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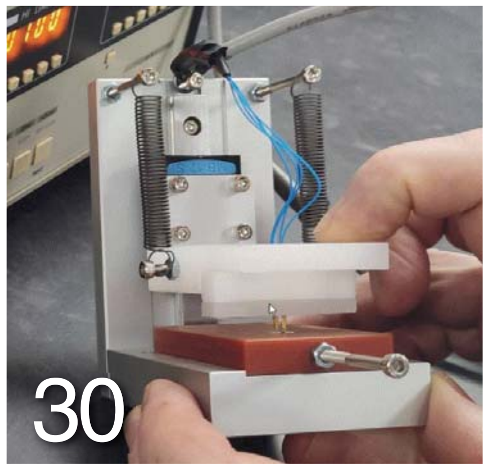

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To provide the most current, accurate, and in-depth technical coverage of the key emerging technologies that engineers need to design tomorrow's products today.

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Editorial

WILLIAM WONG | Senior Content Director

The Evolution of Ethernet

Venerable Ethernet provides the backbone of the internet.

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A LOT HAS CHANGED with Ethernet, but not when it comes to compatibility. My house is wired for 10Base2. That's 10-Mbit/s coax. It also has CAT6 connected to a 52-port Ethernet switch Power-over-Ethernet (PoE). The PoE support powers my security cameras. The switch handles fiber, although I've only used that in installations where I needed distance and isolation. I finally retired my last coax device over a decade ago, but it was on the same net as a 10-Gbit Ethernet.

Though keeping track of the many Ethernet-related standards can be a challenge, at least they work together. The Ethernet Alliance has put together a set of video interviews called "The Voices of Ethernet," featuring Ethernet notables like Robert Metcalfe and Gary Robinson.

Ethernet is pushing the throughput envelope with the 800GBASE-R standard. This may seem fast, but even faster speeds are needed to feed the cloud monster. At this point, there's no such thing as fast enough. Fiber is the norm for these speeds, although engineers continue to tweak copper connections.

Industrial applications tend to require less bandwidth. However, timing remains critical. The IEEE 1588 precision time protocol standard has been useful, but time becomes very interesting with time-sensitive networking (TSN). 1588 works over any Ethernet network and synchronizes clocks on end nodes; TSN is a bit more demanding on switches and interfaces. TSN also provides real-time synchronization and data exchange that can make industrial automation operate faster, more accurately, and safer.

Ethernet is popping up in other areas ranging from robotics to cars. With TSN, Ethernet offers time synchronization provided by networks like CAN while delivering data faster. These new arenas also have fostered new standards like single-pair Ethernet. The 100BASE-T1 and 1000BASE-T1 standards are being employed in cars, and they're ideal for industrial and robotic applications as well. TSN and PoE are in the mix for these standards, too.

Cutting the number of wires to two saves cost and weight. It also foregoes the ubiquitous RJ-45 connectors that are familiar to most Ethernet users. It's possible to use other connectors for conventional Ethernet, but that's generally limited to rugged applications. Even many robots use these internally, simply because switches and adapters already include them.

Wireless technologies like 5G, Wi-Fi, Bluetooth, and LoRaWAN may be the darlings of IoT devices. Still, it's Ethernet that makes IoT possible. ed

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A research team developed an "acoustic fabric" that works like a microphone, converting sound first into mechanical vibrations and then into electrical signals.

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What's New in Quantum Computing?

Many businesses are already working on various ways to create large, stable qubits that will power the quantum future. But how close are we to this, and what do we need to do to get there?

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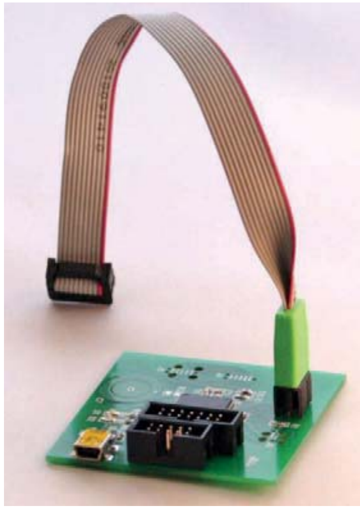

