WHITE PAPER

Selecting the Right Interconnect Solution for Harsh Environments

molex

In commercial vehicles, off-road machinery, outdoor instrumentation and other rugged applications, connectors face extremes of temperature, vibration, moisture, dust, chemicals and electromagnetic interference (EMI). Electrical connectors are often taken for granted and relegated to being the last component selected by design engineers. And although some connectors can be small in physical size, the role they play in ensuring smooth and continuous operation can be critical, whether signal, power or data.

A poorly chosen connector can lead to intermittent faults, downtime, safety hazards or even total system failure. A defective connection or a faulty ground on a children's toy car may cause intermittent starting and stopping, which can quickly lead to frustration. However, it is not mission critical. Regardless of the end application, the design engineer must ask similar questions when evaluating their requirements to establish which interconnect solution best meets their needs—while balancing performance and cost. When connectors are underspecified for harsh environments, common failures include seal breach and corrosion, contact fretting, insulator cracking, terminal back-out, overheating and electromagnetic-induced failures.

Whether an application is a one-time plug-and-play in a clean, dry environment or exposed to challenging conditions such as fluids, dust, chemicals, temperature changes and high vibration—like those found in an automotive engine bay, a control unit on construction equipment or motorcycle, or a home appliance such as a washing machine—Molex offers a wide range of solutions designed to perform reliably in these demanding environments.
Molex offers an industry-proven range of rugged and reliable connectors, primarily used in automotive applications, providing design engineers with cost-effective solutions tailored to their needs. This article outlines the critical factors to consider when selecting electrical connectors for harsh environments. It highlights a selection of innovative rugged and reliable solutions from Molex that can be used to solve many application challenges.

CONFIGURATION: MATCH THE FORM FACTOR, PIN COUNT, TERMINATION AND MOUNTING TO THE APPLICATION

One of the first things to identify when selecting a connector is the configuration required by the application. A wire-to-wire connector is used when two sets of discrete wires are connected to each other and can be either free hanging or panel mounted.

A wire-to-board or wire-to-device connector is needed if connecting a discrete cable harness/wire to a printed circuit board (PCB) or a device that has an integral connector interface, such as an LED driver, PCB or a solenoid or control unit. The method of termination between the header and PCB should also be considered. Through-hole solder, surface mount technology (SMT) and press fit are all common methods, each with its own pros and cons.

Connector termination availability and manufacturing processes will impact the decision. If attaching to a double-sided or multilayered PCB, an SMT header will consume the least amount of space on the PCB. Through-hole solder requires a consistent footprint across all PCB layers, while press-fit termination also demands additional free area on the PCB to allow the assembly press and associated fixtures to support the PCB during assembly.

The next consideration is pin count and layout. How many signal, power data or ground lines are needed? Where are the connections coming from and going to? For a wire-to-board or device connector, whether the connector is to be a right-angled or vertical header should be identified, depending on the application and desired cable harness path. Is there design control over the components or are third-party products being integrated? For example, in a home appliance, a six-wire optical encoder and a two-wire door switch may need to connect to the control unit. If other parameters align, it may be possible to select a single eight-circuit connector. This approach could reduce cost, space required on the PCB and assembly time, but it may complicate service operations. Conversely, if the devices are supplied with the connectors already assembled, this would likely drive the design to two individual connectors on the PCB.

Many connectors also offer mechanical/color-coded keying, which can be useful when multiple connectors of the same family and circuit size are to be used. This not only speed up assembly but also ensures that connector pairs are properly mated.

VOLTAGE AND CURRENT RATINGS: ENSURE CONDUCTORS AND CONTACTS HANDLE SYSTEM LOADS SAFELY

Specifying the maximum system voltage and steady state or peak current will help further identify a connector solution. Incorrectly rated connectors can lead to irreversible damage. Overvoltage can cause clearance and creepage distances to break down, resulting in unwanted short circuits, while overcurrent can lead to overheated contacts that increase contact resistance, melt insulators or even weld contacts together.

Many connectors offer multiple terminal options to accommodate different wire gauges or size of wire and plating options. Some of the most common plating options are tin, silver and gold. Each material offers different electrical and mechanical properties such as conductivity, solderability, corrosion resistance and wear resistance, and is associated with a distinct cost. For example, tin is a cost-effective plating option ideal for applications requiring solder adhesion, where signal levels are moderate and mating cycles are limited, such as with ring terminals. For low-level-signal or high-mating-cycle applications, gold would be a more suitable plating option due to its conductivity and hardness properties. Application examples include low-current switches or sensors found widely in industrial, automotive or commercial vehicle applications.

