Understanding Harsh Environments for Electronic Design

Mighty Guides

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MOUSER ELECTRONICS

Table of Contents

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Meet Our Experts

Harsh environmental conditions—from moisture to corrosion to vibration—present significant challenges for designers of electronic systems. We interviewed nine experts on addressing these challenges and choosing the right connectors to ensure reliability.

We hope you enjoy their insights!

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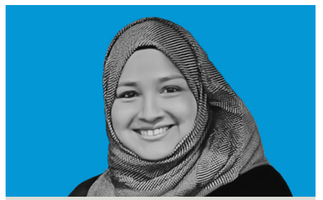

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Introduction

Harsh environments are found in almost every industry. The greatest challenge facing designers is identifying the tough conditions with the potential to damage equipment.

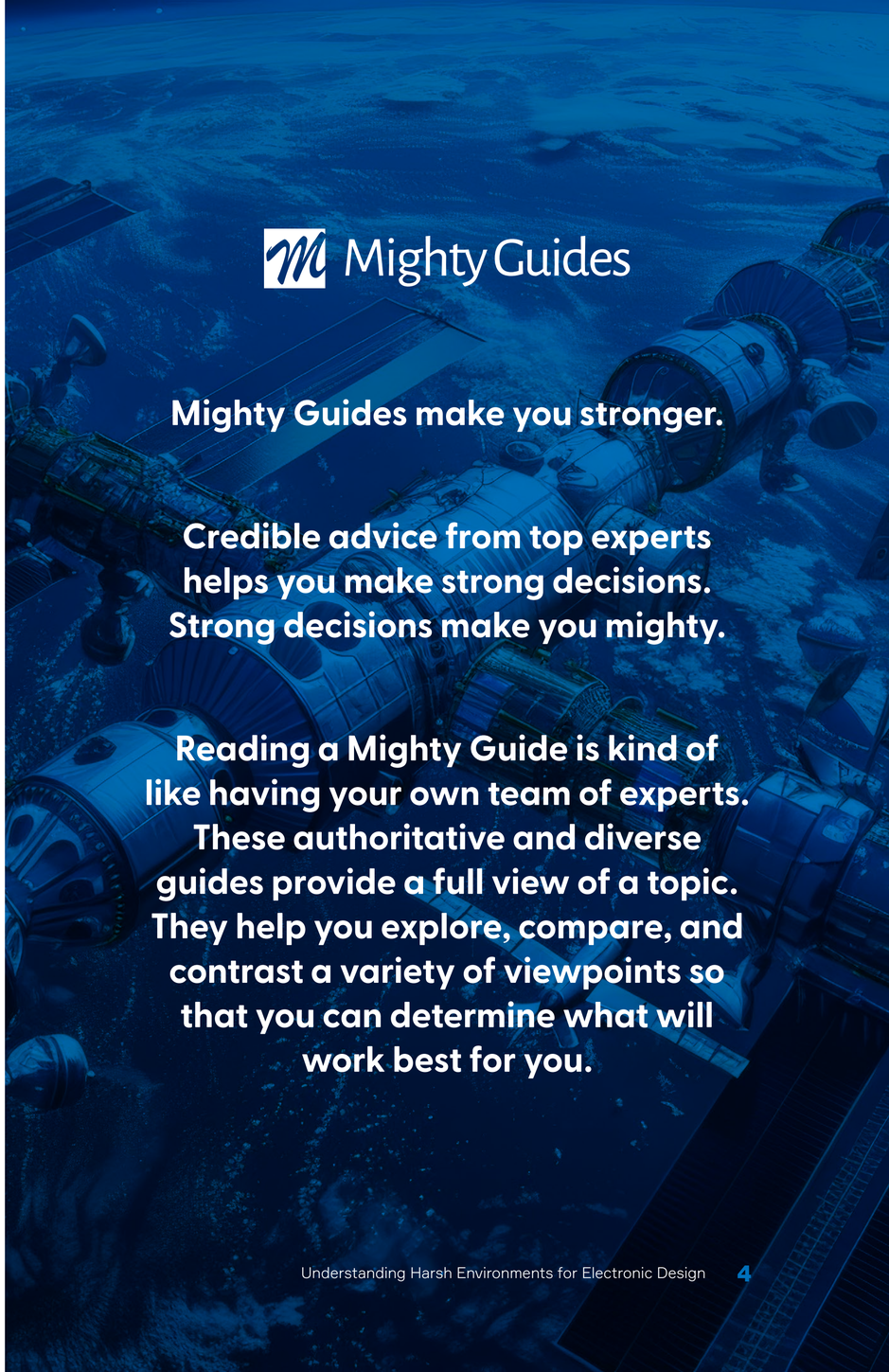
Recent technological advances compound this challenge. In the modern connected world, sophisticated equipment is deployed in new situations. Wireless communication via 5G cellular technology allows handheld and other remote devices to access high-speed internet connections in remote locations. Operators of all types of machinery, from agricultural vehicles to traffic signals, have embraced this functionality.

