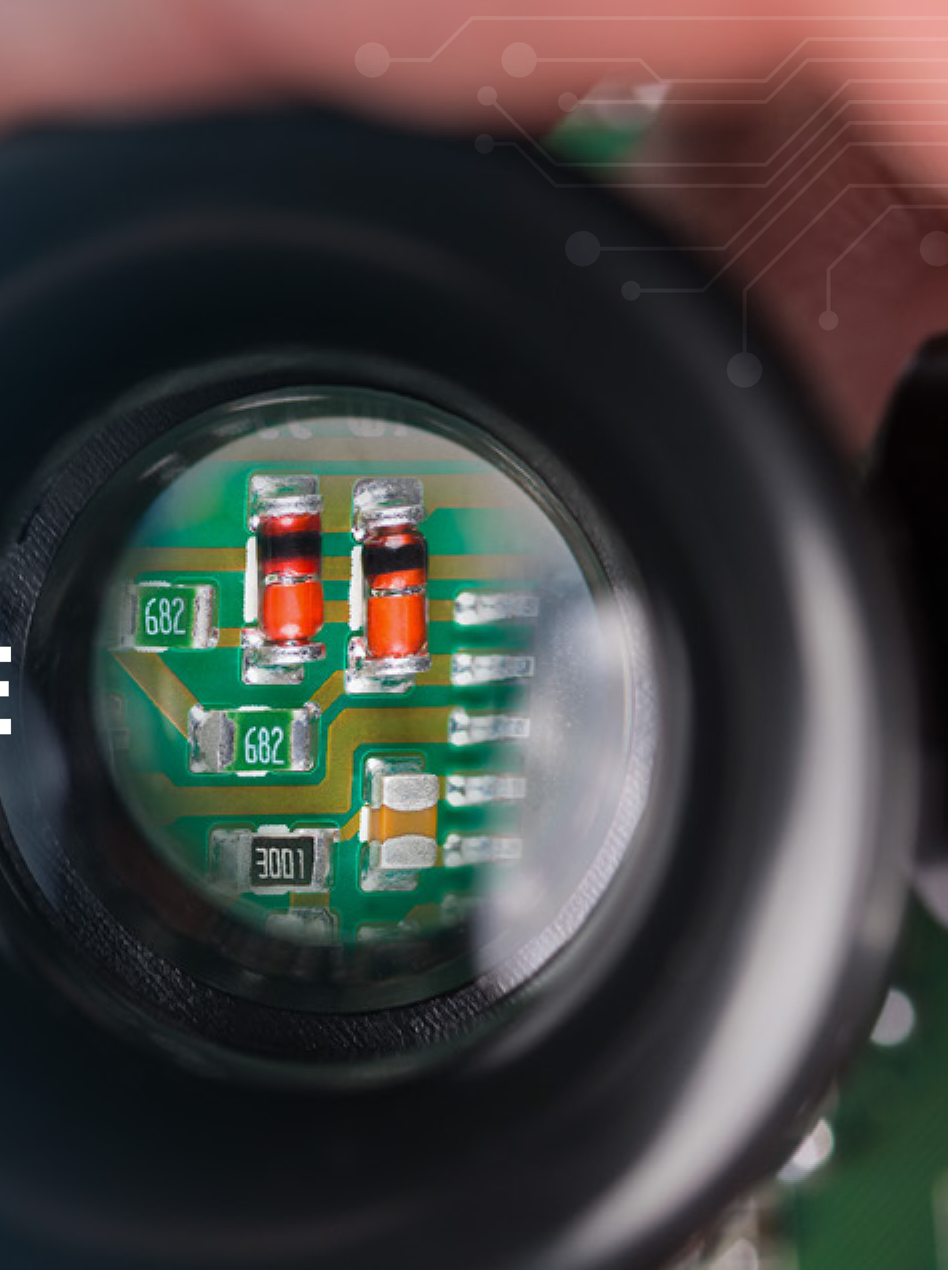
EBOOK

MINIATURIZATION UNDER THE MICROSCOPE

How Shrinking Electronics are Impacting Design Across Industries



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INTRODUCTION

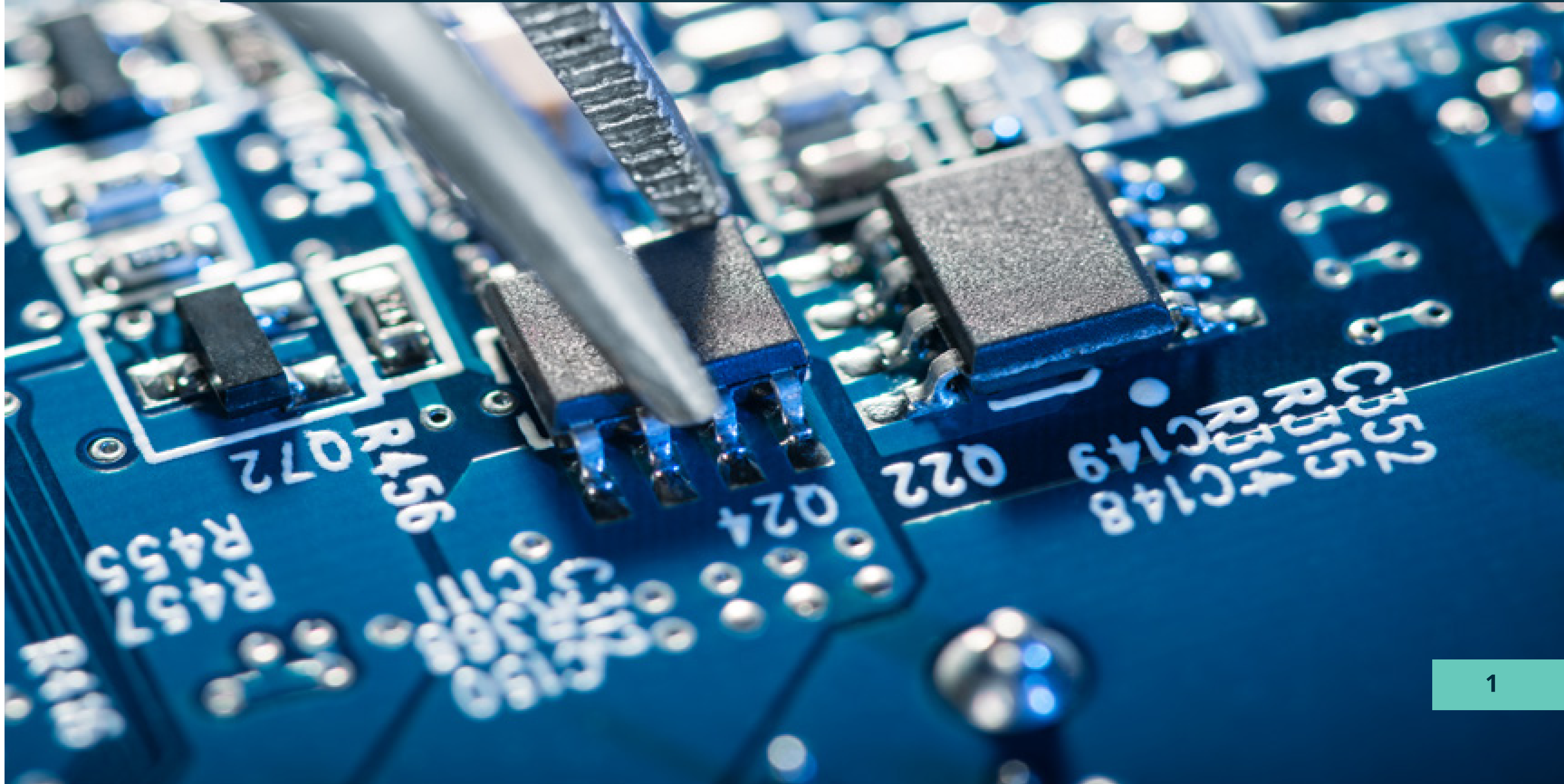
Miniaturization is not a new concept in electronics, but there is little doubt that it is accelerating at an ever increasing pace and scale.

