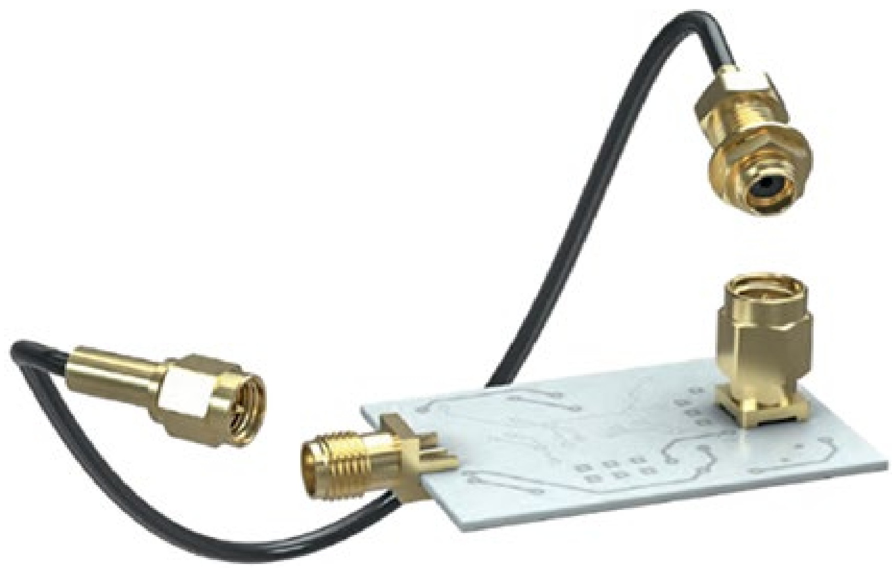


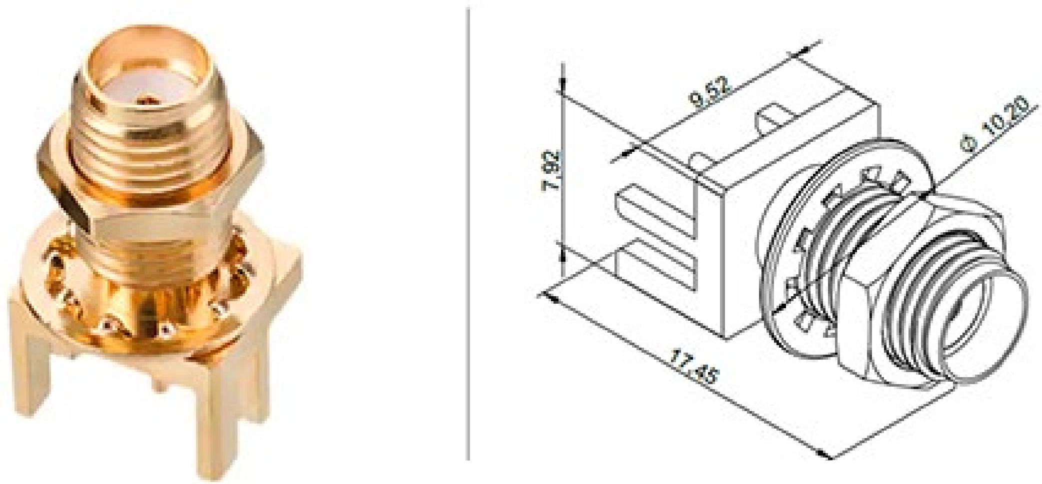
Figure 2: Subminiature SMA series connectors use a threaded coupling for enhanced mechanical integrity in the face of intense vibration. (Image source: Würth Elektronik)

the likelihood that there is one available off-the-shelf that has a specific form factor that is well-suited to the product design and constraints. This means there will be little or no change required to the mechanical design priorities of the product. Now, a closer look at these five families:

•*SMA:* Subminiature SMA series coaxial connectors are designed with threaded coupling technology to ensure high mechanical stability in the face of intense vibration (Figure 2). The connector's captivated center contact and insulator increase axial force and torque. The thick gold plating on the center contact contributes to enhanced electrical performance and up to 500 mating cycles.

A good example of this type of connector is Würth Elektronik's 60312242114510, a DC to 10 GHz SMA connector jack with a female socket (Figure 3). It is designed for board edge use and end launch orientation. This panel mount solder connector also comes with a front-side nut and lock washer to facilitate bulkhead (panel) attachment for additional rigidity in the end product.

Figure 3: The 60312242114510 DC to 10 GHz SMA connector jack with a female socket includes a front-side nut and associated lock washer for additional mechanical integrity when mounted through a panel or bulkhead (all dimensions in millimeters). (Image source: Würth Elektronik)



Key RF specifications include voltage standing wave ratio (VSWR) under 1.2 and insertion loss (IL) of less than 0.14 decibels (dB) from DC to 12.4 GHz, with corresponding VSWR and IL numbers of 1.4 and 0.2 dB from 12.4 to 18 GHz.

•*SMB:* Connectors in the SMB series are designed for snap-on coupling with broadband capability from DC up to 4 GHz. They are smaller than SMA series connectors and thus are well suited for circuit miniaturization. Among the available SMB connectors are pc board receptacles for through-hole and surface mount, as well as edge card and cable connectors for plugs and jacks (Figure 4).

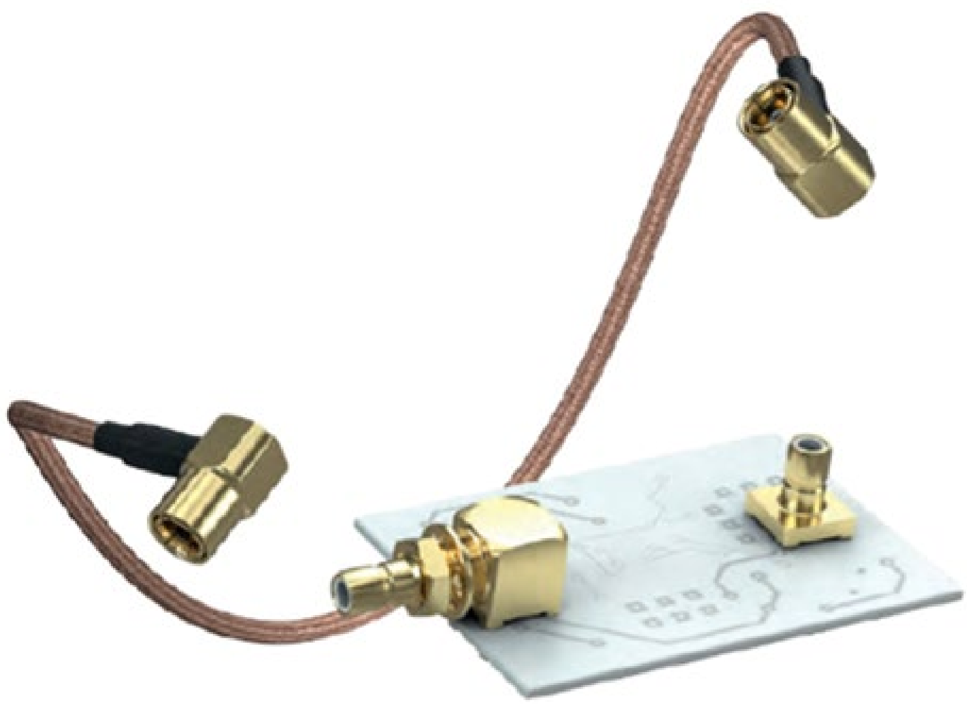


Figure 4: SMB connectors are snap-on devices that are smaller than the SMA connectors and not threaded; they are also available in a range of configurations. (Image source: Würth Elektronik)

An example of an SMB connector is the 61611002121501, a male pin, right angle, through-hole, solder connector jack, with a VSWR of 1.5 and an insertion loss under 0.2 dB (Figure 5). Like the SMA device, it is also rated at 500 mating cycles.