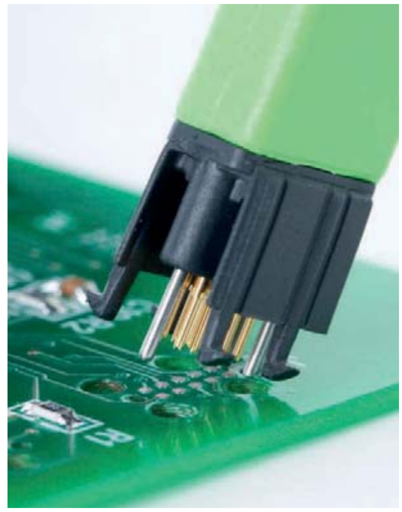

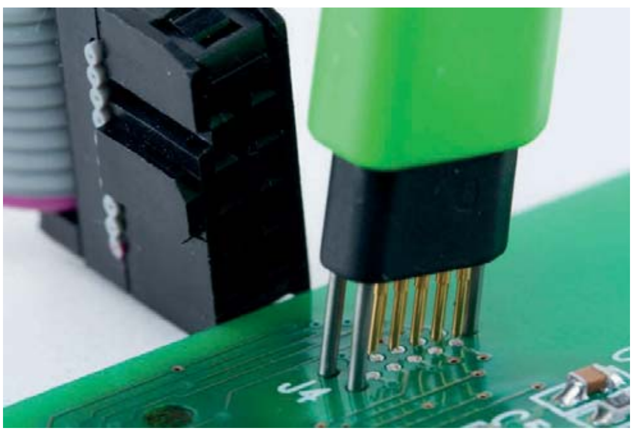

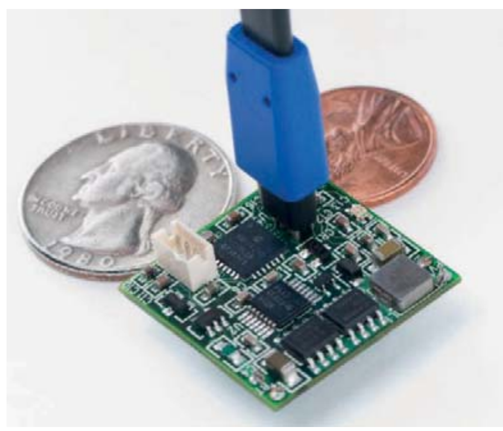

ALIX PAULTRE | Editor-at-Large

The expanding world of advanced electronic systems places even more importance on the connections between them, especially the hard wiring.

Image: Kirill Makarov 24503816 | Dreamstime

System Connectivity is Crucial to Functionality, Reliability, and Safety

In our advanced, connected, electronically oriented society, device-based solutions are penetrating more application spaces than ever. This expansion places hardware systems into extreme situations that they must be prepared to handle.

Most think that exposing hardware to wet and dirty situations is all they have to worry about when it comes to harsh environments. While that assumption is mostly correct, it's incomplete. In addition to moisture and dirt, electronic systems intended for use in challenging environments must be able to handle vibration, shock, and thermal situations as well *(Fig. 1)*.

1. Electronic systems intended for use in challenging environments must be able to handle moisture, dirt, vibration, shock, and thermal situations. *Image: Fotomy 1915955 | Dreamstime*

This is especially important in government- and municipality-oriented application spaces such as military/aerospace and civil engineering, where failure may not only result in loss of human life, but could contribute to a significant civil, political, or strategic impact. Mission failure in these situations is unacceptable, and demand not only the best-performing solution available, but also one that's safe and reliable in the field.

Even though a complex electronic system may be highly sophisticated, unless the interconnections between the subsystems involved are robust and rugged, the overall design is at risk of failure. Like any chain, a system is only as good as the performance of its least-capable link.

Addressing Survivability

Connector safety and reliability is an aspect that cannot be overstated. A poorly designed plug polarity and fit may not only present risk in operation—if the connector interface is poor to lock in place or difficult to implement, it could cause user workarounds that can result in even greater risk situations to operators and equipment.

The performance of the cabling and interconnects are directly related to the safety of the facility and its operators (*Fig. 2*). For example, on January 26, 2013, on a Spartan Offshore Drilling rig operating for Bois d'Arc Exploration offshore in the Gulf of Mexico, a worker for Baker Hughes, a cementing contractor, was troubleshooting an electronic failure. Evidence suggests that he suspected a discharged battery in a box that supplied dc power as the problem.