From the phone in your pocket and the factory machines that assembled it to the Bluetooth-enabled car you drove to purchase it, design engineers in every sector are faced with the challenges of creating slimmer, smaller and more streamlined components for their electronic applications without sacrificing performance or longevity.

In this ebook, we'll dig into these miniaturization challenges, unpacking the biggest drivers, trends and innovative solutions at work in key applications.

Companies working in advanced technologies like consumer electronics, 5G and wireless, Electric Vehicles, medical wearables, and more will continue to face form factor challenges and will require a range of interconnect solutions that provide low profile, signal integrity and required I/O counts.

Molex works at the forefront of these application areas and utilizes decades of experience to produce high-yield, cost-effective products that satisfy the demand for streamlined and miniaturized applications, that deliver optimal functionality and performance — even within the strictest form factor requirements.



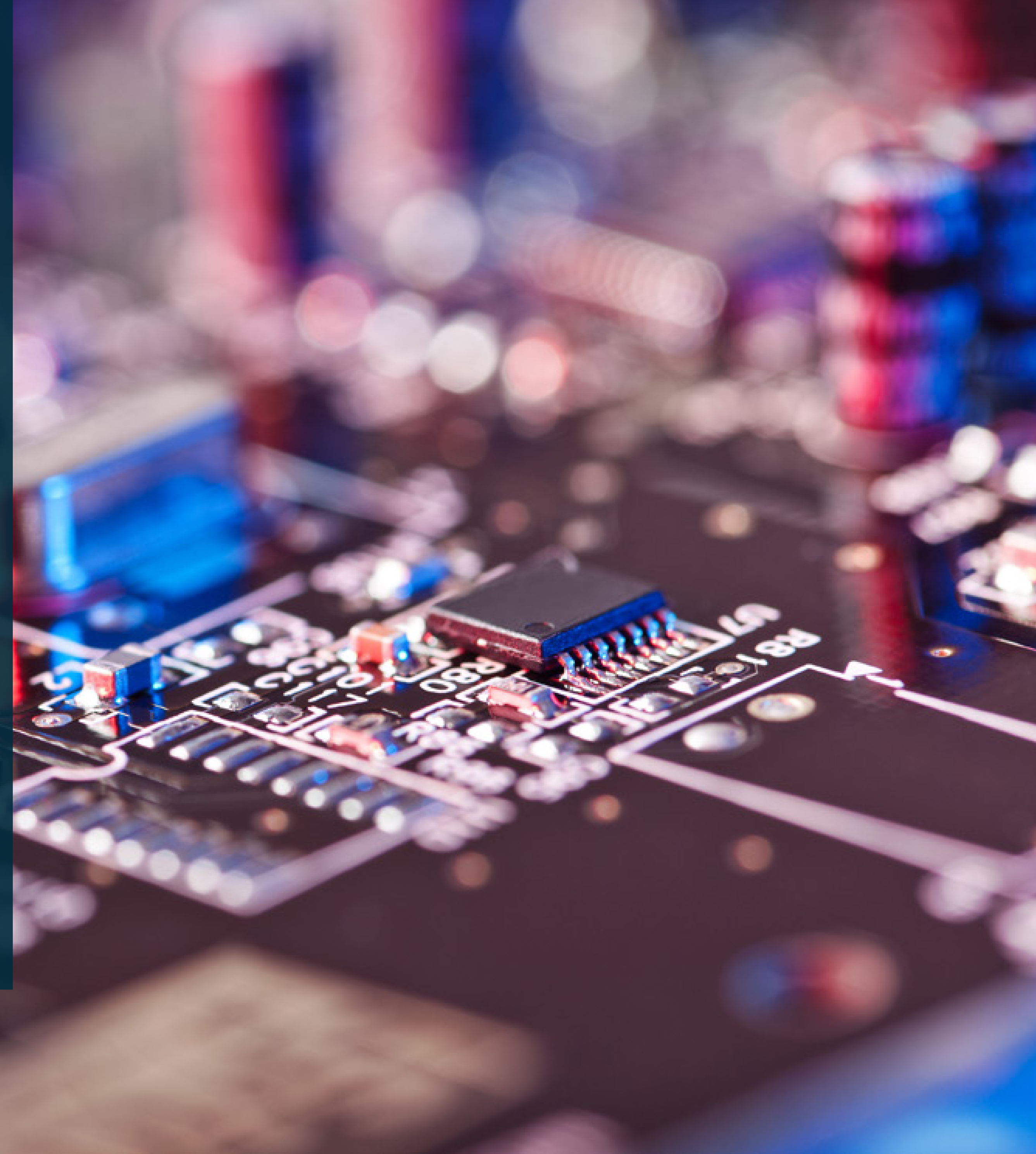
APPLICATIONS DRIVING ELECTRONICS MINIATURIZATION

There are many factors driving the miniaturization trend, far beyond semiconductor scaling.

Moore’s law and more advanced integrated circuits are enablers of more powerful and smaller systems, but it is ultimately a small set of advanced application areas that are driving demand for miniaturized components.

Integrated circuits aren’t the only components being miniaturized in advanced electronics. Application areas like wireless devices, smart consumer devices, data center infrastructure and edge computing require greater I/O and feature density, which are driving miniaturization of every component in an assembly.

In particular, mechanical elements like connectors are prime targets for miniaturization, especially in complex multi-board assemblies found in today’s advanced products.



DRIVING FACTORS IN MINIATURIZATION

Design is a critical driver of the miniaturization of electronic components common to many application areas. Semiconductor scaling is only part of the equation; the trend towards component miniaturization spans to all other areas of the assembly, including mechanical components and connectors. Some of the major factors driving miniaturization include:

- Greater feature density from the standpoint of increasing numbers of components packed into smaller board/enclosure space
- Greater feature diversity to address the many diverse features in a single chip, board and enclosure
- Greater I/O density to support the greater feature requirements highlighted above
- User experience evolution that drives device form factors that then spur miniaturization requirements

Further complicating the drive to miniaturization is the fact that many systems enabling advanced applications are built as complex multi-board assemblies. In some electronic devices, the largest components are the connectors and cables, so miniaturization of these components is very important for hitting form factor targets.

Some of the major application areas where we see the greatest drive for miniaturization include RF/wireless devices, consumer electronics and data center/edge computing.

RF AND WIRELESS SYSTEMS

In the past, RF systems occupied more board space and required bulky external components for wireless communications. The two main reasons for this were scarcity of small, efficient components, as well as the fact that many RF devices were operating at lower frequencies.

Certain RF components and circuits operating at lower frequencies actually require larger components due to the operating wavelengths of signals in these systems. 5G, mmWave radar and mmWave sensing are three of the major application areas where higher operating frequencies create demand for smaller components.

As modern wireless applications rely on operation at higher frequencies, reaching well into the GHz range, RF circuits and components have reduced in size. This includes specialty RF systems relying on printed RF circuits, as well as wireless systems with larger, denser antenna arrays.

The miniaturization issue with antenna arrays arises in two important areas: 5G devices and car radar sensors. The form factor of these devices is highly constrained by enclosures and placement in vehicles, respectively, with form factors demanding very low-profile board assemblies. Low-profile connectors are imperative for hitting form factor and profile targets in these systems while also ensuring signal integrity across board-to-board interconnects.