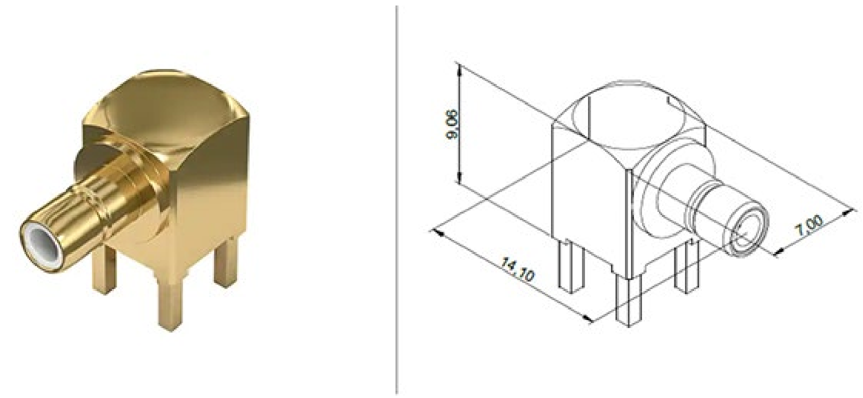


Figure 5: The 61611002121501 SMB connector is a snap-on right angle unit designed for through-hole board attachment and soldering, which is smaller than the SMA unit but has comparable specifications. (Image source: Würth Elektronik)

•*SMP series*: These miniature connectors with both slide-in and snap-on features can be used in applications up to 40 GHz. They are available with three interface types: full "dent" with maximum retention for high vibrant resistance (100 cycles); limited dent with medium to low retention (500 cycles); and smooth bore (1000 cycles) with the lowest retention achieved via sliding contacts for modular systems and applications (Figure 6).

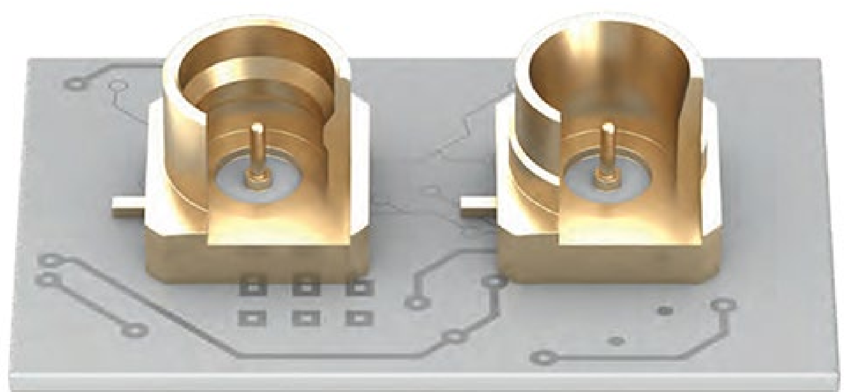


Figure 6: Connectors in the SMP series offer a variety of retention ratings, including limited dent for medium to low retention (left) and 500 cycle rating; and smooth bore (right) with the lowest retention but double the number of cycles. (Image source: Würth Elektronik)

One of the connectors in this series is the 60114202122305, a surface mount, edge card connector with an extended solder leg for circuit boards having up to a 1.2 mm maximum thickness (Figure 7). It is specified to have a VSWR of 1.5 and an insertion loss of 0.42 dB from DC to 12 GHz.

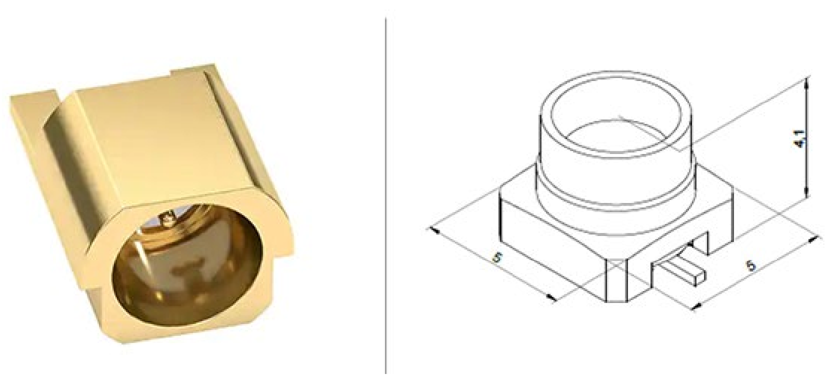


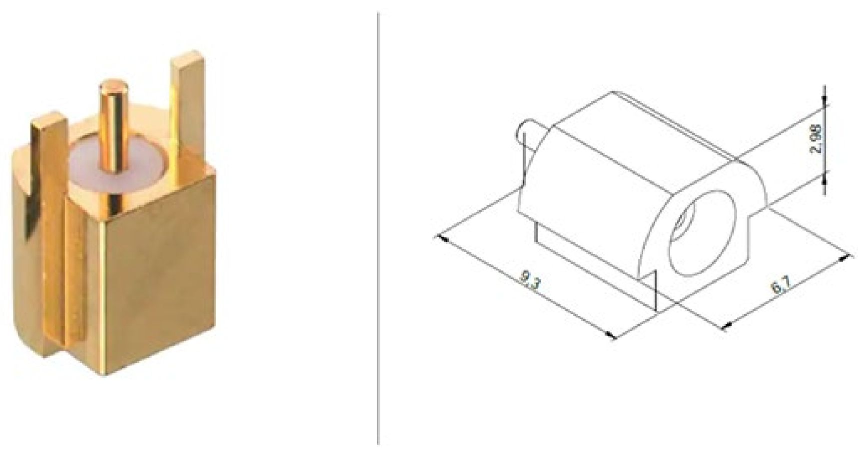
Figure 7: The 60114202122305 is a smooth bore, edge card connector in the SMP series that is rated to 12 GHz. (Image source: Würth Elektronik)

•*MCX series:* Connectors in the MCX (Micro Coaxial) series feature a snap-on coupling mechanism for fast and convenient connection and are intended for operation from DC to 6 GHz (Figure 8). These connectors are compatible with IEC 61169-36, “Radio-frequency connectors - Part 36: Microminiature r.f. connectors with snap-on coupling - Characteristic impedance 50 Ω (Type MCX)”.

Figure 8: The MCX connector series is an even smaller snap-on family of connectors that are compatible with IEC 61169-36. (Image source: Würth Elektronik)

The 60612202111308 is a surface mount, edge launch jack in the MCX series, suitable for boards up to 1.6 mm thick. It has a VSWR of 1.3 and insertion loss of 0.25 dB over that range and is rated for 500 cycles.

Figure 9: The MCX series 60612202111308 surface mount, edge launch jack has an insertion loss of just 0.25 dB to 6 GHz. (Image source: Würth Elektronik)

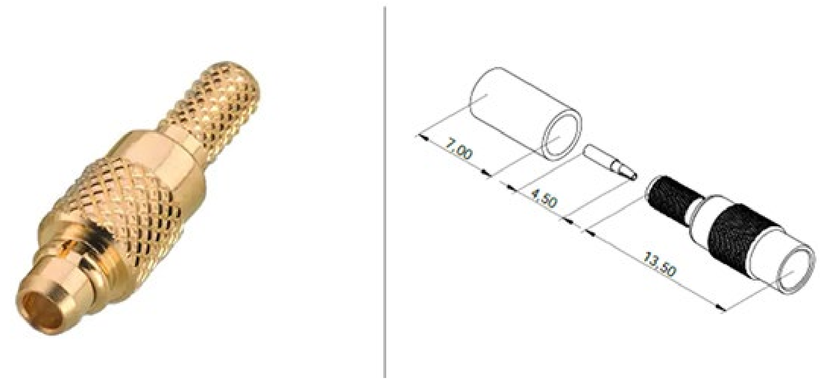


•*MMCX series:* These connectors are approximately 30% smaller compared to the MCX connectors and are suitable for applications with ultra-small design requirements (Figure 10). They have a snap-on coupling mechanism for fast and easy connection and also meet IEC 61169-36.

Figure 10: Connectors in the MMCX series are approximately 30% smaller than those in the MCX series and exhibit comparable RF performance. (Image source: Würth Elektronik)

As an example, the 66046011210320 MMCX plug is a male pin, “free-hanging” (in-line), crimp connector in the MMCX family (Figure 11). This 6 GHz connector works with RG174, RG316, and RG188 coaxial cables, and features a VSWR of 1.3 and insertion loss of 0.3 dB.