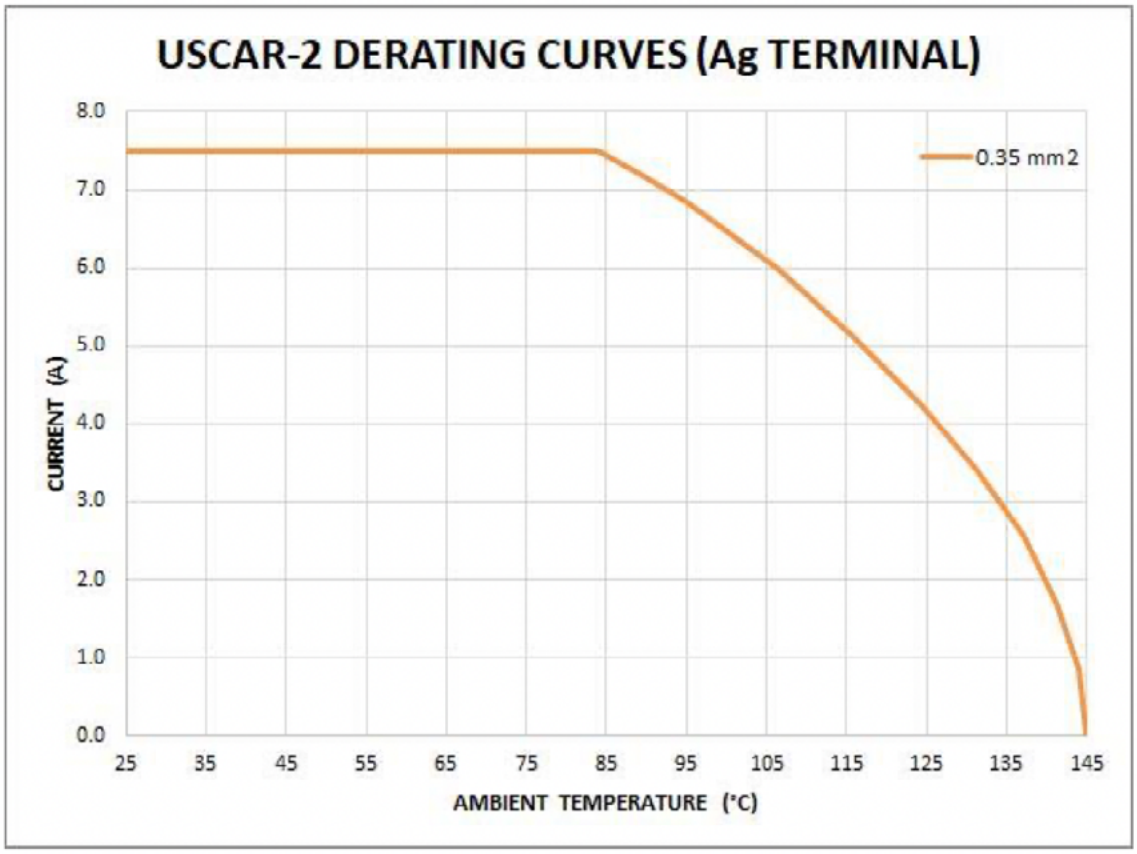
Engineers need to select both sides of the interconnect carefully to ensure similar materials are chosen in the contact area, avoiding unwanted property changes due to galvanic corrosion, which can lead to system failures.

It is equally important to ensure the correct wire gauge and terminal are selected. An underspecified wire gauge may result in harness melt, and an incorrectly specified terminal may lead to increased resistance or intermittency. When specifying the correct wire gauge, the specific product specifications and terminal derating curve should be consulted. An example of the CTX50 terminal used with the Molex Mini50 mat sealed receptacle is shown, right. ([1])

The table below details the current rating for the same terminal design but with different plating options. Tin (Sn) plating has a current rating of 5.0A, while silver (Ag) plating has a current rating of 7.5A, both with a 0.35mm^2 gauge wire.

Product Name	Plating	Wire Size (mm)	Current Rating (A)
CTX50 Sealed	Sn	0.35	5.0
	Ag	0.35	7.5

Terminal current derating curves are used to determine the maximum test current at which a terminal system can operate in a room temperature environment before excessive thermal degradation and/or resistance begins to occur. A curve is plotted for each applicable conductor size. In the example below, temperature rise (X axis) versus current (Y axis) is plotted for the CTX50 terminal with a 0.35mm conductor.