Unfortunately, when he attempted to fix the problem by plugging in a 115-V three-wire extension cord, he was subsequently killed by electrocution. A Bureau of Safety and Environmental Enforcement (BSEE) panel investigated the incident, determining that at some point prior to the fatal incident, moisture entered the electrical connection of the battery box and extension cord. This was caused by a short-circuit in the female plug end of the extension cord, which had a burned-out ground wire inside.[1]

This human loss could have been prevented if the cable and connection systems involved were rugged and reliable enough to ensure proper operation under any foreseeable environmental condition. Heat, humidity, dust, and vibration are safety and reliability challenges, and both the operator and the equipment are key implications when addressing systems deployed in harsh environments.

The quest for optimum performance, safety, and reliability begins at the board level. If the subsystem can't handle high temperatures, shock, and vibrations, good cables can't fix package-level issues. There are many ways to address these issues, including recently introduced materials that can handle high temperature, radiation, shock, and even chemically corrosive environments for extended periods.

2. The performance of the cabling and interconnects are related to the safety of the facility and its operators. *Image: Auremar 160939515 | Dreamstime*

In addition to wide-bandgap (WBG) semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) on the chip side, other solutions like aluminum nitride (AlN) can replace beryllium oxide (BeO) in the semiconductor industry. Not only does AlN address BeO's toxicity, its thermal expansion coefficient is lower than BeO or alumina, closely matching that of silicon wafers.

This enclose-and-protect approach extends to the packaging, which must be made of materials appropriate to the application as well as be resistant to environmental extremes. Beyond encompassing the system, the enclosure presents the user interface and I/O capabilities to the world. Any packaging must not only address form and function, but also harsh-environment resistance. Even the most basic electronic products can leverage legacy solutions like board cladding, potting for thermal transfer and shock absorption, and ruggedized packaging.

Only by providing a reliable and secure anchor for the connection can the link be trustworthy. This starts at the board level and percolates upwards to every aspect of the system architecture. Then the right interconnect solutions can ensure the safety and intended performance of the system as a whole.

Gasketing and filtering are critical considerations, too. Furthermore, any non-convection thermal-management solutions involving cooling and/or heating must address issues such as the integrity of vents and fan protection from the environment.

Standards and Compliance

When it comes to performance, many industries have a variety of standards to address legacy products and/or developing core technology capabilities. For example, when it comes to Ethernet, you can use Cat5, Cat6, or Cat7 cabling and connectors, depending on bandwidth requirements.

In a deployed system, it's important to ensure that all network components support the highest category level presented by a given subsystem. Mixing Cat5, Cat6, or Cat7 cables and connectors on the same network can easily result in degraded system performance.

However, safety must always be standardized at the highest level, which is why it's one of the aspects of a product that's almost always regulated by the governments and/or markets involved. This means that not only must your design satisfy your safety and performance goals, it also must satisfy industry and government regulations and standards. If properly planned, your design can easily accomplish both, but only with proper knowledge and foresight.

For example, ODVA, an international association of leading automation companies, uses the M12 Ethernet standard, a 4-position, D-coded connector for industrial Ethernet applications. The M12 protects against dirt, water, vibration, shock, and temperature extremes, suiting it for harsh industrial environments. However, by planning for such specified solutions in early development, you can ensure ease of compliance.

This extends beyond metal wires, as fiber-optic cabling for industrial applications gains in popularity. Requirements like the ANSI/TIA-568 family of Telecommunications Standards address balanced twisted-pair, optical-fiber, and coaxial cabling, which are constantly updated with the latest TIA telecommunications cabling specifications.

The American National Standards Institute (ANSI) mandates standards must be confirmed, updated, or eliminated every five years. Consequently, the ANSI/TIA-568 family of Standards has undergone three sets of revisions since initial publication in 1991.

Sweeping Automotive Standards

Addressing standards in multiple markets—e.g., when making automotive products—is very important. For example, LVDS, LV214, and USCAR are three significant automotive standards, and any automotive solution intended for multiple markets needs to address them. LVDS stands for Low-Voltage Differential Signaling, a global generic interface standard for high-speed data transmission, which is being applied in automotive systems like electronic braking.

Safety aspects in a connectivity solution for automotive involve critical features like Terminal Positioning Assurance to ensure the correct positioning and retention of the crimp terminal in the housing. In addition, Connector Positioning Assurance specifies that two mating halves must lock in their final position. Another important requirement involves connector polarization to avoid incorrect mating, or the specific crimping force to use in automotive wire harnesses.