Board-to-board or flex-to-board mating connectors set with very low profile along the z-axis, like this **Easy-On FFC FPC Connector**, are a good way to make room for connections when board space is reduced.

CONSUMER ELECTRONICS

Smart phones are the most popular mobile devices in use worldwide, but other devices like personal health products and newer home electronics are also driving component miniaturization. Many consumer electronic products are known for their sleek form factor, which requires miniaturization of the largest components in these products.

Connectors and interconnects in handsets are strong examples. As device profiles have shrunk and board space is reduced to make room for other components, connections between antenna modules, displays and the main PCB require a board-to-board or flex-to-board mating connector set with very low profile along the z-axis.

These kinds of flat connectors enable interconnects with high I/O density, flexibility, very low profiles or a combination of these. As more devices implement foldable enclosures, more interconnect designs will be flexible, typically with a low-profile connector and cable assembly.

These connectors often need to transfer power and signals in the same interconnect, so they may also require high current ratings while ensuring signal integrity for fast digital signals.

DATA CENTER AND EDGE COMPUTING

Hardware for data center infrastructure and edge computing systems shares common characteristics as both areas become more feature dense.

The data center environment continues to require additional computing as more infrastructure integrates more powerful networking equipment, AI acceleration and FPGA/GPU expansion options. This comes with smaller available space inside rack-mount servers deployed in data centers.

The same size constraints are found in edge computing, where there is an attempt to bring the same data center capabilities closer to end users in a smaller form factor. In both areas, the computing systems that continue to see a push towards miniaturization include:

- Mounting and enclosure solutions
- Fan and heat sink profiles
- Expansion/accelerator card form factor
- Mezzanine and board-to-board connector
- Wire-to-board connectors for signal and power
- Optical transceiver and interconnect solutions

In specialized computing paradigms, like AI at the edge, connector systems must provide high data transfer rate capabilities between components on the motherboard, as well as to peripherals and external equipment.

In these systems, connector and cable assemblies may also need to provide power in the same interconnect, depending on the target form factor and application area.

Finally, there is an important element of reliability in these systems, which must have reasonably long lifetimes and may involve exposure to harsh environments.

Connector systems for these products should provide an appropriate IP rating and withstand mechanical shock, but in a small form factor that provides the required pin density and z-axis profile.

UNLEASHING THE POWER OF CONNECTED CARS

Today's consumers move in a digitally-enhanced world, checking sports scores or grooving to the beat of a personal playlist as they walk down the street. As a result, smartphones have conditioned us to expect a user-friendly, customized environment everywhere we go. And that environment increasingly includes the cars we drive.

ELECTRONICS EVERYWHERE

Automakers are adding a slew of new electronics to their vehicles to satisfy customers and keep up with competitors. Autos contain digital dashboards with customizable displays for the speedometer, odometer, temperature gauges and other gauges the driver wants to see.

Multiple screens offer driver and passenger infotainment options, as well as seat controls and lighting they can set to their preferences with a touch instead of fiddling with buttons or dials. And that's just some of the fun stuff.

New cars are now expected to provide a range of advanced safety features to protect the driver and passengers. Vehicles keep position in lanes while maintaining safe following distances, audible alerts are accompanied by visual warnings flashing on the windshield, and brakes are automatically applied in cases of emergency.

All these features rely on instantaneous transfers of information from sensors and equipment located throughout the vehicle. Whether it's for the driver's safety or for comfort and convenience, each feature has its own wiring and is encased in an electronic control unit (ECU) attached to the wiring harness.

Today's vehicles often contain up to 150 ECUs, and that number will only continue to rise as consumers clamor for more features. Automakers and component manufacturers are racing to keep up, miniaturizing everything to fit more content in the same amount of space.

SPACE, ENERGY AND ENVIRONMENTAL CONCERNS

This proliferation of electronics poses challenges for manufacturers. Vehicles were never designed to accommodate so much wiring, and engineers are running out of space to contain it.

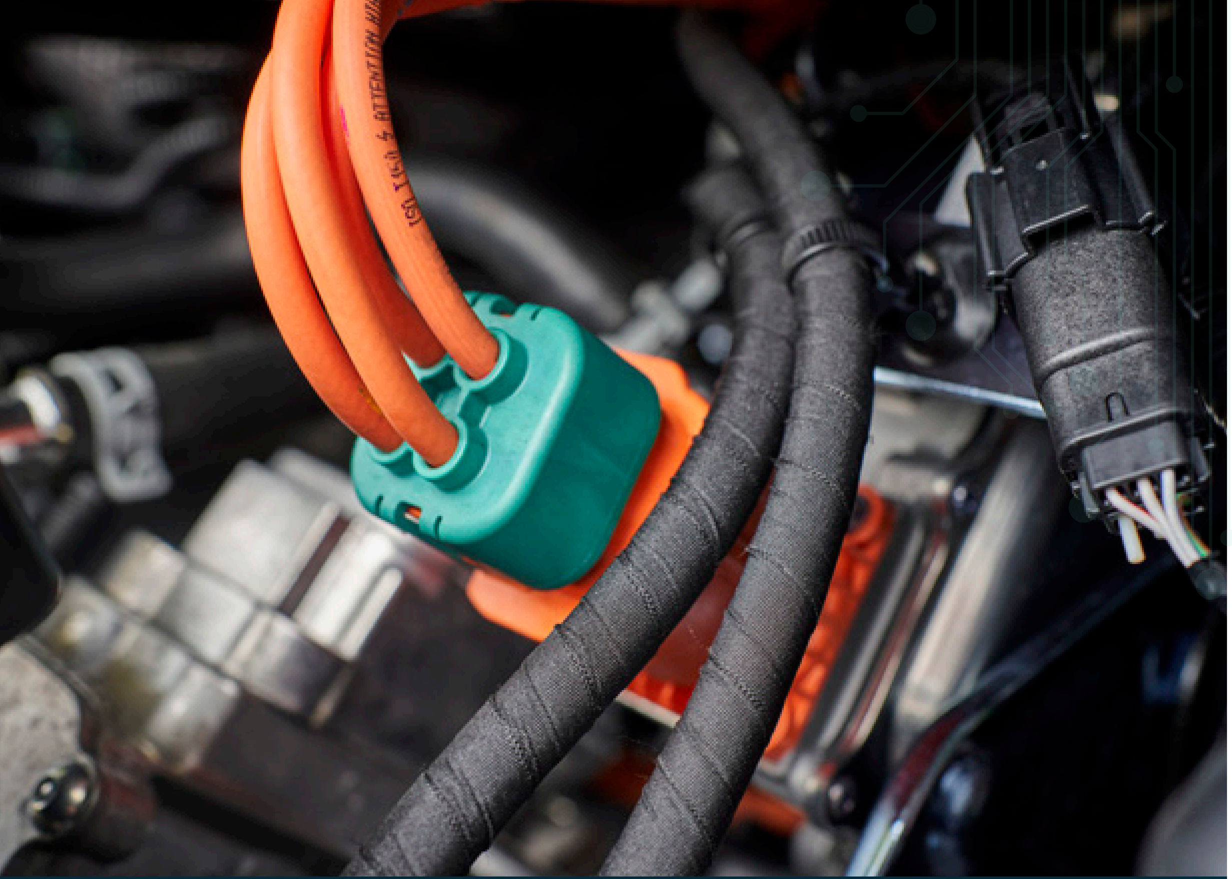
Another concern is weight. A wiring harness today can weigh **over 150 pounds**. It is the **third-heaviest component** in the car, behind only the engine and the chassis, and is the third-most expensive part to produce.