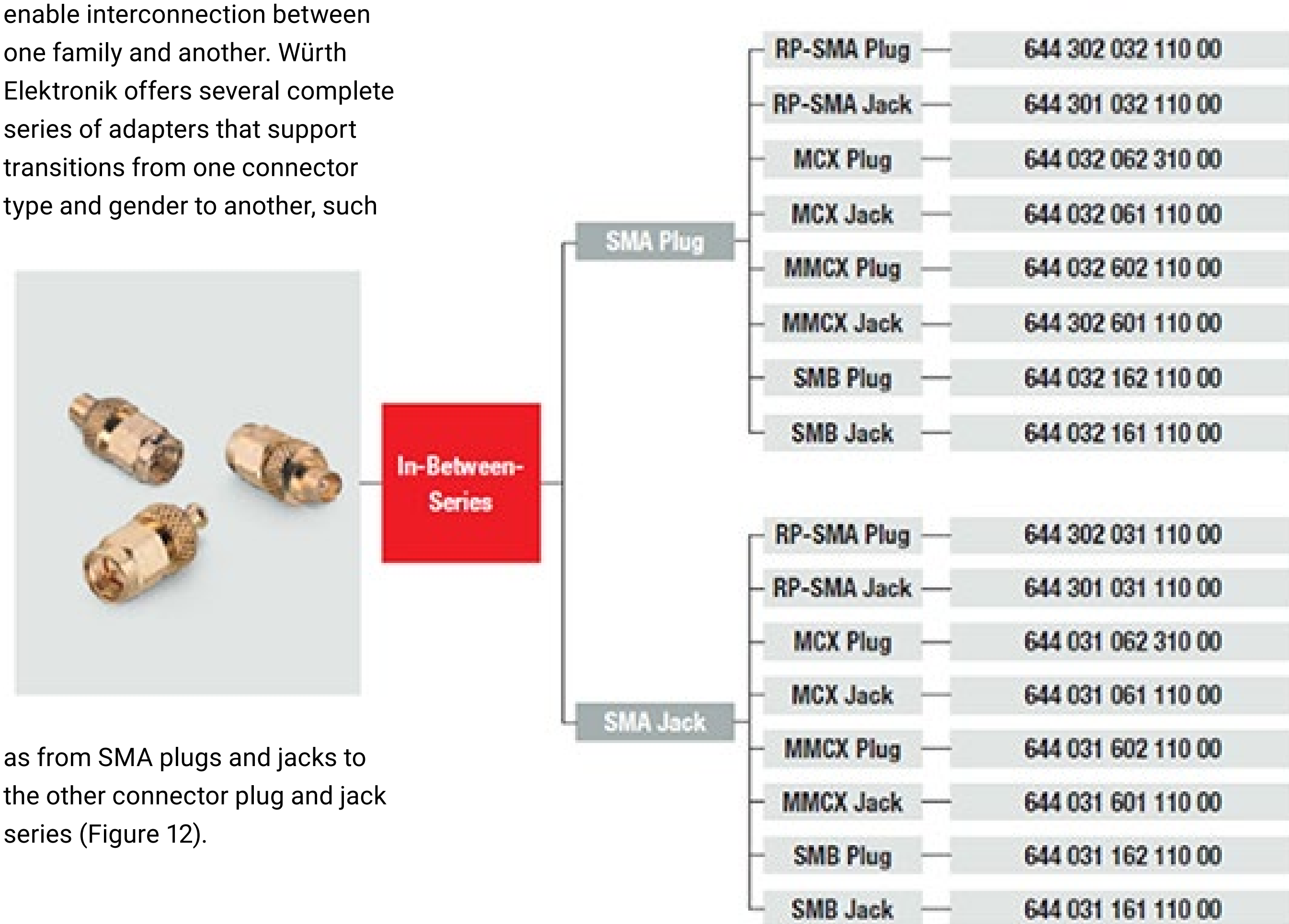
Figure 11: The 66046011210320 MMCX plug is designed to be crimped onto a cable such as the RG174, RG316, and RG188 coaxial types. (Image source: Würth Elektronik)



Specialty connectors, adapters round out the families

Given the wide range of connectors in use, it is inevitable that there would be a need for adapters to enable interconnection between one family and another. Würth Elektronik offers several complete series of adapters that support transitions from one connector type and gender to another, such as from SMA plugs and jacks to the other connector plug and jack series (Figure 12).

Figure 12: Shown are the many available SMA plug and jack adapters that provide a seamless transition to SMB, MCX, and MMCX family connectors of various types. (Image source: Würth Elektronik)



There's another special connector type that can confuse designers at first: the reverse polarity (RP) connector. The standard connector configuration is to have a male (pin) center contact in the plug, and a corresponding female (receptacle) in the jack. But in the US, Federal Communications Commission (FCC) regulations mandate reverse gender "polarity" in some unique cases.

The situation dates back several decades when wireless Wi-Fi routers for consumer use were introduced. They were designed for limited range using a small antenna having a connector at its base which screwed directly into the Wi-Fi unit's antenna connection, and thus with no ability to relocate it. However, the FCC was concerned that end-users would attempt to boost the device's range with add-on amplifiers and/or external antennas, causing Wi-Fi band interference. Their "solution" was to attempt to prevent easy connection of such add-ons by mandating the use of RP connectors on these wireless devices (which often used SMA connectors) to make them incompatible with standard add-ons (Figure 13).

Within a short time, however, cable assemblies terminated with RP connector pairs became widely available and were standard add-ons for devices such as external, relocatable Wi-Fi antennas (Figure 14).

Figure 13: RP SMA plug and jack connectors have the opposite center conductor gender compared to conventional SMA connectors; (left to right) standard SMA male connector, SMA standard female connector, RP-SMA female connector, RP-SMA male connector. (Image source: Wikipedia)

Figure 14: This external Wi-Fi antenna can be moved around to find an optimal location and is connector compatible with the antenna interface on the Wi-Fi router due to its RP-SMA connector. (Image source: Amazon)

One available RP-SMA jack connector is the panel mount, through-hole solder 63012042124504 (Figure 16). This connector features a VSWR of 1.2 from DC to 12.4 GHz, and 1.4 from 12.4 to 18 GHz, while the insertion loss in those two ranges is 0.14 dB and 0.2 dB, respectively.

Cables and assemblies complete the connections

Connectors alone are only part of the RF signal path scenario; their plugs are usually fitted to standard coaxial cables such as RG174, RG316, and RG188, among others. Although all are 50 Ω cables for RF work (75 Ω cables and connectors are available for video systems), they differ in frequency range, attenuation, diameter, dielectric type, phase characteristics, power handling, minimum bend radius, external jacketing, and other mechanical and electrical attributes (Figure 17).

Designers must also decide whether to make their own coaxial cable assemblies or buy them already fabricated—the classic “make versus buy” question. It is possible to terminate these coaxial cables with the selected connectors as needed—the “make” option—but doing so is a challenge which takes skill, practice, time, suitable crimping tools, and other tooling in many cases.

Figure 15: Reverse polarity (RP) connectors are available in range of circuit board styles as well as cable termination configurations. (Image source: Würth Elektronik)

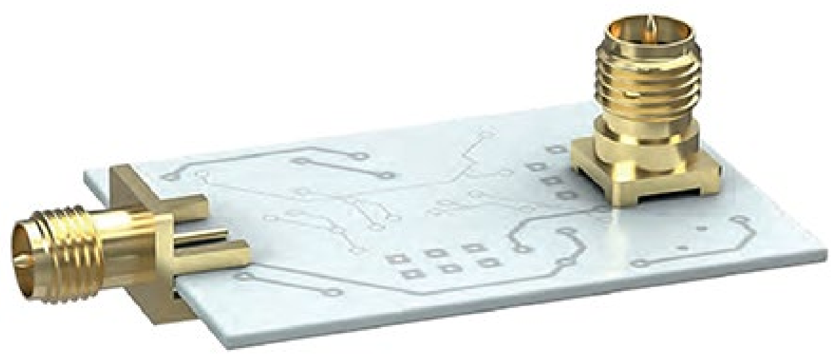
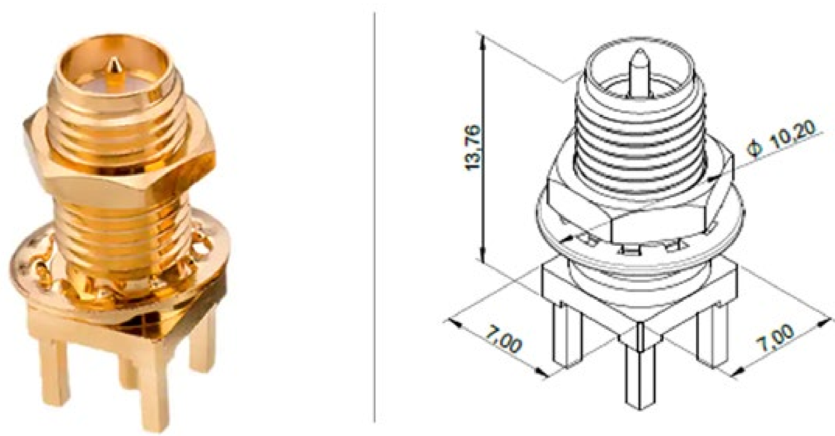


Figure 16: The 63012042124504 is a reverse polarity SMA connector designed for through-hole mounting and soldering. (Image source: Würth Elektronik)



Further, these completed cable assemblies need more than just a simple continuity test; they also need to be checked for RF performance factors such as bandwidth and flatness, impedance discontinuities, loss, and phase shift, to cite just a few factors. These electrical tests take time and require sophisticated measurement equipment, and the assemblies need mechanical ruggedness added via strain relief.