In parallel, advanced computing enables the Internet of Things (IoT), in which devices form a networked environment where data is processed and decisions are made autonomously. With 5G connectivity, these devices do not need to be part of a wired network.

Modern electronic devices are smaller and more compact, facilitating field use. Across various industries, this mobility is enabling the deployment of advanced equipment into wide-ranging applications. Protecting devices from their operational environments is crucial for performance.

This eBook will discuss the challenges that arise when equipment is deployed in tough conditions and provide guidance for selecting connectors to mitigate risk.

Cinch is a leading manufacturer of connectors for high-speed communications, especially those intended for industrial applications. Cinch provides designers with a broad range of interconnect solutions, from precision radio-frequency to high-performance RJ45 connectors.



Foreword

By **Scott Miller**, Director of Product Management, Cinch Connectivity Solutions

In today's rapidly advancing technological landscape, the demand for robust and reliable interconnectivity solutions has never been greater. As industries expand into more challenging environments, from the depths of the ocean to the vastness of space, the need for durable and resilient interconnects has become paramount.

Harsh environments present unique challenges that can significantly impact the performance and longevity of interconnect solutions. Extreme temperatures, vibration, moisture, radiation, and particulate contamination are just a few of the adversities these systems must endure. Addressing these challenges requires innovative design, advanced materials, and rigorous testing to ensure reliability and efficiency.

Cinch products are tested and rated to the highest international standards. Our SealJack™ connectors and cable assemblies, rated IP67, protect against outside elements and moisture, while our SMA and TNC interconnects meet IP68 standards, ensuring peak performance in underwater applications. We also offer interconnects with corrosion-resistant alloys and sealing techniques ideal for harsh environments.

Whether our customers are involved in aerospace, military, industrial, or any other sector requiring high-performance interconnects, Cinch is committed to enabling seamless connectivity in the most demanding conditions, ensuring their systems remain operational and reliable, no matter where they are deployed.

Chapter 1

WATER AND ELECTRICITY

In the context of harsh environments, one of the greatest areas of concern is water and moisture. Moisture is damaging to electronics. Pure water is not corrosive; however, in most applications, water contains chemicals or particles. Tap water often contains disinfectants to prevent bacterial growth, making the water fit to drink, while rainwater often carries dust and chemicals produced by both natural and human-made processes. These contaminants create electrically conductive water, which allows unwanted electricity to flow between components. These short circuits can result in overloaded circuits or even pose safety risks to users.

Moisture can threaten electronics even in the absence of standing water. In most climates, moisture is present in the air, and this humidity will affect electrical performance. Some insulation materials, such as those used in cables and connectors, absorb moisture from humid environments. This absorption can cause reduced electrical resistance, creating paths through which an unwanted electrical current can pass.

Moreover, humidity reduces the electrical resistance of the air itself. Some designs rely on an air gap to provide separation between high-voltage lines. High humidity requires that users reduce electrical loads to provide a sufficient margin of safety.