IMPORTANT: This test is performed on terminals alone, and this graph should NOT to be used for actual terminal application in vehicles or other environments. This will eliminate discrepancies that may be introduced by variations in heat dissipation caused by different connector housing designs and sizes. This test cannot establish the maximum current capability of a specific terminal application. For specific applications, several factors other than current load must be considered.

IP RATING: CERTIFY PROTECTION AGAINST WATER, DUST AND CHEMICAL INGRESS

The ingress protection (IP) rating defines the level of protection that an electrical or mechanical enclosure (e.g., an electronic control unit, a garden light power supply or an electrical connector system when fully mated) has been validated to protect against any ingress from liquids and solids. In a bathroom, the IP ratings of electrical fittings such as lights and fans are specified by zones. Understanding the environment and selecting an appropriate IP rating will help avoid failures due to the ingress of moisture or liquids, potentially causing short circuits, corrosion or insulation breakdown. The ingress of dust particles may lead to an increase in resistance.

The IP rating consists of two digits. The first digit indicates protection against solids, ranging from zero (no protection) to six (dust tight). The second digit indicates protection against liquids, ranging from zero (no protection) to nine (protection against high-pressure, high-temperature water jets). Rugged and reliable applications typically focus on the highest liquid protection ratings:

- 7 = Protected against the effects of temporary immersion in water
- 8 = Protected against the effects of continuous immersion in water
- 9 = Protected against high-pressure and high-temperature water jets

An outdoor TV may have a minimum rating of IP55, whereas an autonomous lawn mower may have a minimum IP67 or IP69 rating.

TEMPERATURE RANGE: PREVENT PLASTIC EMBRITTLEMENT OR CONTACT FAILURE AT EXTREMES

Connectors should be rated for the application's lowest and highest ambient temperatures, plus any transient peaks such as underhood engine heat spikes or thermal rise in an industrial control box once fans have shut down. The consequences of connectors operating below their minimum rating include cracking of the plastic insulators, which can result in short circuits or ingress if the housing cracks. Operated above the maximum rating, the contacts may soften or the plating may degrade, causing intermittent connections or short circuits.

Many unsealed connector systems designed for applications such as in-vehicle infotainment systems may have lower temperature ratings than sealed connector systems found in the engine compartment.

The table below shows typical temperature ranges for products validated in automotive applications, along with examples of both automotive and nonautomotive applications. The Molex **stAK50h unsealed connection system** is an example of a hybrid, modular wire-to-board system specified to operate from -40 to +85°C.

Temperature Range	Transportation Example	Application Example(s)	Molex Example(s)
-40°C to +85°C	Passenger compartment (not recommended for new applications)	Industrial or building automation	stAK50h Connector System
-40°C to +105°C	Passenger compartment	Food processing, electronic enclosures, consumer	HSAutoLink II Interconnect System[3] DuraClik standard receptacle[4]
-40°C to +125°C	Engine compartment	Commercial vehicle, agricultural, construction, ATV, industrial	MX150 sealed connectors and receptacles, sealed headers, panel-mount connectors, pass-through connectors[5] DuraClik TPA receptacle[4] DuraClik ISL receptacle[4]
-40°C to +150°C	On engine	Commercial vehicle, agricultural, construction, ATV, industrial	MX150 Sealed Connectors and receptacles (Ag)[5]

VIBRATION AND SHOCK: AVOID TERMINAL BACK-OUT, UNINTENDED CONNECTOR UN-MATING AND MECHANICAL WEAR

Many harsh environments expose connectors to continuous vibration or shock, introducing mechanical stresses that can significantly affect their performance and longevity. Consequences of underspecified connectors can include unintended disconnects, terminal back-out from the connector housing, mechanical failure of the housing or fretting of the terminal, among others.

Terminal position assurance (TPA) is a design feature used to ensure that terminals are correctly and fully located in and locked into the connector housing. This feature helps prevent failures due to vibration that might cause the terminal to loosen or back out.

Connectors often have a primary mechanical feature to secure the terminal in the housing. For example, a tang on the terminal may locate against a feature in the housing, or a feature in the housing may secure a tang-less terminal into position.