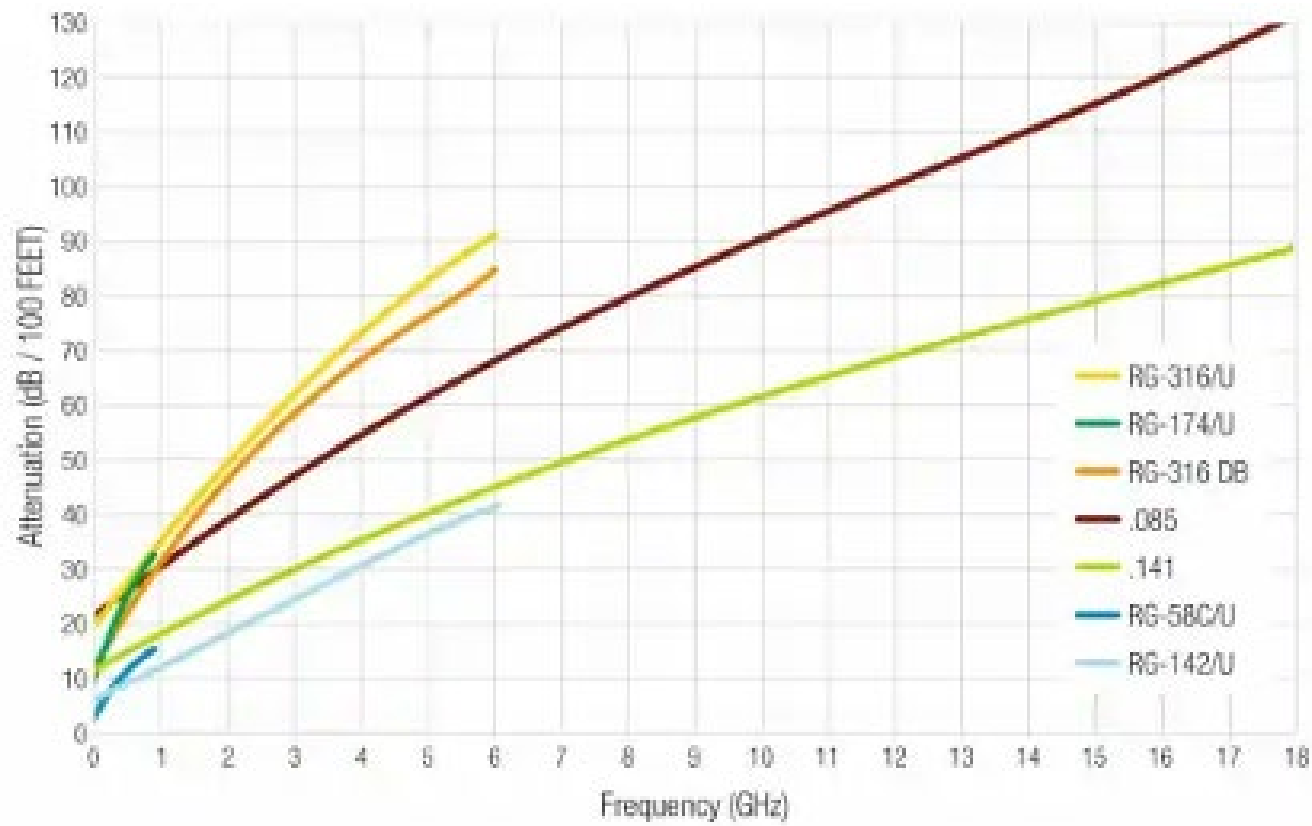


Figure 17: Designers can choose among a wide array of 50 Ω coaxial cables, differing in many electrical and mechanical characteristics. Shown is the attenuation versus frequency—an important specification— for some common standard coaxial cables. (Image source: Würth Elektronik)

Fortunately, cable assemblies are available in many lengths as standard, stocked items for the most common cable and connector types. They also come in custom lengths and connector pairings with fairly short delivery times. Consider, for example, the Würth 65503503530505, a 12 inch/305 mm cable assembly with a straight SMA male plug on each end, using RG-316 coaxial cable (0.102 in/2.59 mm outside diameter), with heat shrink tubing added over the connector/cable junctions for strain relief and ruggedness (Figure 18).

The datasheet for this cable assembly includes comprehensive mechanical and material details and dimensions, as well as guaranteed specifications for VSWR (1.3) and insertion loss (1.2 dB) from DC to 6 GHz. There is also a chart showing

Figure 18: The 65503503530505 is a standard 12-inch coaxial cable assembly using RG-316 cable with straight SMA male plugs on each end; note the strain relief between connector and cable. (Image source: Würth Elektronik)

Figure 19: Shown is the attenuation versus frequency for the 65503503530505 cable assembly. (Image source: Würth Elektronik)

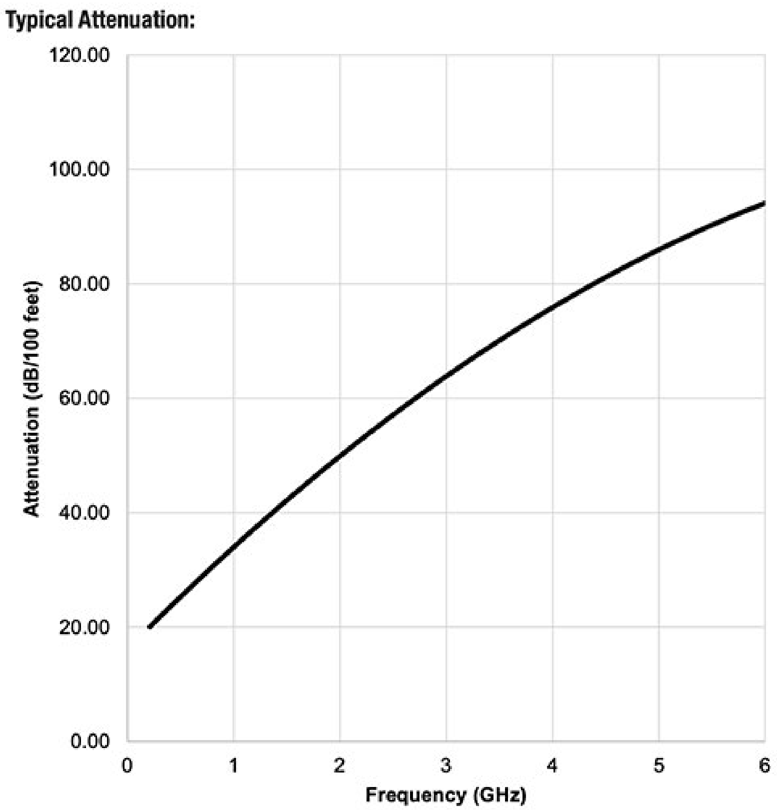


Figure 20: Cable assemblies can also be used as transitions between different connector families; the 65530260515303 assembly, for example, uses RG-174 cable and has an RP-SMA bulkhead male jack on one end and a straight MMCX male jack on the other. (Image source: Würth Elektronik)

attenuation versus frequency per 100 feet, so users can quickly determine the attenuation for this or any chosen length of cable assembly style (Figure 19).