The latest automotive system designs employ high-performance inter-device communication systems using high-speed I/O connectors like HSD, HSBridge, NETBridge, USB, and HDMI. These need to be validated to USCAR specifications and LVDS protocols to address advanced automotive designs with demanding requirements.

No matter how functional and powerful the automotive system, all of its advantages are lost if the interconnects and other connection solutions that carry the data between the subsystems and the vehicle logic fail to do their job, or fail under environmental stress, or pull out under the wrong conditions *(Fig. 3)*.

3. All of the advantages of even the most powerful automotive systems would be lost if failure occurs with the interconnects and other connection solutions that carry the data between the subsystems and the vehicle logic.
Image: Erchog 208492500 | Dreamstime

These issues transcend automotive and impact every modern application space involving electronics. From the user interface of a product to the control electronics on the board to the power supply, every part of the system needs reliable, capable connections for both power and signal. These cable and connector solutions also must continue to migrate upwards in capability, performance, and reliability along with the capabilities of technology.

This applies especially to application spaces known to have harsh operating environments. For example, in Europe, heavy commercial and industrial connectors are made to IEC 60309 and standards based on it like BS 4343 and BS EN 60309-2. Often referred to in the UK as CEE industrial, CEEform, or simply CEE plugs, the maximum voltage rating of IEC 60309 connectors is 1000 V dc or ac with a maximum current rating of 800 A. Plugs are available in unbalanced single-phase with neutral; balanced single-phase; three-phase without neutral; and three-phase with neutral, at currents up to 200 A.

Military and aerospace systems have requirements for every aspect, and quite a few are related to safety and performance. For example, MIL-DTL-83723F covers the requirements for the environmental resistance of circular, electrical connectors and their associated contacts and accessories. Hermetic receptacles with non-removable contacts must operate from −65 to 200°C.

Compliant with the MIL-DTL-83723 standard, EN2997 is a related connector specification for applications in extreme environments such as engine aircraft applications, where vibrations, EMI, and high temperature issues are paramount.

Considering Connectivity

It's important to remember that the connectors attached to an enclosure are an integral part of that enclosure's integrity and reliability. Cables and connectors must be able to withstand the same external environment extremes in temperature, pressure, and moisture as the systems they connect. This is further complicated by issues like permissible cable flex and stretch, as well as potential user error in attaching the connector.

The construction and material of any given plug directly impacts performance. Using high-grade, corrosion-resistant materials, along with plating and contact finishing, will ruggedize connectors, leveraging the packaging's encapsulation and gasketing. Where systems are expected to be exposed to water, having secure and waterproof connections are vital. Connector design also impacts performance, as poor termination haptics can increase user error, resulting in a failed or improper seal.

Moreover, it's important to remember that environmental hazards include insects, birds, and vermin that may gnaw on things like insulation and potting. The interconnects and electronic systems involved are equally co-dependent, forming an integrated structure that must function together to provide the functionality and performance desired. This is especially important in applications where system failure can result in significant loss of life and property.

These performance demands are in addition to the basic need to address the power and signal requirements of the device(s) involved. Every hole in the enclosure is an ingress opportunity that can lead to potential failure of the system. Connector failure can bypass any packaging precautions, enabling hazards to bypass protections. In some cases, it's also important to pay attention to aspects like matching the coefficient of thermal expansion between the various connected systems, so as not to cause stress or fracture risk from temperature cycling.

In most industrial applications, a connector with an Ingress Protection Rating of IP65 or IP67 is desired to protect against anything entering the connector and degrading performance. A connector designed for industrial applications typically has a positive locking mechanism with a sealing gasket to protect against contaminants and vibration. Every cable and every connector in a given system must be as robust and reliable as every other component in that system, or it has the potential for compromise.

The connection should be easy and intuitive to make—any misalignment error can lead to situations that may cause failure of the system. It's important to have very obvious and intuitive connection mechanisms, especially where cables are often coupled and uncoupled for things like battery swaps and maintenance. A rugged connector with reliable contact technology reduces qualification and maintenance costs.

Properly assessing the required performance and environmental performance, as early as possible in the design phase, will create a durable product that can perform as desired in a cost-effective manner, anywhere it may wind up. Using available resources, from the open-source community to the component, enclosure, and interconnect vendors, will reduce the design burden and maximize available resources. ed

REFERENCE

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HENRY MUYSHONDT | Senior Manager, Automotive Infotainment Systems Group, Microchip Technology

Single-Pair Ethernet Comes Just in Time

Industrial facilities and automakers needed a cost-effective connectivity solution for low-data-rate devices, and 10BASE-T1S and 10BASE-T1L deliver it with low cost and simplicity.