> ***Humid environments lead to corrosion and insulation breakdown, requiring robust sealing and protection for electrical components. In urban areas, these components also face high pollution levels, extreme temperatures, and vibrations from heavy traffic and construction, which can cause mechanical failures.”***

Nida Qamar

Electrical Engineer, Powertech

> ***Different environments can present mechanical, environmental, thermal, or electrical factors that may compromise a component's functionality, lifespan, or safety. This risk is particularly significant for off-the-shelf components not specifically designed to withstand such conditions."***

Filipe Romero

Electrical Engineer, ASML

Protection against the ingress of water is therefore a priority. When creating a device required to work in tough conditions, designers must not only understand the ways in which the device may be affected but also how water may find its way in. A significant difference exists between a device that will be fixed to the exterior of a building, exposed to wind and rain, and a device that will be used inside a factory. While indoor environments may be protected from everyday exposure to the elements, other mechanisms, such as high-pressure cleaning sprays, need to be considered. The requirements for a device that will be immersed in water are entirely different.

The ingress protection (IP) rating system is intended to help designers choose the correct level of protection. Ratings use a two-digit code that denotes the level of protection. The first digit describes the size of a solid against which protection is provided. The highest rating is 6, which indicates protection against dust and other small particulates for a sustained period. The second digit describes the extent of sealing against water ingress.

One of the most frequently used ratings for connectors and other components is IP67, which protects against everyday dust and grime and limited immersion in water. IP67-rated components are suitable for installation in outdoor applications that will experience wind and rain—for example, a closed-circuit television (CCTV) camera mounted to a building's exterior.

Products that need higher performance or require specific conditions will typically use the IP68 rating, which provides protection against long-term immersion. Equipment destined for tough agricultural or military applications are prime examples of this type of product.

A specific consideration in the interconnection market is that connectors are usually used in mating pairs. A sealed or IP-rated connector is frequently sealed against harsh environments only when mated. If left unmated—for example, during installation or maintenance—the connector may not be protected.

Connectors designed for service in harsh environments must be sealed against water, dirt, and dust; providing this protection requires careful consideration of design features. The most important area of sealing is between the face of the male and female connector, which is achieved through the use of a doughnut-shaped O-ring. Locking the mating halves of the connector in place provides the force required to compress the O-ring between the male and female connectors, creating a watertight seal. Preventing water ingress around the cable entry is also necessary. Because most cables are circular in cross-section, a simple rubber gland or gasket can be used.

Robustness encompasses not only the durability of a connector and its ability to endure multiple cycles but also its adaptability to specific applications. Designers must consider the available options and select connectors appropriate for the application requirements and the expected service life.”

Carlos González Avelino

Product Development Test Engineer, Philips Micro Devices

A sealed connector can mean the difference between safe operation and a disaster. Imagine an individual at a washing station who hears their name and turns while spraying a substance. This mistake could result in significant damage to expensive equipment. Therefore, it is essential to seal all types of electronic functions, both indoors and outdoors.”

Tim Kurten

Product Manager, Stewart Connector, Bel Fuse, Inc.

IP67 USB Type-A Cable Assemblies

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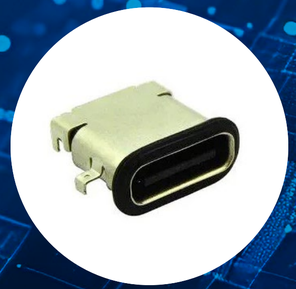

USB 3.1 IP67 Type-C Connectors

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Key Points

- **Water and moisture pose a major threat to the long-term reliability of electronics.**
- **The IP rating system is vital during a product's design stage.**
- **Many connectors are often unsealed when unmated; a sealed option is best if connectors are to be left unplugged.**

Chapter 2

CHEMICALS AND CORROSION

While designers are frequently concerned about water and its effects on electrical systems, other processes are at work. One such process is corrosion, in which water plays a crucial role. Iron oxide, otherwise known as rust, is formed in the presence of water and oxygen. Connectors use iron or steel, but oxidation is not limited to ferrous materials.

In some metals, oxidation forms a hard layer on the surface, which prevents further damage. Stainless steel behaves in this way; connectors intended for exposed conditions are often constructed of stainless steel.