The wide range of vendor-supplied cable assemblies is not limited to having the same connector type at each end, but can instead also directly address interconnect and transition issues as well. For example, the 65530260515303 is a short (6 inch/152 mm) cable assembly using RG-174 cable with an RP-SMA bulkhead male jack on one end and a straight MMCX male jack on the other (Figure 20).

There's one more thing to keep in mind with these connectors and their cable assemblies: they are small and sometimes difficult to handle when tightening or loosening their threaded body. At the same time, they need to be torqued to a specified value: too little torque and they may not make reliable contact; too much and their threads may be stressed and deformed, causing their number of mating/unmating cycles to be reduced. For this reason, *Würth Elektronik* offers the 6006330101 WR-Tool, a small torque wrench for all WR-SMA connectors (Figure 21).

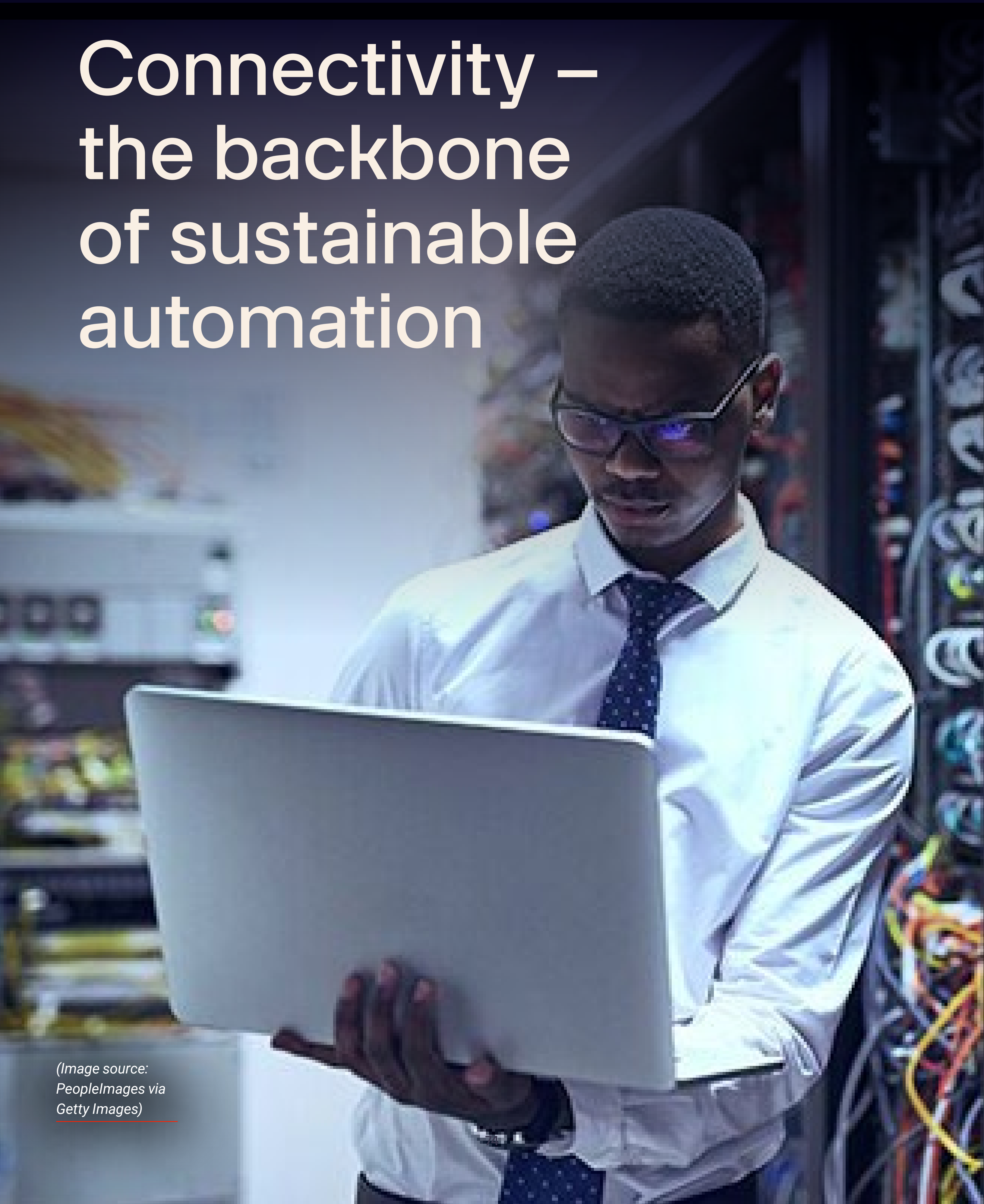
Figure 21: The 6006330101 WR-Tool ensures that the SMA connector threaded body is properly and consistently torqued, which is often challenging given the small size of the SMA body. (Image source: Würth Elektronik)

The use of this tool ensures that the applied connector torque is at the specified level, thus ensuring proper contact mating, maximizing reliability, and consistent performance.

Conclusion

Designers of RF circuits and systems with frequencies extending into the gigahertz range have a choice of connectors with different sizes, body styles, gender arrangements, and other critical parameters. By selecting a connector with appropriate electrical and mechanical specifications, and torquing it correctly, the challenges of ensuring reliable, consistent, low-loss signal paths between circuits, subcircuits, and systems are minimized.

Connectivity – the backbone of sustainable automation



(Image source: PeopleImages via Getty Images)

By Dr. Matthias Laasch,
laasch:tec technology editorial consulting

Technologies such as SPE, PoDL, and Ethernet APL overcome traditional limitations of industrial communication. Advanced interfaces for signals, data, and electrical power are essential here: they help automation providers save resources and costs when networking production equipment.

Digitalization and seamless data networks penetrating corporate processes right down to the field level of production are a lasting trend in automation technology. Their goal is to create highly flexible production environments that can be customized to achieve an unprecedented level of diversification and productivity. For this purpose, the manufacturing industry is experiencing a disruptive transformation under the umbrella of 'Industry 4.0', with the sustainable use of all available resources being one of the most important aspects.

From field to cloud seamlessly

Seamless connectivity between machines, products, and – in the final instance – people is characteristic of this transformation, which is beginning to massively penetrate the traditional boundaries between Operational Technology (OT) and Information Technology (IT). With Industrial Ethernet, a technology is available today that can seamlessly interconnect even field-level devices via TCP/IP to companies' cloud-based data infrastructures broadband and cost-efficiently. Unlike fieldbuses, Industrial Ethernet crosses all levels of automation – end-to-end, from the field device to the cloud. Factory and plant operators can thus access device data in real time and use it for their production planning, process control, and data analysis.

The Industrial Ethernet enables, for example, the real-time acquisition and analysis of data from sensors, power supplies, or drives. Information about temperature change or vibrations at critical points as well as load profiles allow conclusions to be drawn for the optimization of process parameters. They announce when overload situations are to be expected and signal the need for maintenance at an early stage. Predictive maintenance is of particular importance here, as it helps operators to improve the availability of their plants and machines, as well as to minimize energy consumption and use of resources – which, on the one hand, lowers operating costs but, on the other hand, makes a decisive contribution to the sustainability of process and factory plants.

Rugged RJ45 alternative

The physical backbone of these networks, particularly of Industrial Ethernet, is high-performance interconnect technology that allows for reliable transmission of signals and data between the various nodes of the automation networks. In addition to the physical robustness they require in industrial use, such solutions face a number of new challenges today, resulting, for example, from the sheer quantity of network nodes, their miniaturization, or the high transmission bandwidth. These include, in particular, compact form factors, reduced installation and cabling effort, high signal integrity – i.e., sophisticated shielding against electromagnetic interference – and reliability over long transmission distances. The latter is particularly relevant in extended plant fields. Increasingly, the power supply of devices using data connectors is also required.

The standard interface for Ethernet communication is the widely used RJ45 connector. Users frequently report problems with the contacts or broken latching elements; RJ45 also limits miniaturization due to its size. In contrast, alternatives such as the ix Industrial interface from German supplier HARTING (Figure 1) are substantially smaller and much more robust, particularly resistant to shock and vibration. According to the manufacturer, space savings of up to 70% on the circuit board are possible compared to standard RJ45. The 360°-shielded connector is designed for 10-Gbit/s Ethernet communication and is compatible with PoE (Power-over-Ethernet) as well as PoE+ for power transmission.