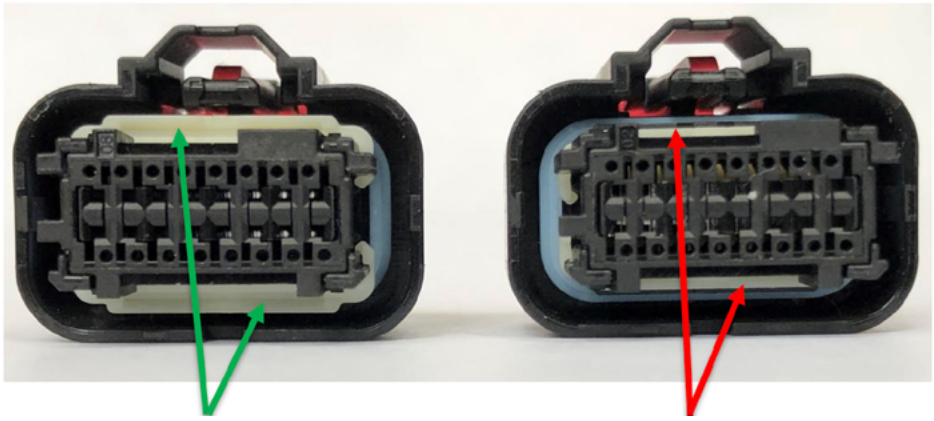
An independent secondary lock (ISL) is another terminal retention feature used to securely lock the terminals in the connector housing. As suggested by its name, this feature is independent from the primary locking feature. The Molex **DuraClik 2.00mm Wire-to-Board Connection System** integrates features that enhance connection security and deliver exceptional stability and performance in high-temperature applications requiring smaller connectors, such as automotive LED lighting or major appliances.

The table below details the performance improvement of the different features when they are applied to the DuraClik receptacles.

Receptacle	Retention Force
Standard	9.8N
TPA	20N
ISL	50N

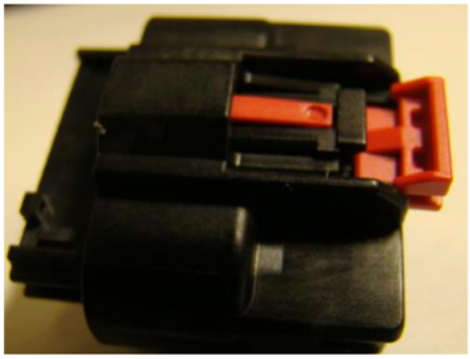
TPAs and ISLs often work alongside other design features, such as connector position assurance (CPA), which ensures two connector mating halves are properly engaged and fully mated. The CPA is often a brightly colored plastic clip or latch that slides into place only upon correct and full engagement of the connector halves. The CPA provides a mechanical block to the primary connector latch or locking feature, preventing accidental disconnection and providing a visual confirmation to the operator or quality inspector that the connection is full and secure. The CPA is often optional, and if one is selected, the connectors are shipped with the CPA in the pre-lock position.

Molex **Mini50 connectors** are available as unsealed wire-to-board or sealed wire-to-device connectors. By utilizing the CTX50 terminal, Mini50 connectors offer significant space savings over USCAR 0.64mm connector systems ([6]) and exemplify a product family designed with these features. ([7])

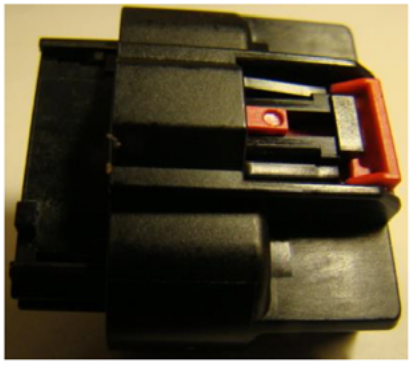


ISL (2x) in “as shipped” open pre-lock position

ISL (2x) in closed locked position



CPA in “as shipped” open pre-lock position



CPA in closed locked position

SHIELDING AND GROUNDING: MAINTAIN SIGNAL INTEGRITY IN NOISY ENVIRONMENTS

As automation and safety increase in many market applications, the number of sensors, cameras, displays, control units and the volume of data requiring processing continue to grow. Electronic devices generate electrical noise that can be transmitted to other devices, and likewise, those devices can be susceptible to EMI. As everyone and everything becomes more connected and devices consume more power, there are more risks of EMI from motors, high-power cables or radio equipment, and signal integrity becomes more important. If not correctly specified, unshielded or poorly grounded connectors can allow noise coupling to corrupt the critical signals being transferred via data lines, leading to data dropouts, bit errors in high-speed data lines or unintended actuation or deactivation of control circuits.