Other metals are also subject to corrosion. Aluminum and its alloys are frequently used to construct connector shells. The combined strength, light weight, and electrical conductivity of aluminum makes it a popular choice for the aerospace industry. Aluminum bonds readily with oxygen, forming a layer of aluminum oxide, which protects the body of the connector underneath. However, aluminum oxide is vulnerable to corrosive chemicals.

Rainwater, with its everyday contaminants, is slightly acidic, with a pH value of around 5.5. This acidity level is not enough to damage the aluminum oxide layer, but acid rain, which is contaminated with other chemicals, will damage the surface layer. Similarly, seawater, which has a pH value of 8 (slightly alkaline), will cause an aluminum surface to rapidly

“The wind industry is a great example of a harsh environment where components must operate in challenging conditions, like offshore locations with corrosive conditions, cold climates with freezing temperatures, and desert regions with fine dust and extreme temperature fluctuations.”

Naresh Radaliyagoda

Test Engineer, Vestas

Harsh environments are characterized by extreme temperatures, high humidity, corrosive chemicals, fine dust, elevated radiation levels, and electromagnetic interference. These conditions can result in thermal degradation, corrosion, short circuits, and diminished reliability, making them challenging and potentially hazardous for electronic components."

Abdulrahman Alqadami

Assistant Professor,
King Fahd University of Petroleum & Minerals

deteriorate. This deterioration exposes the fresh aluminum underneath allowing further corrosion to occur.

Metals can be protected against corrosion with a protective layer such as powder or paint coatings or surface treatments like anodizing or electroplating. However, housings must be conductive to shield the electrical signals passing through the connector, thereby limiting the use of nonconductive surface treatments.

Another hazard is associated with conductive metals: When two different conductive metals make contact in the presence of moisture, galvanic action occurs. This effect is particularly damaging to aluminum connectors that come into contact with steel. Connectors are designed to be used as a mated pair, so the use of incompatible metals is uncommon. However, care must be taken when these components are fixed to a panel or enclosure to ensure that materials are compatible.

Operating temperature has a direct impact on component selection. Some common materials become brittle at low temperatures or can melt at high temperatures. Plastics and polymers are affected more than metal, but they play an important role in connector design. Insulators and dielectric components are usually made of plastic such as PTFE, and O-ring seals of rubber. Therefore, choosing the right material for your application is key. In addition to the conventional effects of temperature, many hazards associated with corrosion or chemical compatibility can be accelerated by extreme temperatures.

Not only do harsh environments damage critical components, but they also risk the safety of operators and users. Measures must be taken from the beginning of the design process to ensure safety standards are met.”

Carlos González Avelino

Product Development Test Engineer, Philips Micro Devices

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Key Points

- A complete understanding of the operational environment informs component selection.
- Choosing the right materials is vital for reliable performance.
- Components should be considered within the context of how they interact with the rest of the device design.

Chapter 3

UNSEEN HAZARDS – SHOCK, VIBRATION, AND ELECTROMAGNETISM

Hazards include those that are not visible but have a measurable impact on the reliability of any device. Unlike the expected presence of chemicals or moisture in some applications, these hazards cannot be truly quantified until a piece of equipment is in use. Therefore, they demand that the designer plans carefully to fully mitigate their dangers.

Shock and Vibration

Many devices must withstand constant shock and vibration during their operational lifespan. While this requirement may be expected in automotive and aerospace applications, vibration is also common in industrial machinery devices. Shock and vibration are hazards with both immediate and long-term effects.

Short-term consequences include accidental disconnection of equipment. Long-term damage is harder to identify. Vibration causes individual components to rub together, causing significant damage over time, including wearing down of protective or conductive coatings and physical damage to components such as electrical contacts. In turn, issues ranging

> ***One of the conditions we design for is extreme temperatures, which can lead to thermal stress, vibration, and shock. These factors can loosen connections and result in fatigue failure of critical components.”***

Rahul SreeKumar

Senior Engineer, Nordex Group

We follow simple and reliable strategies to mitigate the dangers of harsh environments: utilize high-quality sealing materials and coatings for dust and chemical protection, select materials that resist corrosion and radiation, and design robust enclosures to minimize mechanical stress.”