Figure 1: Considerably smaller and more robust than standard RJ45 connectors: HARTING's industrial Ethernet interface ix Industrial. (Image source: HARTING)

Figure 2: Amphenol ix Mag: Ethernet communication up to 10 Gbit/s, 360° shielding and PoE++ up to 90 W (Image source: Amphenol Communications Solutions)

ix Industrial is an interface developed by HARTING in conjunction with Japanese connector specialist Hirose. Its dimensions, electrical properties, and coding comply with the IEC 61076-3-124 standard. Other manufacturers, such as the US company Amphenol Communications Solutions, also offer products with comparable properties that are intermateable with ix Industrial: for example, push-pull connectors for harsh environments in protection degrees IP65/66/67, ix Mag connectors featuring integrated magnets (Figure 2), or Ethernet-to-RJ45 cable assemblies with angled RJ45 connectors; they provide both 100-Gbit Ethernet and PoE/PoE+ functionality.

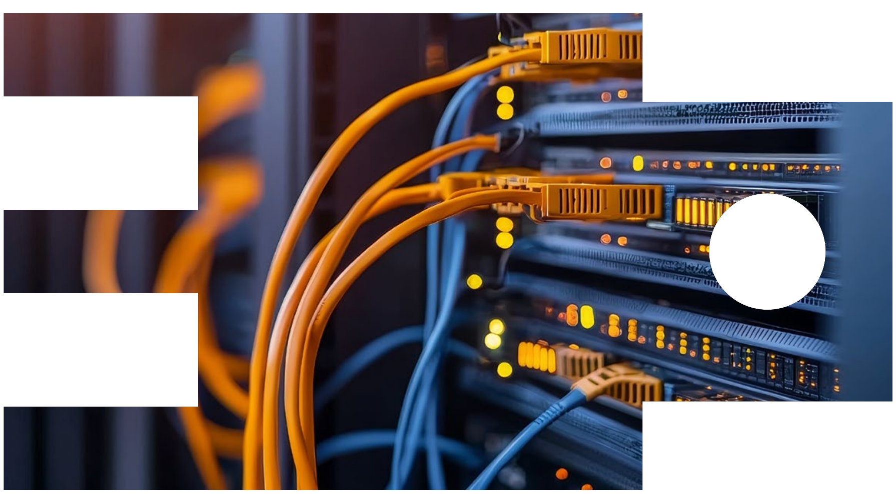
ix Industrial use case

The following example illustrates the enormous potential of high-performance, miniaturized Ethernet interfaces for Industry 4.0 applications:

The XTS linear transport system from automation specialist Beckhoff is a drive solution that uses magnetically driven movers traveling along a track of fully integrated motor modules. According to Beckhoff, their independent control allowing for individual motion profiles is the starting point of new machine concepts that enable more flexible manufacturing processes with shorter downtimes, such as retooling.

In order for the movers to follow their movement pattern, a computer must constantly calculate the switching and current supply of the respective motor modules. For this purpose, a total of three computer boards can be combined, each of which previously had four RJ45 sockets as ports. To allow more movers to be operated in the latest generation of the XTS system without having to change the dimensions of the system, the RJ45 sockets were replaced by the ix Industrial interface from HARTING. Reliable shielding and high data throughput were the main requirements here. Unlike RJ45, each ix Industrial connector allows for two 100-Mbit/s Ethernet connections. Thus, eight instead of four ports could be mounted on the same board, and two Ethernet channels could be installed per port instead of one.

As a result, 48 instead of twelve ports were implemented on the three computer boards. Accordingly, with the latest XTS generation, 48 instead of twelve XTS lines can now be used per unit, corresponding to a 400-% increase in the performance of the transport system.



Two wires – instead of four or eight

One distinctive attribute of today's industrial automation technology is its migration from hierarchical to decentralized architectures. These are considered advanced and particularly productive and, moreover, promise increased network security. This is because intelligent nodes such as smart sensors or edge computers, which are capable of performing certain data processing tasks autonomously, reduce sensitive data traffic between the edge and the cloud. The advantages of decentralization are self-evident, but the number of connected devices in the field is growing enormously, and so are the efforts for cabling and connectivity. Their economic use, both in terms of material and installation effort as well as energy consumption, is becoming a strong criterion for the sustainability of manufacturing facilities.

Single-Pair Ethernet (SPE) is considered a decisive breakthrough in efficiency and cost-effectiveness. The communication technology is defined by the IEEE 802.3 standard; the IEC 63171-x series of standards applies to the respective connectors. Essentially, it enables field components to be connected via just one twisted pair, i.e., two wires instead of the previous four or even eight: low-cost, resource-efficient, and therefore extremely sustainable. Originally developed for automotive electronics,

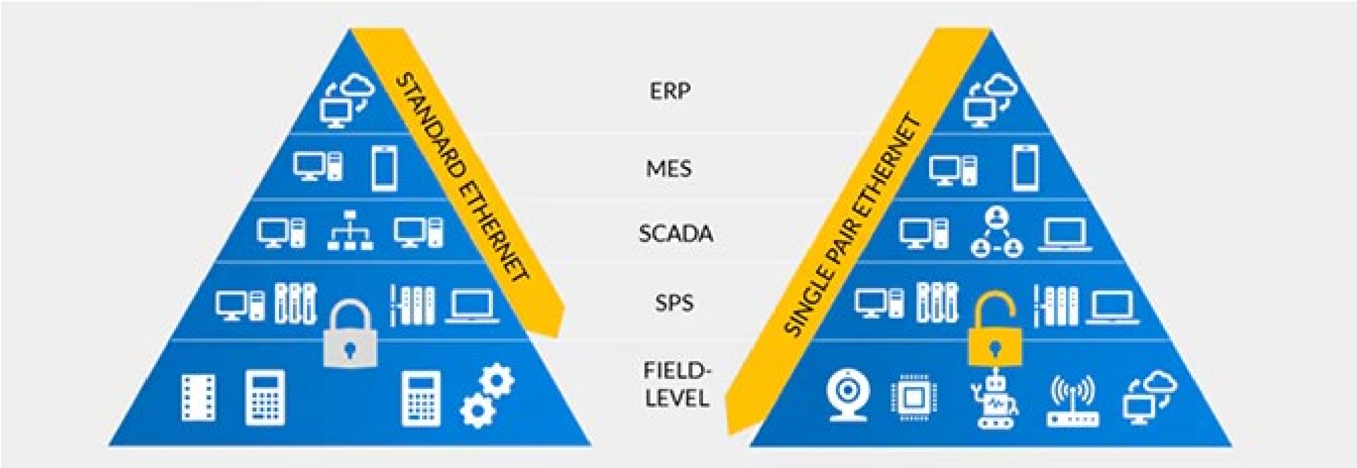


Figure 3. Single-Pair Ethernet allows for resource- and cost-efficiently integrating the field level into broadband Ethernet communication. (Image source: SPE Industrial Partner Network)

SPE meets the requirements of many automation providers: The single pair of wires enables them to integrate a large number of instruments, controllers, and other devices into Ethernet networks at gigabit data rates (Figure 3).

Another advantage: thanks to PoDL compatibility (Power-over-Data-Line, IEEE P802.3bu), the same pair of wires is able to deliver not only data but also electrical power to the field devices. In addition to actuators and sensors, in the power range of the previous PoE supply, camera-based instruments can be connected and powered via PoDL, for example.

Products for Single-Pair Ethernet

In the SPE segment, HARTING is taking a position with its T1 connector, including locking and 360° EMI shielding (Figure 4). The PoDL-capable T1 is available in circular designs, including M8 and M12. In terms of protection degrees, the product spectrum ranges from IP20 to IP67, and according to the manufacturer, the respective interface counterparts are designed to meet the protection classes and ensure interoperability.

Phoenix Contact also provides a comprehensive SPE portfolio for field cabling to and from control cabinets, sensors, switches, and gateways. This supplier's products include, for example, board connectors or cable assemblies for use in industrial IP20 to IP67 environments.