While consumers crave electronics, they also want better energy efficiency. Unfortunately, these preferences are not compatible. A feature-heavy harness adds drag and reduces gas mileage for cars with internal combustion engines.

In EVs, every new feature has the potential to drain power from the battery and decreases driving range—already a sore spot for consumers contemplating a shift to electric.

In addition to seeking energy efficiency for their vehicles, consumers are increasingly concerned about other environmental attributes such as emissions. A harness weighed down with wiring and ECUs produces more carbon-laden emissions. In in EVs, it means a shortened battery life.

Today's vehicles often contain up to 150 ECUs, and that number will only increase as consumers expect additional features. Electronics producers must work closely with manufacturers and Tier 1 suppliers to design miniaturized components that cut down on both space and weight.



Molex has reduced the size of wiring harness terminals carrying heavy currents from the standard 1.5 mm^2 to just 0.13 mm^2 and lower-current terminals from 0.64 mm^2 to 0.5 mm^2. Miniaturized connector systems like these can create 50% more board space over traditional systems.

MINIATURIZING ELECTRONICS

To fit all the new electronic features into vehicles while lightening the load, manufacturers and their suppliers have to consider out-of-the-box solutions.

They have to think small to achieve more, shrinking modules and components to the maximum extent possible while still enabling **100 million lines of software code** to be transmitted quickly and reliably throughout the car. That's especially important for safety features, which require high pin-count connectors to relay information to other parts of the vehicle.

Electronics producers have been working closely with manufacturers and Tier 1 suppliers to gain in-depth knowledge about their challenges and have designed miniaturized components that cut down on both space and weight.

For example, Molex has reduced the size of wiring harness terminals carrying heavy currents from the standard 1.5 mm^2 to just 0.13 mm^2. Lower-current terminals have been reduced from 0.64 mm^2 to 0.5 mm^2.

While these numbers may appear small, when you're trying to fit more and more content into a confined area, they add up to a big difference. In fact, compared to traditional systems, Molex miniaturized connector systems can create 50% more board space on devices within the vehicle.

This frees room for the OEM to incorporate more advanced semiconductors on the board to support expanded functionality while helping harness manufacturers reduce weight: a best of both worlds.

In addition, the weight saved by using smaller connectors and wires improves energy efficiency while reducing emissions output. This allows EVs to use smaller battery packs and extend their range — an important consideration for buyers who want to spend as little time as possible waiting to complete a charge.

Miniaturized connectors also enable engineers to route wiring into vehicle spaces where it couldn't fit before, allowing them to place ECUs closer to the mechanisms they control and opening the door to new possibilities for future applications.

THE GROWING NEED FOR RUGGED, RELIABLE — AND SMALLER — CONNECTORS

Though small and slim, vehicle connectors must be tough enough to withstand extremely high temperatures, strong vibrations and moisture capable of destroying circuitry as well as dirt and grit that inevitably find their way into the chassis.

Humidity can cause condensation both on the surface and inside the connectors. Water can also become trapped inside components during the manufacturing process and condense later, after the temperature changes. In addition, poor designs, assembly errors and operator fatigue can lead to connection backouts and system failure.

With safety systems dependent on electronics, ensuring reliability has never been more important. As manufacturers move up the scale towards Level 4 and Level 5 autonomy, more responsibility will fall on them to provide dependable connectors for primary systems and backups.

The future is also likely to bring more shared mobility to the auto industry. The two largest ridesharing platforms are already booking more than **40 million** trips every day. The advent of autonomous vehicles could bring a new dimension to shared rides, with self-driving cars dropping off passengers and briefly self-parking before heading off to the next customer.

The efficiency and cost-effectiveness of this system could shift consumer preferences from public transit to shared private transportation. If that happens, vehicles will be in constant use, instead of sitting idle in parking garages all day and driveways all night. This would put more strain and wear and tear on parts — including vitally important connectors.

Thankfully, innovations in connector technology have enabled connector systems to simultaneous provide high reliability and durability, small sizes and simplified assembly: minimizing the risk of manual error during manufacturing.

BUILDING FOR THE FUTURE

As cars increase their dependence on digital systems for navigation, safety, comfort and entertainment, connectors take on outsize importance. Making them smaller and lighter while increasing resilience and reliability is no small feat.

Molex is at the forefront of these miniaturization efforts, brainstorming with manufacturers and Tier 1 suppliers to create breakthrough solutions, such as the rugged **Mini50 connectors**, which increase reliability, provide manufacturers with more configuration options and make servicing easier.

Mini50 Connection Systems

SOLVING THE CHALLENGES OF MINIATURIZED MEDICAL DEVICES

In the past few years, consumer demand for fitness apps has led to an explosion of new health-monitoring applications.

Smartphones, smart watches and hand-held gadgets can now measure everything from blood oxygen level and respiratory rate to heart rate and rhythm, sleep quality and wrist temperature. Nearly 30% of U.S. adults are now using some type of wearable medical device, according to the **National Institutes of Health**.

While these devices are fun and informative, they aren’t designed or manufactured to meet medical standards, and can’t be relied on for diagnostic accuracy. But the movement has inspired medical-grade device makers to strive to minimize the footprint of their own patient-monitoring devices — the kind doctors can prescribe to help patients manage their care and medication.

Making these devices and implants smaller, less obtrusive and easier to manage increases compliance and allows patients to live a more normal life. It also helps inform clinicians in making treatment decisions.

SMALLER, MORE COMFORTABLE AND MORE EFFECTIVE

Remote patient monitoring devices can be used for conditions including heart disease, chronic obstructive pulmonary disease, asthma, diabetes, and sleep apnea – just to name a few. As populations age, more people are experiencing these chronic conditions, and personalized, remote management can help cut down on doctor visits and hospital stays.

But the devices are only useful if patients agree to wear them. Early devices were cumbersome and complicated. Heart monitors, for example, contained electrodes that spanned the entire chest and had to be spaced just so. Even then, signal transmission was often spotty.

Miniaturizing heart monitors and other devices allows patients to wear them unobtrusively as they go through their daily lives. Many can now be worn during sports activities and even in the shower. Some, such as swallowable "pill cameras" that record images of the gastrointestinal tract, can replace uncomfortable and time-consuming clinical procedures.

Others make home procedures easier, more comfortable and more effective. For example, continuous glucose monitors measure the blood glucose levels of diabetics every 10 seconds with a sensor placed just below the skin, reducing the need for painful finger pricks.

Constant monitoring provides early warning of danger signals, prompting patients to take quick action to avoid a heart attack or stroke if their glucose level goes too low or too high.

Drug injectors with tiny sensors make medicine delivery faster, easier and more accurate for patients who self-administer. The Phillips-Medisize **Aria smart autoinjector** makes a sound to indicate injection progression, ensuring a correct dose every time.

For conditions such as allergies and asthma, drug injectors with tiny sensors can ensure flawless delivery. For example, the Phillips-Medisize **Aria smart autoinjector** provides audible sounds to inform users about injection progression, ensuring a correct dose every time. Sensor technology can also monitor drug expiration dates and warn patients and physicians as they draw near.

Miniaturized devices and sensors can collectively gather and integrate an enormous amount of information, fostering a holistic approach to health. Thanks to advances in circuitry and sensor design, a single sensor can now monitor several bodily functions.

Placed in different body locations, sensors can also communicate with one another, giving both patients and their physicians a better overall view of physical condition.