Nida Qamar

Electrical Engineer, Powertech

from intermittent circuits to the failure of safety-critical systems can occur.

The short-term effects of shock can be countered by choosing a connector with a robust locking system. Many connectors employ a screw-locking system, but under certain conditions sustained vibration at specific frequencies can shake screw threads loose.

Bayonet-locking devices such as those found on radio-frequency (RF) connectors offer resistance to shock, as they cannot be undone by sustained vibration. The latch design fitted to the popular RJ45-style connector is another ideal solution for applications that experience shock.

The long-term effects of vibration can be reduced by choosing specific materials. Connectors with stainless steel shells of housing are designed for high-reliability applications. The material of the electrical contacts also provides key benefits for reliability. Many connectors use brass as the base material for contact design, but sustained exposure to vibration can cause damage. Alternative materials such as beryllium copper offer superior strength and resistance to wear, resulting in a connector with a longer operational lifespan.

Electromagnetic Interference

The modern world is filled with electromagnetic energy, sometimes known as RF radiation. Some RF transmissions are created intentionally, as wireless communications rely on RF to carry data, while others are unintended. The link between electrical current and RF radiation means that almost any electrical equipment can be the source of radiation and therefore has the potential to interfere with the correct operation of other devices.

This interference is known as electromagnetic, or RF, interference (EMI or RFI). Connectors and cables are especially vulnerable to EMI, as their length can act as antennae that capture unwanted signals. Electrical and electronic devices can be protected by providing them with shielding, an electrically conductive covering that encloses equipment, preventing EMI from getting in or out.

Magnetic Environments

Although related to EMI, magnetic fields affect several other applications. For example, magnetic resonance imaging (MRI) employs a strong magnetic field to create accurate 3D images of patients. Designers of MRI machines must select components with a low magnetic signature to prevent them from being affected by, or interfering with, the magnetic field.

Another example is geomagnetism, or the measuring of tiny fluctuations in the Earth's magnetic field to advance scientific knowledge. In this instance, a component with a high magnetic signature can interfere with sensitive instrumentation and create inaccurate results.

Even the most up-to-date technology is susceptible to magnetic interference. The latest quantum computing systems use magnets as part of their operation, and the use of nonferrous materials in their construction is advantageous.

The use of magnetic metals is therefore to be avoided. Connectors frequently employ steel and nickel in their construction, so alternative materials offer the best solution for these applications. While creating a truly nonmagnetic connector is difficult, the right material choices can significantly reduce its impact on the environment around it.

> ***"Harsh environments subject electronic components to conditions and forces that push them beyond their normal operating limits. Robust designs, redundant systems, and regular maintenance help mitigate risk with our components."***

Naresh Radaliyagoda

Test Engineer, Vestas

“Damage to equipment in harsh environments varies depending on the component and the conditions. For electrical functions, proper grounding and EMC design are key strategies to mitigate electromagnetic contamination, while mechanical robustness and corrosion resistance are crucial for dynamic or corrosive environments.”

Filipe Romero

Electrical Engineer, ASML

Non-Magnetic RF Connectors

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Key Points

- Shock and vibration cause both short- and long-term problems.
- EMI is everywhere and must be accounted for in the design process.
- Nonmagnetic components are available for applications in which ferrous materials are unfavorable.

Chapter 4

IDENTIFYING POTENTIAL HAZARDS – HARSH ENVIRONMENTS IN UNUSUAL PLACES

Designing equipment capable of withstanding harsh environments requires designers to understand the conditions that exist in these applications. The rise of connected technologies and their adoption by a wide array of industries means that sophisticated equipment may need to survive in a highly interconnected ecosystem. Despite the growth of wireless communications, physical connectivity is important. Power transmission still requires the use of copper cables, and physical networks provide reliability and security on which many users depend. Therefore, connectors will continue to face tough conditions.

Some hazards are simple to identify. For example, the agricultural industry employs a range of technology on the smart farm. Embedded vision systems, communication devices, and heavy machinery come together using the IoT to increase yield and reduce the resources needed to grow and harvest crops.