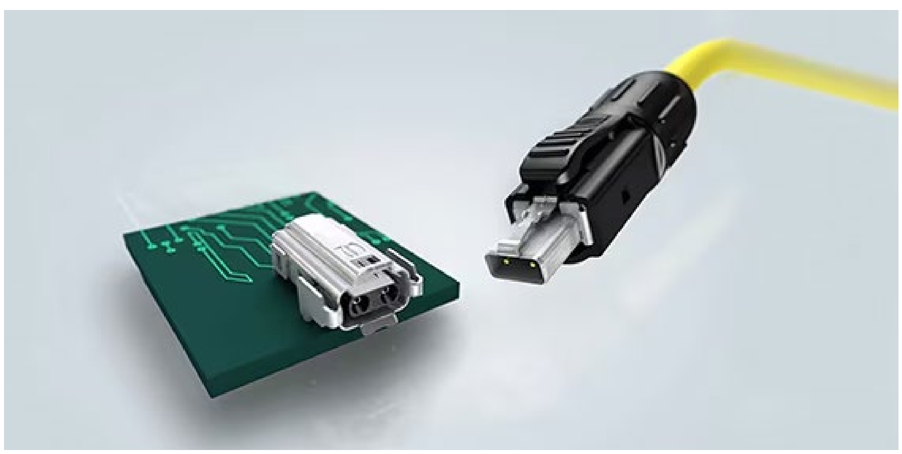


Figure 1: Considerably smaller and more robust than standard RJ45 connectors: HARTING's industrial Ethernet interface ix Industrial. (Image source: HARTING)

The open-source tool provider SparkFun Electronics offers an SPE function board to support developers in designing applications with Single-Pair Ethernet (Figure 5). The board, called MicroMod COM-19038, includes an ADIN1110 Ethernet transceiver from Analog Devices, passive components from Würth Elektronik, and a HARTING T1 connector. An integrated MAC (Media Access Control) interface enables serial communication with a host controller at 10 Mbit/s in full duplex mode. The board supports network nodes via 1700 m cable lengths, but it is not designed to supply power to the nodes via this cable. Kirk Benell, CTO of SparkFun, presents the development board in a demo video.

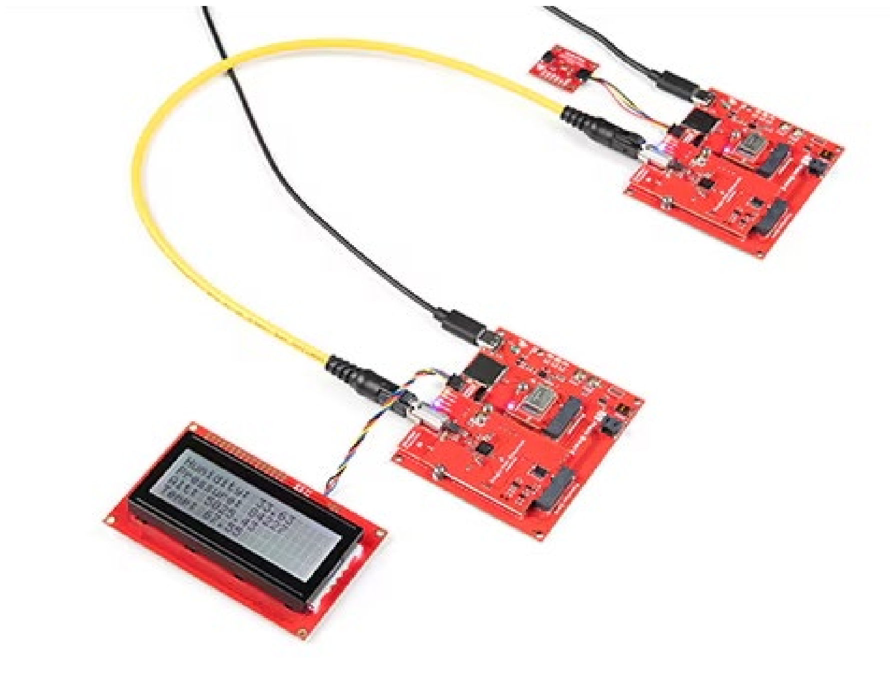


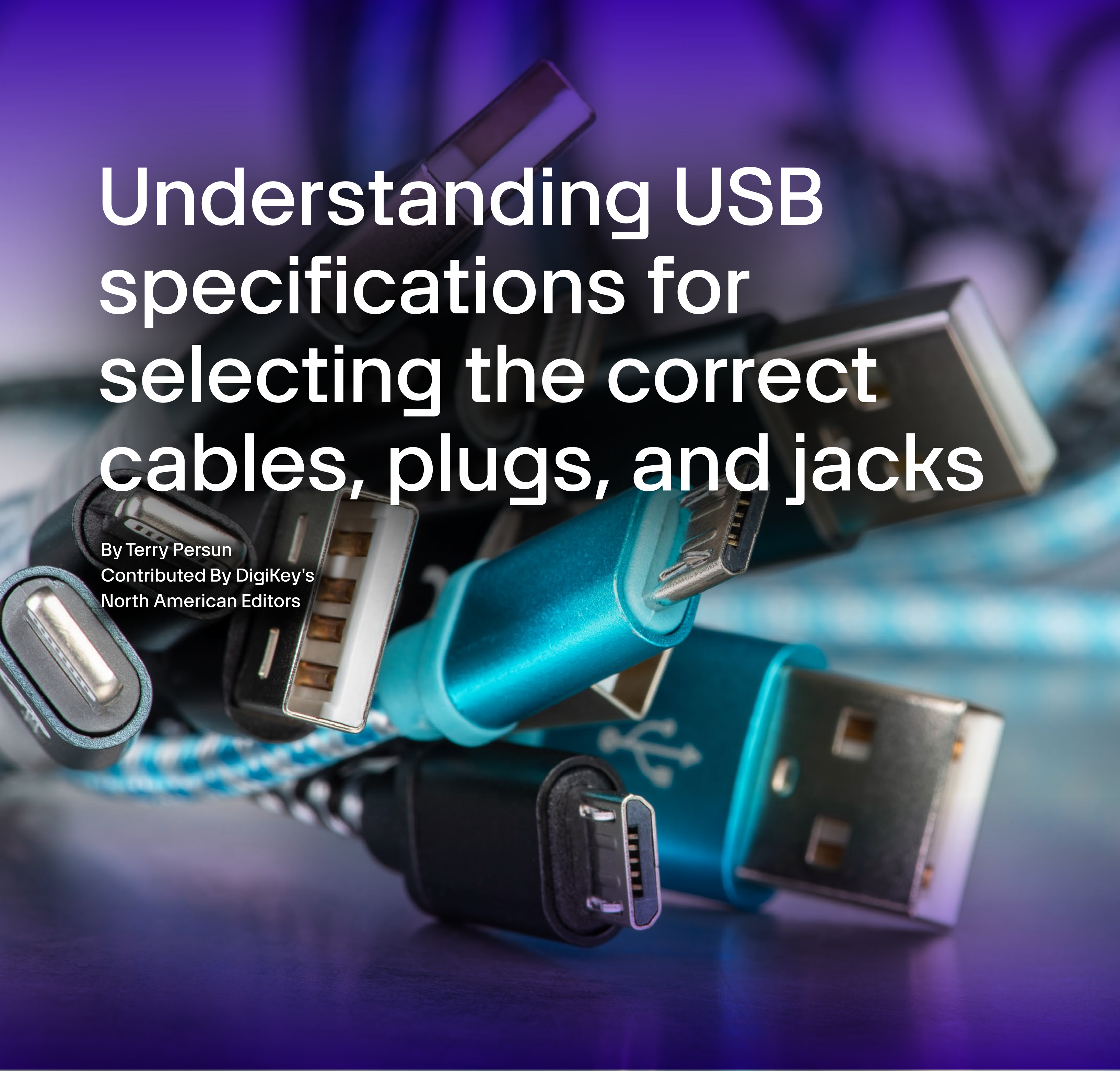
Figure 5: Demonstrator for an ambient sensor featuring a display. (Image source: SparkFun Electronics)

End-to-end networking in process technology

The technical advantages of Single-Pair Ethernet, for example, concerning condition monitoring and predictive maintenance, are also beneficial for process automation. However, an extended requirements profile for Ethernet connectivity applies here. In addition to robust and broadband real-time communication, as it is also required on a shopfloor, wide-ranging process plants require data transfer over long distances. Furthermore, automation components must be intrinsically safe for use in potentially explosive environments. This is where the so-called Ethernet Advanced Physical Layer (Ethernet APL) enters the scene: it defines a physical transmission layer for Ethernet communication at 10 Mbit/s as well as for power supply via one twin wire – as with SPE – over distances of up to 1000 m. Like SPE, Ethernet APL is perfectly suited for universal, multipurpose field instrumentation.