The world is awash in data-communication protocols, with most of them designed to deliver the highest possible data rates. However, the vast majority of devices, such as switches and actuators, are simple, don't produce massive amounts of data, and thus don't require high-speed communications. There are billions of them worldwide and their numbers are growing exponentially.

What's been needed for some time is a single, simple, low-cost data-communication solution that can serve all of these devices in industrial, automotive, and other markets. The solution appeared in late 2019 in the form of the IEEE's 802.3cg standard. As we'll see, it has immense potential because it brings low-cost, single-pair Ethernet cabling to the edge of the network.

The initiative for the standard came from an IEEE task force studying how to provide a low-speed technology that could cover very long distances and deliver a data rate of 10 Mb/s over a single, balanced pair Ethernet cable. In addition, there was a desire to have multidrop capabilities over shorter distances. Although 10 Mb/s doesn't sound impressive, it's more than enough to control a switch, relay, actuator, or robot arm and many other devices, and at the time, "Industrial Ethernet" had no version that could provide these capabilities in a cohesive manner.

Automakers in the task force requested a shorter-reach solution with the same basic capabilities along with multidrop capability, in which each node connects to a single cable. It thus eliminates the need for a switch and requires fewer lines, switch ports, and transceivers. This version would use Ethernet for everything, from the lowest to the highest speeds.

In the end, almost everyone got their wish, which resulted in Ethernet 10BASE-T1S for distances up to at least 25 m and 10BASE-T1L that covers up to 1 km. They joined 100BASE-T1 and 1000BASE-T1 in the family collectively known as single-pair Ethernet (SPE). The transmission medium ranges from a single twisted pair of wires to other wire-pair configurations and parallel traces on a printed circuit board (PCB) or server backplane. All are easier to install, lighter, more flexible, and less costly than alternatives *(see table)*.

The Basics

Other than their maximum transmission distances, two primary differences exist between 10BASE-T1S and 10BASE-T1L. First, only 10BASE-T1S offers multidrop as well as point-to-point connection ability. The second is that only 10BASE-T1S employs Physical Layer Collision Avoidance (PLCA), which is a key ingredient when used in real-time applications that require deterministic performance such as automotive, industrial, and building automation *(Fig. 1)*.

PLCA is designed for half-duplex, multidrop networks such as 10BASE-T1S. It eliminates the problems with Carrier Sense Multiple Access with Collision Detection (CSMA/CD) in multidrop mixing segments.

CSMA/CD can exhibit random latencies caused by data collisions. PLCA provides guaranteed maximum latency and other characteristics that overcome these limitations. With PLCA in place, the transmission cycle begins with a beacon sent by a coordinator node (Node 0) that the network nodes use to synchronize.

After the beacon is sent, the transmit opportunity passes to Node 1. If it has no data to send, it yields its opportunity to Node 2, and so on, with the process continuing until each node has been offered at least one transmit opportunity. A new cycle is then initiated by the coordinator node, which sends another beacon.

Standard	Cable length (m)	Data rate	Duplex Capability	Wires
10/100/1000/10GBASE-T	100	10 Mb/s to 10 Gb/s	Full	4 to 8
10BASE-T1S	>25	10 Mb/s	Half or full	2
10BASE-T1L	1000	10 Mb/s	Full	2
CAN	500	1-10 Mb/s	Half	2
FlexRay	40 (at 1 Mb/s)	10 Mb/s	Full	2

Comparison of connectivity standards.

To prevent a node from blocking the bus, a jabber function interrupts a node's transmission if it exceeds its allotted time, allowing the next node to transmit. The result is that there's no impact on data throughput and no data collisions on the bus.