> ***Harsh environments are not limited to industrial settings—they can be found in military applications, space, or polar regions. Each location presents unique challenges, including exposure to extreme temperatures, pressure, corrosion, or shock. Each specially designed connector can deliver reliability under these conditions.”***

Abdulrahman Alqadami

Assistant Professor,
King Fahd University of Petroleum & Minerals

While non-magnetic connectors are frequently used in the medical industry, two other key areas of focus for us are space exploration and quantum computing.”

Ketan Thakkar

Sr. Product Manager,
RF Connectors & Cable Assemblies,
Cinch Connectivity Solutions

The challenges of working on the farm are readily apparent, but not all applications have obvious challenges. Though a highly managed environment, the factory floor is still subject to vibration, noise, and chemicals. Even the cleanest of manufacturing facilities—such as those associated with food or pharmaceuticals—are home to unseen hazards. Production lines and equipment must be cleaned, and water is frequently combined with other chemicals to achieve the cleanliness demanded by these industries. These chemicals can adversely affect components.

The transportation sector depends on reliability: Trains and vehicles must deliver high serviceability to ensure the best return on investment. The transportation environment represents one of the greatest challenges for designers. Trains and vehicles must be ready to perform in various climatic conditions, from the frozen landscape of the Arctic to the heat and humidity of the tropics. In addition, these systems are subjected to constant vibration during their service life, placing great demands on the reliability of components.

Harsh environments also exist away from the factory floor or transportation sector. A unique example is in the hospital operating theatre. From cleaning chemicals to steam sterilization, the high standards required for the treatment of patients can make equipment vulnerable to damage if not handled correctly.

Beyond the Atmosphere

An especially demanding example of a harsh environment is that of spaceflight. Vacuum conditions combined with exposure to extreme temperatures and long-term radiation make designing equipment for use in space a unique challenge. Without the protection of our atmosphere, any object in space receives the full force of solar radiation. Without the benefit of an insulating atmosphere, temperatures vary between dangerously high in sunlight to extreme cold in shadow. The lack of atmospheric pressure also causes materials to exhibit unusual behaviors. A process called outgassing releases gas that has become trapped inside another material during production, and plastics are especially at risk. The released gas can condense on cold surfaces, such as those of optical instruments and sensors, degrading their effectiveness while being out of reach of repair.

In the Home

A surprising example of a hazardous environment can be found within the home. The kitchen is an unforgiving location filled with extremes. Kitchens are fitted with ovens that generate temperatures capable of melting plastic or causing physical harm. Kettles and stoves boil water, creating a warm, high-humidity environment that can affect electrical circuits.

The average family kitchen commonly contains a range of acids and alkalis in the form of different ingredients. Vinegar and lemon juice have pH levels of between 2 and 3, while baking soda

“Connectors on spacecraft like NASA’s Mars rovers must endure extreme temperatures and radiation. These connectors are often made with radiation-resistant materials and lightweight, durable composites to ensure reliability over long missions. This highlights the importance of designing connectors that can withstand extreme conditions.”

Harsh Chandra

Technical Delivery Manager, Vodafone

> ***Unusual environments like food processing plants and mining operations present significant challenges for connectors, such as exposure to high temperatures, vibration, and shock. In electromagnetic environments, proper shielding is also required.”***

Rahul SreeKumar

Senior Engineer, Nordex Group

dissolved in water has a pH level between 8 and 9. Also found in the kitchen are abrasive cleaning chemicals, hot water, and steam.

These conditions can quickly destroy sensitive electronics. Yet the rise of connected technology means that such devices are common, and consumers expect them to work regardless of the conditions. Designers need to understand both the environment and user expectations to choose the right components for devices from televisions and smart speakers to autonomous appliances.

Therefore, the key task for any designer is to understand the conditions in which their device must function and identify the potential dangers. While the hazards present on the battlefield or in the factory are obvious, those found elsewhere are harder to spot but no less vital to component choice.