MINIATURIZATION HELPS MINIMIZE WASTE

In addition to providing comfort and convenience, miniaturized medical devices help address another consumer concern: promoting environmental sustainability.

Healthcare is one of the most carbon-intensive industry sectors, accounting for 4.4% of global net greenhouse gas emissions and toxic air pollutants, according to a research paper published by the **Journal of Health Services Research & Policy**.

Smaller devices use less material, making them more energy-efficient to produce and ultimately resulting in less waste. Manufacturers are also using more rechargeable and recyclable electronics and designing drug injectors with fewer single-use components to diminish the waste generated by traditional devices.

Healthcare accounts for 4.4% of global net greenhouse gas emissions and toxic air pollutants, according to the Journal of Health Services Research & Policy. Smaller devices use less material and are more energy efficient, another driving factor toward miniaturization.

MANAGING DESIGN AND REGULATORY CHALLENGES

Miniaturized medical devices offer many advantages to patients and clinicians but designing and producing them is a complex endeavor that requires expertise in several fields.

Small-sized electronics must be designed with enough power to reliably collect and relay high volumes of information while fitting into tight and irregular spaces.

Manufacturers must use biocompatible materials that are soft enough to provide the comfort patients expect while also withstanding sweat, bumps, drops and moisture. Skillful use of precision injection molding — and a lot of trial and error — can help them achieve the right balance of flexibility and durability.

Devices must also be easy for the average person to operate, regardless of technical competency. And they must follow strict rules to always keep patient data private and secure at all times.

Implants and devices that offer a diagnosis or dispense drugs are subject to much greater regulatory scrutiny. Manufacturers must provide studies demonstrating use, effectiveness and success rates. In some cases, they must undertake full clinical trials to gain approval, a process that can take up to 10 years.

CONTINUITY FROM DESIGN THROUGH MANUFACTURING AND ASSEMBLY

The manufacturing of miniaturized devices containing microelectronics entails specialized processes, including different material handling techniques and technology to ensure precision alignment, which can be tough to execute when parts are sometimes too small to see with the human eye. Machinery must be adjusted to handle components without damaging them while also packaging them without generating static from plastic enclosures.

To produce devices at scale, manufacturers need to develop custom procedures to replace manual assembly with automation. Small, printed circuit boards may require multiple x-ray and software tests, as well as visual inspection.

Using the most effective processes for fabrication and assembly often involves tweaking the original product design. For that reason, it is important for designers to work with manufacturing experts from the start, so that teams can share their expertise at every stage as products evolve from initial plans to final production.

A ONE-STOP SHOP FOR MINIATURIZED DEVICE EXPERTISE

Unlike other medical device makers, **Phillips-Medisize**, a Molex company, has an extensive range of experts with years of experience in every phase of designing, manufacturing, assembling, and testing high-performance, miniaturized medical products.

That means fabrication and assembly considerations can be incorporated into designs from day one. This allows device manufacturers to work with the same team of experts throughout the process, eliminating frustrations, rework, delays, and cost overruns and, ultimately, deliver products to market ahead of competitors.

5G: AS WAVELENGTHS GET SMALLER, SO MUST THE DEVICES

The first substantial deployments of 5G infrastructure began in 2019, along with the release of handsets advertising 5G capabilities.

Although rollouts to true mmWave 5G at scale have been slow to materialize, some of the biggest wireless component manufacturers have supported both sub-6 GHz and mmWave access with their products.

In anticipation of greater access to the mmWave spectrum, component releases have focused on dual-band operation to support low, mid and high frequency 5G networks.

The current trend in 5G continues pushing towards higher operating frequencies to access greater data rates and lower latency. For systems designers and product designers, higher frequencies bring design challenges that are only solved with more specialized components.

In devices operating at higher frequencies, a few key areas are behind the need for smaller form factors:

- Greater antenna density
- Increased battery power needs and the need for a physically larger battery
- Alternative packaging strategies and materials for RF components
- Greater feature density in 5G-enabled devices

WHAT HAPPENS IN 5G SYSTEMS AT HIGHER FREQUENCIES?

Devices operating at higher frequencies are subject to greater signal loss, which requires anything interacting with a 5G signal to potentially be re-engineered.

Connectors, antennas, cables and enclosures are all components that can interact with an incoming or broadcast 5G signal; the components and materials normally used in 4G systems and deployments are not always compatible with the higher frequencies used in 5G infrastructure and devices.

Some of the major themes driving designs to smaller form factors include:

- Greater antenna density for high-frequency antenna arrays
- 5G connectivity requires more battery power and the need for a physically larger battery, which consumes more real estate in a device
- Alternative packaging strategies and materials for RF components
- Demand for greater feature density in 5G-enabled devices

Within these broader themes, where is miniaturization occurring at the system level?

ANTENNA ARRAYS

With 5G devices being wireless, the antenna is obviously an essential component. Antenna arrays are driven smaller at high frequencies because their operating frequency is inversely proportional to their size.

This has required size reduction in antenna arrays, and it creates etching difficulties for PCB fabricators, as well as packaging manufacturing for antenna-in-package modules and modems, and component manufacturers.

As smaller sizes bring manufacturing difficulties, this creates a challenge in designing a land pattern for a connector that can support the required signal bandwidth.

For component manufacturers, support for mmWave-capable antenna arrays enables smaller devices. This is then beneficial for system/product designers as they will free up real estate on their board for other components.

Antenna arrays used in 5G-capable handsets are typically 2×2 patch antenna arrays. As these arrays are driven smaller, manufacturers need to take an additive approach when fabricating components for use in the mmWave regime.

Fabrication limits can be pushed off with lower Dk/lower loss materials, but eventually antenna arrays for 5G/6G will reach the limit of what can be reliably fabricated with standard and additive processing.

COAX CABLES AND CONNECTORS

Coaxial cables and connectors are used in RF devices where form factor is not a major challenge, yet high power handling is needed with minimal dispersion and losses.

While standard larger form factors (e.g., SMA connectors) can operate at mmWave frequencies with wideband connector lands, greater feature density and size constraints in small deployments require a physically smaller connectors that can still operate in mmWave bands.

These connectors may be customized when off-the-shelf components do not hit form factor targets.

Another challenge that appears in 5G systems is passive intermodulation (PIM), which interferes with data transmission in wireless systems that use carrier aggregation. In fact, passive intermodulation is sometimes called the "rusty bolt effect."

Connectors can also be a source of PIM, and a very small amount of PIM near the carrier frequencies is sufficient to create errors that reduce data transmission rates.

Some smaller or custom connectors can provide lower PIM values that are essential in systems operating at higher frequencies.

With mmWave signals experiencing higher loss, the link budget for a system will be smaller, and thus the allowed PIM specifications in a system are brought lower. This may require smaller connectors and cable assemblies to reduce the opportunity for PIM to occur.

OTHER SPECIFICATIONS ON SMALL COMPONENTS

Small components used in handsets, micro/pico cells, and 5G-enabled modules have another set of specifications that are complicated by reduced component size.

As there is a drive to accommodate higher frequencies with smaller components, this complicates the mechanical design and durability of these components.

Handsets and cell equipment must operate in harsh environments at a range of temperatures with perpetual uptime, requiring components that meet environmental specifications:

- **Weatherproofing and waterproofing –** Components exposed to the environment (particularly connectors) may require an IP6x rating to ensure reliability.
- **Retention in mated connectors –** Retention mechanisms help to prevent unintentional disconnects in a system due to vibration or mechanical shock.
- **Consolidated connectors –** Smaller devices have less room for multiple connectors, so pinouts may need to support both power and signal on the same cable.