The versatile **HSAutoLink II Interconnect System** from Molex provides exceptional long-term reliability by utilizing the proven low-force helix (LFH) terminal interface within a fully protected shield case to ensure good signal integrity and dependable performance.

Another example is the Molex **High-Speed FAKRA-Mini (HFM) system**, which enables high-speed communication with high-resolution cameras, telematics and infotainment devices. HFM achieves this by utilizing fully shielded coaxial cable connections.

Trends and Solutions

As mentioned above, many industries face similar challenges, including:

- Increased processing speeds, data rates, number of inputs/outputs and power requirements
- Reduced total cost (BOM + cost of assembly)

However, many applications do not change in size or get smaller, leaving the design engineer with the challenge of how to integrate the increased electronics and associated interconnects without increasing the size, weight or cost. Molex is at the forefront of ruggedized miniaturization technology, with a complete suite of off-the-shelf interconnect solutions and custom capabilities as shown below. ([10])

	Connector	Configuration	Row	Orientation	Operating Temp	Sealed	Circuit Count	Pitch	Max Current	Vibration Resistance
	DuraClik	Wire-to-board	Single, right angle, vertical	Right angle, vertical	-40 to +125°C	No	2 to 15	2.00mm	Up to 3.0A	High
	Mizu	Wire-to-wire	Single	n/a	-40 to +155°C	IP67, IP69k	2 to 6	2.50 to 5.00mm	Up to 7.0A	High
	HFM	Wire-to-board, Wire-to-wire	Single, dual, quad	Right angle, vertical	-40 to +105°C	IP68	Up to 4	4.00mm	1.5A	High
0.50mm Terminals										
	Mini50	Wire-to-board, Wire-to-wire	Single, dual	Right angle, vertical	-40 to +125°C	IP68, IP69k (with backshell)	2 to 114	2.00mm	Up to 4.0A	High
	stAK50h	Wire-to-board	Multiple	Right angle, vertical	-40 to +105°C	No	Up to 56	2.00 to 5.20mm	Up to 30.0A	High
	ConnTAK50	Wire-to-board	Single, dual	Right angle, vertical	-40 to +105°C	No	2 to 22	1.80mm	Up to 4.0A	High
0.64mm Terminals										
	Stac64	Wire-to-board	Dual	Right angle, vertical	-40 to +105°C	No	8 to 80	2.54 to 5.25mm	Up to 36.0A	High
	MX64	Wire-to-board	Single	Vertical	-40 to +125°C	IP67	Up to 8	2.54mm	Up to 10.0A	High
1.20mm Terminals										
	MXP120	Wire-to-device	Single	Straight	-40 to +125°C	IP69k	Up to 6	4.00mm	Up to 13.0A	Extreme

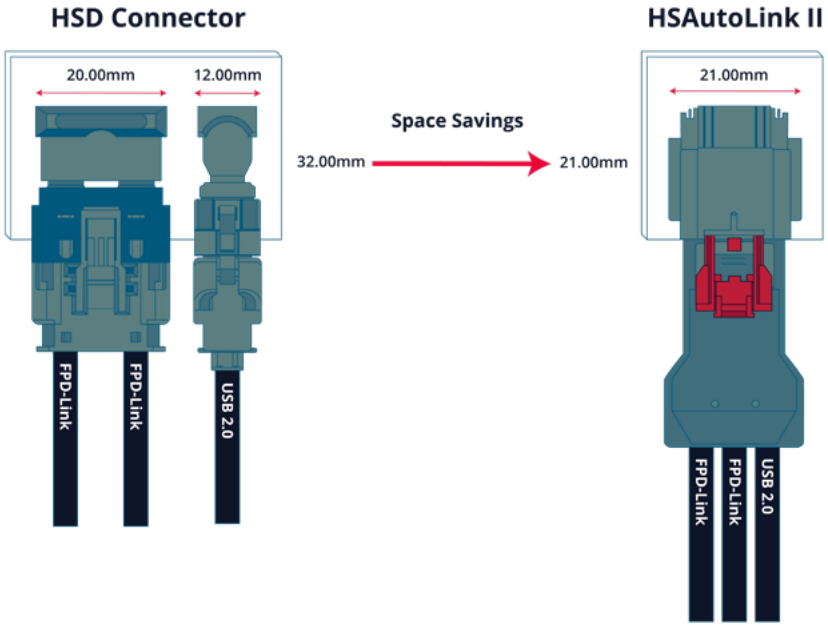
The **Molex MX150 sealed connector system** uses a 1.50mm terminal system with an integrated mat seal and TPA and CPA options. These connectors are rated to IP67 and IP69 to help eliminate individual cable seals and reduce assembly time, making it ideal for applications exposed to high-temperature extremes, vibration, dust and moisture. Such applications range from automotive, agricultural and construction vehicles to marine and solar storage systems. Capable of carrying currents up to 22.0A, the MX150 family offers two to 20 circuits in wire-to-wire, wire-to-board and panel-mount pass-through headers. ([5])