SealJack™ Harsh Environment RJ45 Jacks

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Automotive Grade RJ45 Connectors

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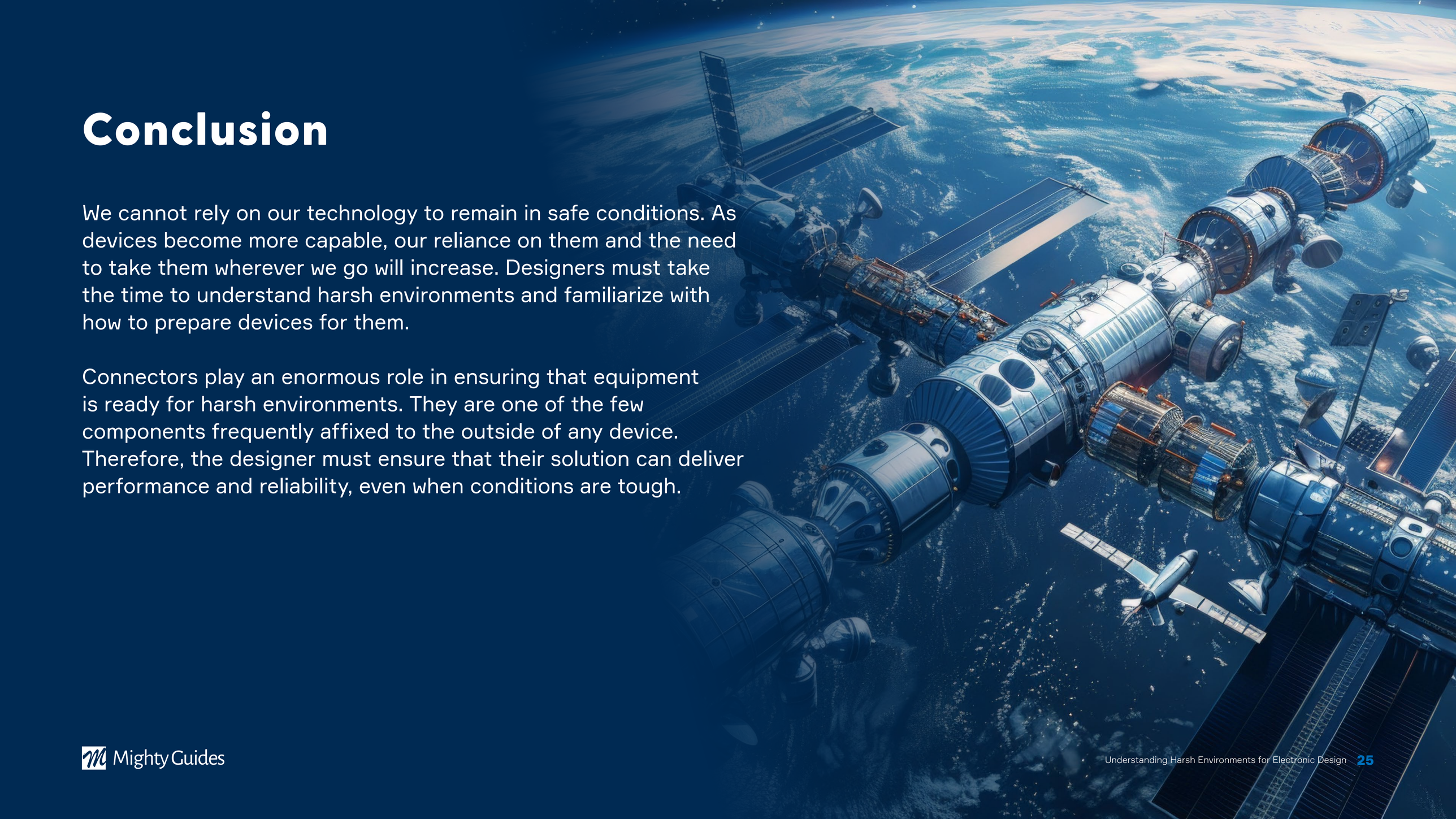
Key Points

- **Harsh environments can occur anywhere.**
- **Some hazards are not visible or measurable until the equipment is deployed.**

Conclusion

We cannot rely on our technology to remain in safe conditions. As devices become more capable, our reliance on them and the need to take them wherever we go will increase. Designers must take the time to understand harsh environments and familiarize with how to prepare devices for them.