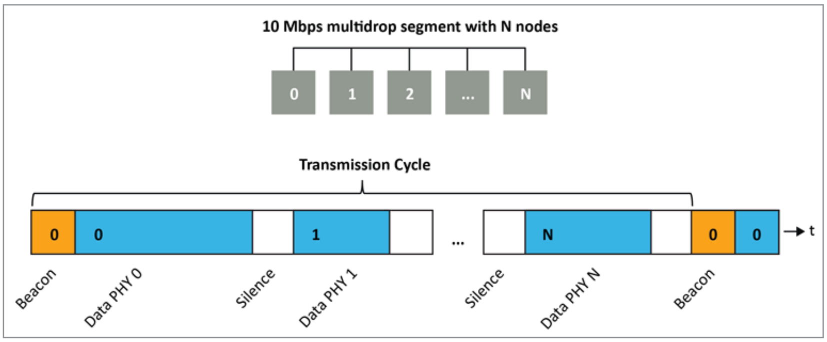
Both solutions have considerable benefits, not the least of which is that Ethernet is globally ubiquitous in both the information technology (IT) and operational technology (OT) worlds, is well-understood, and is supported by hundreds of companies. Its cost is relatively low and decreasing, and it has maintained its core structure through every iteration from inception. This means that when Ethernet is the primary communication protocol used in a system, there's no need for protocol conversion and the gateways required to perform it.

Every kind of device can be supported without conversion, from the simplest low-data-rate switch to high-data-rate sensors such as cameras that produce vast amounts of data and require gigabit-per-second speeds. They can all be aggregated in an Ethernet switch and sent on to the cloud at Ethernet's highest data rates for processing and analysis *(Fig. 2)*.

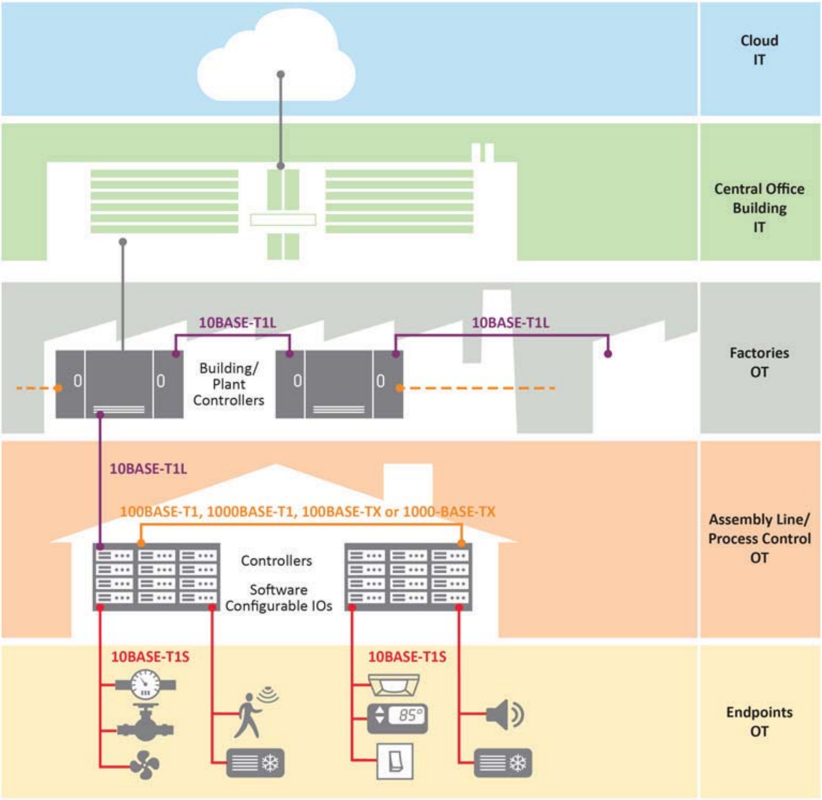
Rewards for Automakers

Settling on a single protocol for most functions has monumental benefits for automakers faced with supporting not just the CAN bus, but multiple application-specific standards. Every model year brings enhancements to advanced driver-assistance systems (ADAS) systems, often requiring new cameras, radar, ultrasound sensors (and LiDAR in the future), as well as changes to infotainment and navigation systems.

The result is that in today's vehicles, it's not uncommon to have 40 different wiring harnesses, 80 to 100 electronic control units (ECUs), and 300 wires that collectively span 2.5 miles and weigh up to 250 lb. The multiple types of cables required for various applications also present electromagnetic-compatibility (EMC) challenges as each one has its own requirements.



1. Shown is the Physical Layer Collision Avoidance (PLCA) architecture, which is designed for half-duplex, multidrop networks such as 10BASE-T1S. It eliminates the problems with CSMA/CD in multidrop mixing segments.