5G DESIGN SUPPORT

With the multi-faceted challenges of high-frequency applications and how quickly circumstances and standards change, many design engineers look for partners with extensive knowledge in the field.

Molex takes a collaborative approach to system design, offering test expertise and custom component design to help customers scale their 5G products to high volume. The goal is to produce high-yield, cost-effective products in form that will enable a smoother transition to 5G, despite the complexities.

BIG DATA DOESN'T ALWAYS MEAN BIGGER FACTORIES

Visions of a factory conjure up a large space, big machinery and many people working hard to keep products rolling on the production line.

Modern manufacturing introduces challenges that often can't be addressed through expansion of physical space. The vast majority of manufacturers can't afford to tear down and rebuild factories to incorporate the latest ideas and capabilities.

FACTORIES NEED ROOM TO BE MODERN

Modern manufacturing leveraging Industry 4.0 means more data, faster analysis, Internet of Things (IoT) and advanced embedded technologies like machine learning and computer vision. Together they transform the process of making products, parts, components and assemblies by making all parts of the manufacturing processes “smart.”

It’s an added challenge to make manufacturing more efficient, effective, flexible and responsive — doing things never before possible — while supporting required workflows.

Previous manufacturing facilities were designed to be productive, resilient and stand the test of time. In terms of traditional IT technology, supervisory control and data acquisition (SCADA) networks and physically connected industrial controllers were very typical. These technologies have limited bandwidth and may not take advantage of the latest technology advances as compared to Industry 4.0.

Miniaturization plays an important role in incorporating new capabilities. By physically miniaturizing the technologies, they can more easily fit into the footprint of existing factories while delivering significant technology advancements.

RIGHTSIZING THE NETWORK ARCHITECTURE

There’s a clear need to move beyond old technology to enable new capabilities. But a conceptual step must be taken first: Miniaturization everywhere — because the paradigm shift in factories requires a new, innovative approach to network architecture.

Not long ago, an advanced factory used sensors and industrial controller collected data from automated machines and equipment. The data was pushed out over proprietary networks that brought the information to central servers that ran the software to undertake analysis and provide reports to managers for analysis.

The current state-of-the-art factory involves highly decentralized networks using edge computing at the controller or even sensor level. Embedded circuits are specialized computers that can run sophisticated software, including artificial intelligence apps, to perform a first level of data processing. These edge devices transform the monitoring and control processes into collections of intelligent subsystems that pass along digested data in the form of information. The result is higher throughput of digital intelligence.

Decentralized network architectures and remote processing systems are in buildings that can’t be easily expanded to provide additional space. The network channels and all the control and monitoring devices, inside and outside, need to be as small as possible to operate at the functional and performance level required.

BUILDING A ROBUST COMMUNICATIONS NETWORK

Modern factories need the ability to move data from one area to another, collect the data and then process the data centrally. Add to this the need for Industrial Internet of Things (IIoT) applications to access available power that runs reliably and uninterrupted. The first basic step a facility can take toward becoming fully connected and integrated is to install networking and communications capabilities, including effective and efficient power delivery.

IOT is the backbone of Industrial Ethernet, which can use Cat5e/Cat6 cables and standard networking hardware for up to 1 Gbps transmission rates. However, this too has limitations, such as the maximum covered space capping at a length of 100 meters. Industrial Ethernet typically uses M8 or M12 connectors, which seem large for some applications such as connections to sensors. There are repeaters, or an implementation could be run over fiber optic media, but these options are more expensive and harder to maintain and repair. Present cable versions support Power over Ethernet (PoE) at 15.4 or 30 watts per port using 4-pair cables for gigabit Ethernet.

Single Pair Ethernet (SPE), a relatively new option for Industrial Internet of Things (IIoT) applications, is a superior solution. Rather than using 2-pair or 4-pair cables, one twisted pair does all the work to support 1 Gbps transmission rates and offers Power over Data Line (PoDL) up to 50 watts. Under the IEEE 802.3ch standard, transmission rates of up to 10 Gbps should be possible.

In Single Pair Ethernet (SPE), one twisted cable pair does all the work to support 1 Gbps transmission rates and offers Power over Data Line (PoDL) up to 50 watts.

The reduced wire count compared to previous 2-pair and 4-pair cable options enables miniaturization of connectors, and SPE's compatibility with existing Ethernet infrastructure simplifies design and reduces costs.

The reduced wire count enables miniaturization of connectors and electronics associated with the receptacle that are size-optimized — making it easier to squeeze SPE ports into tight spaces. In addition, SPE is compatible with existing Ethernet infrastructure, and single connectors providing both power and signal while simplifying design, reducing size and managing cost.

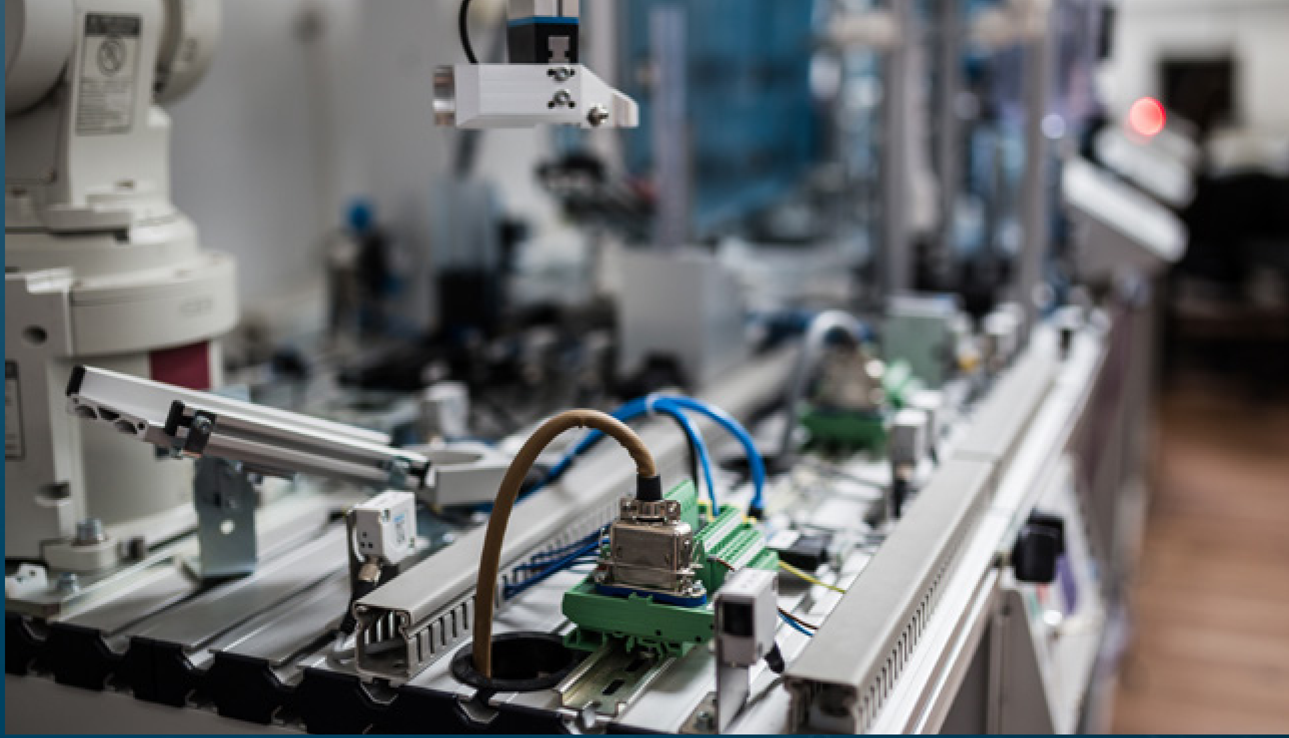
ADDING THE END POINTS

The next step is monitoring what is happening on the factory floor. Are products the right size and shape? Are there delays in the output of a machine? Maybe the factory wants to control automation or robotics in addition to collecting data.