Summary

Industrial Ethernet, and particularly Single-Pair Ethernet, support broadband networking of production equipment. They enable seamless communication from the field level to the cloud and allow real-time access to device data, which supports operators in plant and process optimization. Their benefits are clearly evident in reduced operating costs, higher availability, and optimized use of energy and resources. Advanced connection technologies such as ix Industrial interfaces and SPE connectors with PoDL capability ensure reliable data and power transmission between all network nodes. This makes them key components of Industry 4.0 and a backbone of sustainable automation concepts.



Understanding USB specifications for selecting the correct cables, plugs, and jacks

By Terry Persun
Contributed By DigiKey's
North American Editors

USB (universal serial bus) cables, connectors, and jacks are used in a wide variety of industrial applications, such as industrial sensors, control modules, digital signage, point-of-sale terminals, and much more. The key to incorporating the right product for an application is to remember that different generations of USB devices directly affect performance.

USB has long been the standard for connecting everything, including keyboards, mice, cameras, phone chargers, computers, and wall adapters. These connectors are used to transfer data and power between devices. Early USB cables and connectors could only transfer data at slow speeds of up to about 12 Mbps, until the year 2000 when the USB 2.0 was introduced. That is when the drive toward higher device speeds began to grow quickly.

In this article, the necessary detailed knowledge of the different types of USB connectors and cables, as well as their capabilities, will be discussed to provide the information needed to make the right selection for a specific application.

USB versions and their capabilities

USB 2.0 offered 480 Mbps to its users, a speed increase over 40 times the original USB offering in the 1990s, which could only handle 12 Mbps. The newer version was designed with four connector wires and could interconnect devices with cable lengths up to 30 meters (98 feet). Although they were considered capable of high-speed data transfer, these cables could not support video. The connectors and cables could support power with up to 500 mA of current, whereas the older version could not. The four-wire cable used white and green wires for data transfer, while red and black wires were used for power — red for 5 volts and black for ground. USB 2.0 can easily be identified by the black interior of the connector port. These updated USB capabilities allowed for greater flexibility in multiple applications at the time and are still relevant today.

Eight years after the introduction of the USB 2.0, the USB 3.0 became available. The 3.0 version provided users with even higher data speeds — 10 times higher, to be exact — and are considered SuperSpeed devices. These cables and connectors can support video data transfers. The USB 3.0 cables and connectors were designed to transfer data at speeds of 4,800 Mbps (nearly 5 GB). This super-fast transfer speed rate came in handy when used for backing up or transferring large amounts of data to and from a hard drive or controller. The additional wires are used to provide two-way communications simultaneously. Professional photographers are keen on using USB 3.0 connectors due to their need to transfer high-resolution images between multiple devices as well as uploading to high-speed network computers.

The 3.0 USB version was faster but could only be interconnected to devices within an 18-meter (59-foot) cable length. The unit's nine-wire connectors, instead of the USB 2.0's four-wire connectors, provided the right environment for the increase in speed and bandwidth the devices were required to handle. The technology also allowed the cables and connectors to be compatible with up to 900 mA of current, plus provided greater power efficiency for use with power-hungry devices.

Note that the USB 2.0 standard version connectors and USB 3.0 standard connectors provide radically different specifications. Be sure to match an application to the specific capabilities of the USB connectors and cables you plan to incorporate. USB 2.0 connectors can be recognized because USB 2.0 ports are black, while USB 3.0 ports are blue. USB 3.0 devices are backward compatible and will work with other USB versions, such as USB 2.0. However, the connection will be limited to the maximum speed of the USB 2.0. By about 2012, USB 3.0 was used on all new computers and became a manufacturing standard. These devices can be found in most industries that use USB cables to connect everything from sensors and transducers to data hubs, controllers, and computers.

USB cables and cord assemblies

A full offering of USB cables and cord assemblies is available in multiple configurations and combinations from GlobTek,Inc., including nonstandard configurations based on a customer's specific application requirements.

Their entire line of USB cable assemblies meets USB 2.0, USB 3.0, and/or USB 3.1 standards and comes in a wide variety of shielded and unshielded lengths. Additional cable connector options are also available, such as DC power plugs and blunt cut or stripped and tinned terminations. Cable assemblies are sheathed in either PVC or a TPE, halogen-free jacket material. In addition, customized USB connector overmolds with additional features are also available upon request.

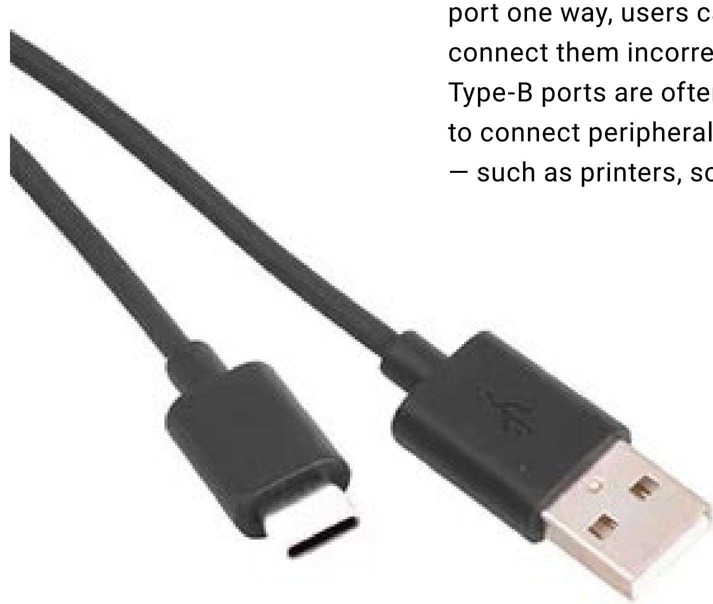


Figure 1: Shown is the USBA2C1MOUSBC(R), a USB 2.0 Type-A male plug to Type-C male plug incorporating a 1.00 meter unshielded cable. USB Type-A connectors can only go into the device port one way, so users cannot connect them incorrectly. (Image source: GlobTek, Inc.)

For cable and cord assemblies, GlobTek, Inc. provides a wide variety of lengths from 100 mm and longer, as well as multiple colors for use in sensitive equipment where quick visual identification is a definite plus. Many off-the-shelf products are available with standard terminations, plugs, and receptacles already installed.

USB Types have specific uses in most commercial and industrial settings. For example, USB Type-A are used with power outlets and computers for charging devices. Since these connectors and cables, such as the USBA2C1MOUSBCR shown in Figure 1, only go into the device port one way, users cannot easily connect them incorrectly. USB Type-B ports are often used to connect peripheral devices — such as printers, scanners, and external hard drives — to a computer or controller. These connectors are not as common as those used for general use.

Products such as the USBCM302M0MICBMMBKR, shown in Figure 2, are used for mobile devices, such as cell phones, tablets, MP3 players, and cameras, as well as portable meters or control units used in industrial settings. The USB Type-B micro allows data to be read without being connected to a computer in applications such as flash drives or memory sticks connected directly to a device. Similar to the Type-A connectors, these devices only go into a port one way and can be damaged if not done so.

The newest connector device is the USB Type-C. These connectors and cables, such as the USBCM311M0USBCMMMWHR shown in Figure 3, are designed specifically for high-speed data transfer and higher current flow, allowing devices to charge more quickly. Unlike other USB Type connectors, the USB Type-C can be plugged into a device in either direction.

Figure 3: The USBCM311M0USBCMMMWHR is a shielded, 1-meter-long, USB-C male to USB-C male cable capable of handling 10Gbps data rates. (Image source: GlobTek, Inc.)

Figure 2: The USBCM302M0MICBMMBKR, USB Type-B micro male plug to Type-C male plug with 2.00 meter shielded cable shown, is often used to connect devices directly to flash drives or memory sticks without needing to connect through a computer. (Image source: GlobTek, Inc.)

Conclusion

USB connectors and cable assemblies are an integral part of everyday life. These assemblies have made it into almost every home to interconnect laptop and desktop computers to multiple peripherals, as well as for connecting mobile phones and tablets to power sources. USB components are also used in automation, where high-speed data transfer between computers and remote sensors and transducers is essential. GlobTek's certifications and commitment to quality position them as a dependable source capable of meeting the demands of consumers and manufacturers alike.