Connectors play an enormous role in ensuring that equipment is ready for harsh environments. They are one of the few components frequently affixed to the outside of any device. Therefore, the designer must ensure that their solution can deliver performance and reliability, even when conditions are tough.



Learn More About Our Experts

Abdulrahman Alqadami

Assistant Professor,
King Fahd University of Petroleum & Minerals

Abdulrahman Alqadami is an assistant professor at King Fahd University of Petroleum & Minerals. Abdulrahman has a deep understanding of RF and communication systems across various applications. He previously worked as an RF communications system engineer at Boeing and as a senior RF design engineer at L3Harris Technologies. He earned his PhD in Electrical and Electronics Engineering from the University of Queensland.

Harsh Chandra

Technical Delivery Manager,
Vodafone

Harsh Chandra is a seasoned professional with over 15 years of experience in the software industry. He specializes in technical delivery and agile transformation. Harsh has held senior engineer roles at prominent companies such as Tech Mahindra and Samsung. He holds a degree in Technology, Electrical, Electronics, and Communications Engineering.

Carlos González Avelino

Product Development Test Engineer,
Philips Micro Devices

Carlos González Avelino is a seasoned hardware engineer with a passion for medical devices. He has a proven track record of leading hardware teams and delivering innovative solutions. With a strong foundation in electrical and biomedical engineering, Carlos excels in agile development, regulatory compliance, and mentoring. His experience spans diverse roles, from hardware design to verification and production support.

Learn More About Our Experts

Tim Kurten

Product Manager,
Stewart Connector,
Bel Fuse, Inc.

With over 25 years of experience in RF and fiber optic technologies, Tim currently serves as a product manager of Stewart Connectors at Bel Fuse, Inc. Over his career, he has held key roles in applications and field engineering, technical support, sales management, business development, and product management. Tim holds a B.S. in Electrical Engineering and an A.S. in Business from Penn State University.

Nida Qamar

Electrical Engineer,
Powertech

Nida Qamar is an accomplished electrical controls engineer with expertise in signal processing and digitization. She has extensive experience working with switchgear, transformers, and switchrooms and has successfully managed large-scale projects, consistently delivering cost-effective solutions. Nida holds a master's degree in Controls Engineering and is recognized for her technical proficiency and leadership in complex engineering environments.

Naresh Radaliyagoda

Test Engineer,
Vestas

Naresh is a test engineer at a leading wind turbine company specializing in the reliability testing of turbine components and materials. With expertise in advanced testing methods and failure analysis, he focuses on identifying the root causes of failures and enhancing the performance of critical components. Naresh holds a bachelor's degree in Mechanical Engineering and a PhD in Materials Engineering from Coventry University in the UK.

Learn More About Our Experts

Filipe Romero

Electrical Engineer,
ASML

Filipe Romero is an electrical test engineer, originally from Portugal. He has a proven track record in power electronics research and development, wind turbine technology, and systems engineering, having previously held roles at Vestas, ASML, and others. Filipe holds a bachelor's and a master's degree in Electrical and Computer Engineering from the University of Coimbra.

Rahul SreeKumar

Senior Engineer,
Nordex Group

Rahul is a skilled design engineer with a focus on wind energy. His expertise is designing and integrating steel tower internal components, utilizing software like AutoCAD and NX. With a strong foundation in design and manufacturing processes, Rahul is passionate about driving innovation and efficiency in the industry.

Ketan Thakkar

Sr. Product Manager,
RF Connectors & Cable Assemblies,
Cinch Connectivity Solutions

With over two decades of experience in the electronics industry, Ketan has honed his skills in a variety of roles. He started as a hardware design engineer in the communications and consumer electronics industry, then moved on to sales and field applications engineering in the electronics and semiconductor industry. Today, as a product manager, Ketan combines his deep technical knowledge and business acumen to drive innovation and growth in the electronics/interconnect industry.