With the right communications network in place, it is possible to add significant capabilities into the existing factory. Ethernet-compatible equipment can be made to work with SPE, so existing equipment can be connected to the network.

Adding sensors and equipment to increase capability becomes relatively simple with this approach. For example, one of these boxes with a sensor that can register vibration can be placed on a machine to measure the vibration level. If the vibration measurement starts to increase, it could be a signal of an unbalanced load on a motor, a loose part or something that potentially signals a range of other malfunctions. Alternatively, a small video sensor can be added to measure infrared light to determine if a piece of produce passing on a conveyor belt displays hidden bruising. It can then signal a device to divert the damaged goods for separate processing.

Another solution to the signaling challenge is 5G communications, which brings with it the particularly attractive feature of handling high data rates using next-to-no cabling. 5G technology requires antenna arrays in individual devices throughout the factory to capture short-range transmissions.



MOLEX KNOWS MINIATURIZATION

Molex has a long history of expertise and capability making assemblies, parts, connectors and cables small enough to accommodate all requirements, with a broad product line that addresses a multitude of industry needs. The company has also been an early entrant in SPE technology. This means a large team of experienced engineers can help expand capabilities and intelligence by adding miniaturized connectors, wiring, sensors, or other technologies for smarter, more agile factories. The bottom line? Your factory doesn’t have to grow with the changing requirements of modern technology. In fact, it may even get smaller with the right approach.

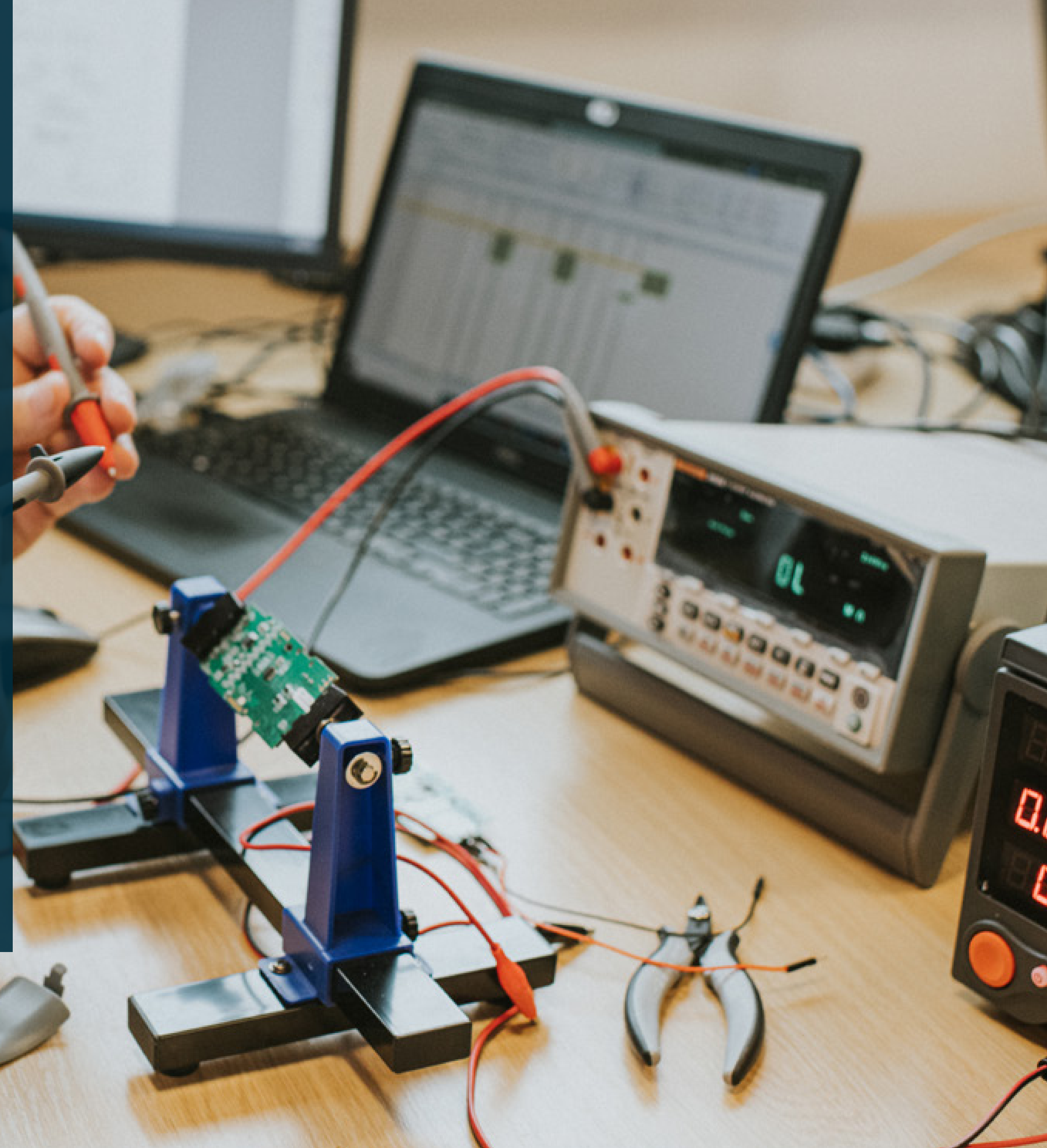
BEARING UP UNDER MINIATURIZATION: THE CONNECTOR CONUNDRUM

As we’ve seen in the previous sections of this ebook, miniaturization has become a constant companion of engineers in virtually any type of product that incorporates electronics.

Automobiles, mobile devices, medical equipment, defense systems, consumer electronics, appliances – every last one of these categories have one thing in common: the requirement to shrink with shifting market demands.

Competition, consumer and industrial preferences and market requirements push designers to find ways to shrink the size of electronic assemblies, components, wiring harnesses and enclosures.

At the same time, the constant need to add functions and capabilities to support the latest evolving technology means making it all fit is a significant challenge. Consumers don’t want mobile devices to grow larger, for example.



Electrical connectors play an integral role in design, sending power and signals throughout a device and ensuring individual parts can successfully interact.

Automobile manufacturers need to constantly cut back on the overall size and weight of vehicles to improve mileage of legacy internal combustion cars and trucks and the range of electric vehicles (EVs). Wearable medical devices become smaller and lighter to improve patient convenience.

One aspect of design that plays a surprisingly important role is the use of electrical connectors: wire-to-board, wire-to-wire, board-to-board, flexible flat cable (FFC), flexible printed circuit (FPC) , input/output (I/O), power and radio frequency (RF) connectors are part of the electrical circular stream, bringing power and signals throughout a device and tying together all the individual parts so they can successfully interact.

As overall designs shrink, either to enable device streamlining or to make room for other critical components, so must connectors. And that can be a real challenge for designers.

APPLICATIONS DRIVE CONNECTOR MINIATURIZATION

Mobile devices are expected to remain conveniently sized and yet as technology evolves, the demand for incremental electronic functionality grows. Take 5G, for example. New antenna arrays are being added to support the advanced capabilities of 5G.

Likewise, semiconductors incorporate additional functions and have increased I/O needs. And larger batteries needed to meet power requirements or extend operating times are also presenting a significant challenge for designers.