The latest additions include **MX150 mid-voltage connectors** capable of up to 60V to support 48V architectures and applications in automotive, commercial vehicle and beyond. Hybrid options are also available for mixed signal and power scenarios. Another recent addition are the MX150 pass-through sealed connectors designed specifically for oil-cooled motor applications. The design uses potting on the terminal interface to ensure the oil stays where it is supposed to: inside the motor. ([11])

HSAutoLink II is available in six, 12 or 14 circuits, with the same shielded cores contained in high-temperature plastic housings to provide the same electrical performance in both sealed and unsealed options. The sealed connectors and headers feature fully protected IP67-rated perimeter seals, with IP69K-rated sealing available in customized designs. With the ability to have single, dual or triple cable exits, HSAutoLink II allows design engineers the ability to support multiple protocols through the same single connector, reducing the amount of space on the PCB required by multiple headers. ([8])

Reduces PCB footprint with customizable pinout configurations

With multiple high-speed pinout configurations and cable exit options, HSAutoLink II saves space on the PCB compared with alternative products.



Protocols supported include Ethernet, DisplayPort, LVDS, USB 1.0 to 3.0 Gen I, FPD-Link I to IV, and GMSL 1 to 3 and others with data rates up to 13.5Gbps per lane, depending on the cable. ([9])

The HFM connector system delivers data rates of up to 28Gpbs at frequencies up to 20 GHz and supports protocols such as APIX, ASA-ML, Ethernet, FPD-Link III/IV, GMSL 2/3, GVIF, HDBase-T, MIPI A-PHY and PCIe. Single, dual and quad connectors for wire-to-wire and wire-to-device applications offer a compact design and up to 80% space savings compared to FAKRA connectors, with the possibility to reduce the assembly time of mated cables by 75%.

The integration of CPA and ISL, coupled with the operating temperature of -40 to +105°C, makes it suitable for applications ranging from automotive ADAS, camera and infotainment systems to autonomous driving systems and telematics. ([12])

Designed to meet the needs of automotive zonal architecture, the innovative **MX-DaSH** from Molex combines high-speed data, signal and power into one connector. Available in sealed and unsealed wire-to-wire configurations and wire-to-board designs, MX-DaSH can replace a number of traditional connectors, reducing size, weight, cost and assembly time. Terminal sizes range from 0.50mm to 4.80mm for signal and power, and HFM or H-MTD connections are utilized for data. Secure mating and reliable connectivity are achieved thanks to the ISL, CPA and industry-leading male-blade-stabilization features. ([13])

The Molex **CMC and CMX connector systems** are designed for reliability in harsh environments and provides a wide range of sealed, high-density, hybrid wire-to-board and wire-to-wire solutions. CMC/CMX connectors offer a wide range of options, including 22 to 154 circuits, ISL, CPA and TPA configurations, as well as vertical and right-angle headers. They support a broad operating temperature range from -40 to +125°C. These connectors provide solutions from engine control units (ECU) and inverters to applications in marine, construction, agriculture and motorcycles, among others. ([14])

DuraClik is named after two of the features and advantages this product offers: durability and an audible sound when mating (the “click”). DuraClik headers are available from two to 15 circuits in right-angle and vertical configurations. A robust version offers 100N contact retention to the housing. As previously mentioned, the DuraClik temperature and vibration/shock options and small size make it ideal for applications from automotive lighting, major appliances, LED lighting and vending/gaming machines to battery management systems. ([4])

CONCLUSION

Selecting the correct connector for harsh environments is a multidimensional challenge. Temperature extremes, vibration/shock, ingress protection, electrical ratings and EMI concerns all play pivotal roles. By aligning these performance attributes with the right Molex family and features, costly field failures such as overheating, blade damage, water ingress or signal dropout can be avoided.

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12. High-Speed FAKRA-Mini (HFM) Interconnect System
13. MX-DaSH Connectors | Molex
14. CMC/CMX Connector System

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