The same challenges have emerged in automobiles, where electronics such as digital cockpits and sensing features have proliferated to such a degree that the total wiring harness is one of the heaviest and most expensive components.

Medical patients want smaller and more comfortable wearables as well. Whether in consumer electronics or medical devices, industrial controls and IoT add more capabilities to become independent edge devices that can process and store data until they can relay it back to a cloud processor.

Connectors frequently become one of the major limiting factors on mechanical size in these critical applications. The pitch size — the distance between the centers of two contacts that are next to one another in a connector — must shrink to fit smaller boards and higher pin densities that support expanding I/O requirements.

Connectors are often a major limiting factor on mechanical size. The pitch size (the distance between the centers of two adjacent contacts in a connector) must shrink to fit smaller boards and higher pin densities that support expanding I/O requirements.

THE NEED FOR INNOVATION

Making things smaller to accommodate the needs of users and industries is one challenge. However, there are other design limitations and requirements.

Connectors often don’t perform a single duty in devices, but rather carry high-frequency signals like 5G or other cellular and Wi-Fi communications, as well as other forms of signaling and even power. Shielding becomes complex, needing walls between pins but also external enclosures for the connectors.

The small sizes of pins and contacts leave less material to make a given connection, which then puts stricter limits on the amounts of signals or even power they can carry. The smaller geometries can then create additional thermal issues, with smaller connections creating more resistance and then having to dissipate the resulting heat.

The compressed nature of component layout and smaller physical space around assemblies also means less room to channel air to cool components and connectors alike.

Smaller connectors result in less capacity to carry signals and may increase signal loss. Selecting the right type of connector and designing it into the proper location on a printed circuit board can have a major impact on the form factor and overall signal-to-noise ratio performance.

MANUFACTURING CHALLENGES

If electrical considerations require inventive thinking, so does engineering for manufacturing.

Miniaturized connectors present many hurdles that a manufacturer must learn to clear.

Connectors can be very small, which can make them difficult for humans to assemble — especially when a connector can be the size of a grain of rice.

These smaller connectors are also more fragile, breaking easily if not handled with proper care. This can make assembly more complex and time consuming, whether done by a machine or a person.

Slightly too much exertion of force on a factory line can destroy not only the connectors but the overall assembly units, resulting in tremendous operation costs. These challenges become exponential when factory line workers are often required to handle thousands of connectors each day.

In addition to the fragile nature of miniaturized connectors, manufacturers face a number of other considerations when designing with them. These include an understanding of how to repair a broken connector, dialing in the correct mating force and factoring in the required geometry based on the layout of an assembly or device.

All of these manufacturing challenges make choosing the right connection partner an essential step in the design process.

SUMMING UP THE BIG PICTURE OF SMALL COMPONENTS

Not only is manufacturing electronics with such small connectors a challenge, but so is making the components themselves. And for many designers, connectors can be an afterthought.

Indeed, in a world of exciting details about the latest “cool” device, connectors can be overlooked — but their importance cannot be understated.

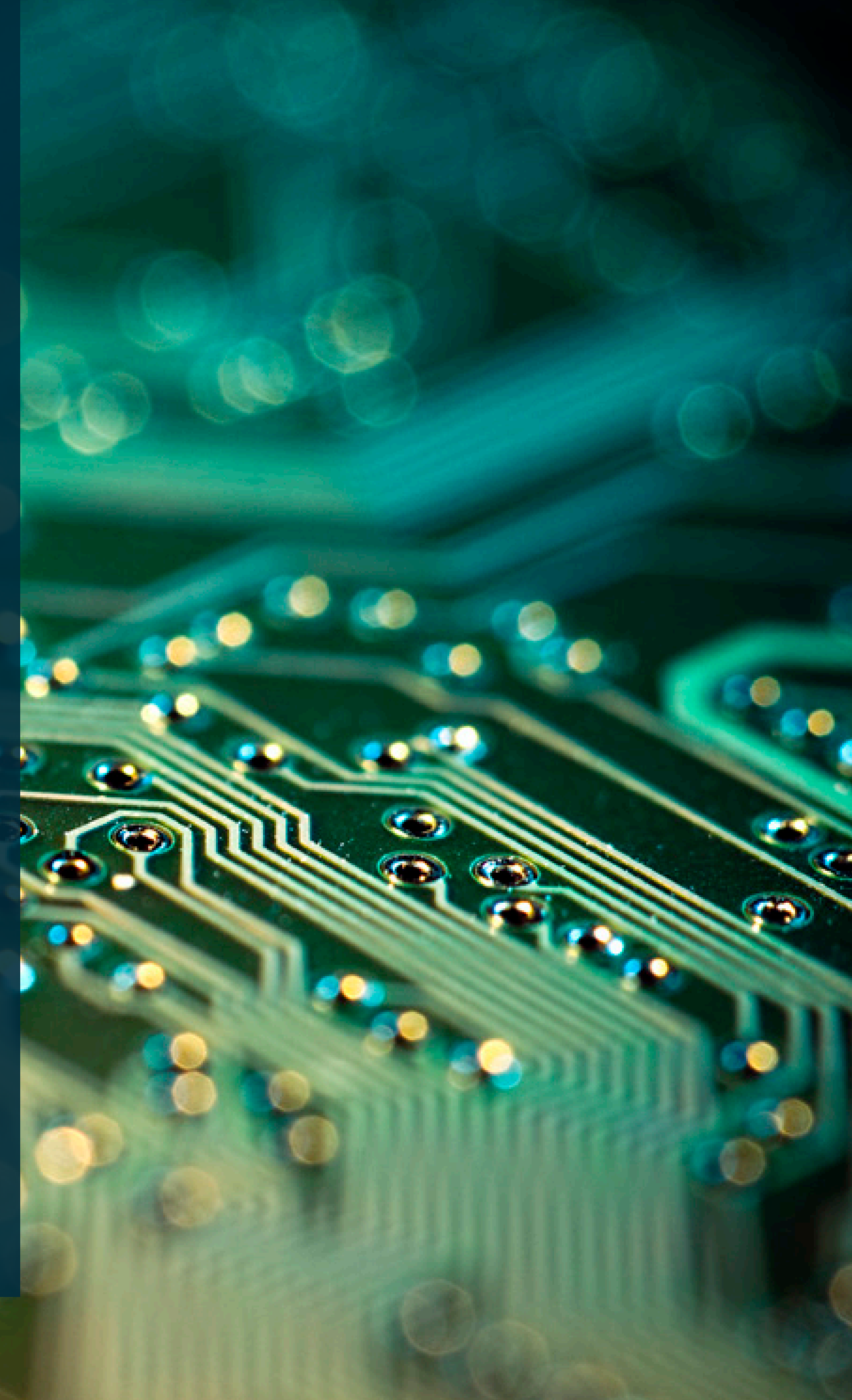
Case in point, Molex has developed an **entire line of micro connectors** to support the ever-shrinking requirement of electronics applications.

With a variety of wire-to-board, blade, ribbon, wire-to-wire, milli-grid, micro TPA, board-in, board-to-board, FPC, FFC, board-to-FPC, IEEE 1386, USB and HDMI connectors, Molex has both the range of existing products and the expertise to help companies develop unique solutions to their connector needs.

Our mission is to serve as your expert partner as you break new ground (with smaller products). Molex engineers work collaboratively with your team to deliver systems optimized for cost and quality.

Our proven legacy of design, production expertise, advanced manufacturing capabilities and extensive supply chain management enables us to offer a broad portfolio of connectors, sensors, antennas and more ideal for any miniaturization effort.

EXPLORE THE MOLEX MINIATURIZATION SOLUTION PORTFOLIO



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