2. How Ethernet extends from the edge to the cloud.

To meet the demands of cars that will soon employ hundreds of millions of lines of code compared with 100 million lines today, the industry is transitioning to an Ethernet-based zonal electronic/electrical (E/E) architecture. It aggregates sensors into a single link from the zonal gateway to a backbone *(Fig. 3)*.

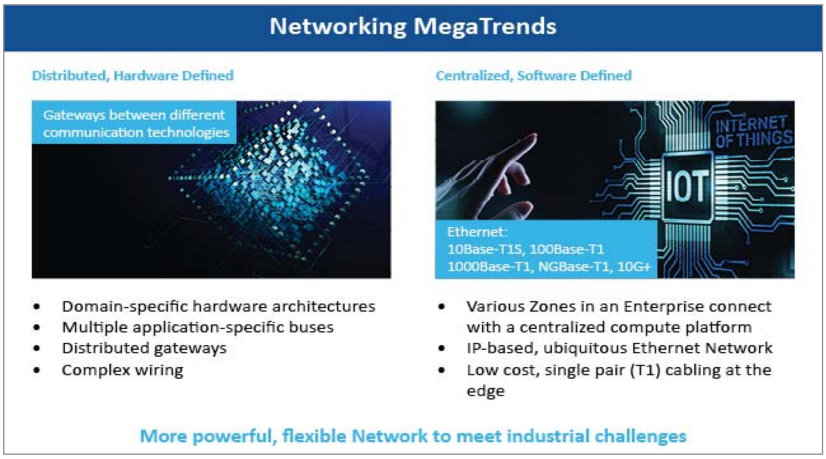
It's based almost entirely on Ethernet, whose plug-and-play capabilities are uniquely suited to the service-oriented environments that will define vehicles in the future. Devices can be connected and disconnected in real-time, with no downtime—a significant advantage over CAN buses. That said, the CAN bus has served the auto industry well for many years and it continues to do so for those applications for which it's best suited, so it will likely be retained for years.

An Industrial Solution

Although the auto industry stands to benefit most from 10BASE-T1S, the industrial sector can benefit substantially from 10BASE-T1S and 10BASE-T1L for several reasons. First, industrial facilities use many different communication technologies to interconnect devices, from I_2C to RS-485, UARTs, and CAN, and they connect everything from control cabinet wiring to temperature sensors, HVAC actuators, elevators, fans, voltage monitors, dc-dc converters and other modules, and computer backplanes. Many of these devices require only low data rates that the standards are designed to serve.

Although it's not yet a major topic of discussion, it can play a key role in IoT by connecting devices that would otherwise use one of the various short-range wireless solutions such as Zigbee, Bluetooth, or Wi-Fi. As many early adopters have learned, making wireless "work" for IoT is easier said than done. These solutions will obviously play an immense role in industrial IoT, but they needn't be the only solution considering Ethernet's benefits.

Next, 10BASE-T1S multidrop capability enables many devices to be connected, removed, or replaced without affecting overall network performance, and the process is very simple. Finally, Ethernet is invariably already present in almost every facility, so moving outward from the cloud to the edge can be accomplished with a single standard. It's also important to note that as industry moves to its fourth generation, the zonal approach is being applied



3. Among today's automotive networking megatrends is the transition to an Ethernet-based zonal electronic/electrical architecture.

in this market, too, and Ethernet is the chosen solution. There are other benefits, but these alone make SPE very appealing.

The First Transceiver

Implementing 10BASE-T1S requires Ethernet transceivers that support it. The first of these, which serves 10BASE-T1S, is Microchip's LAN867x family of Ethernet transceivers. The LAN8670/1/2 allows for the creation of both multidrop and point-to-point network topologies. Point-to-point link segments of up to at least 15 m are supported and multidrop mode supports up to at least eight transceivers connected to a common mixing segment of up to 25 m.

Note that these are "minimum maximum" in the IEEE specifications. More nodes and longer distances are possible when system implementers verify proper operation. The transceiver operates from a single 3.3-V dc supply and has an integrated 1.8-V dc regulator. It can be used in harsh environments as its temperature range is –40 to +125°C, and is compliant with industrial EMC and EMI requirements.

The LAN8670/1/2 supports communication with an Ethernet MAC via standard MII/RMII interfaces, and an integrated serial-management interface provides fast register access and configuration at up to 4 MHz. Access to the physical medium is managed by CSMA/CD or by PLCA, allowing for high-bandwidth utilization by avoiding collisions on the physical layer and burst mode for transmission of multiple packets for high-packet-rate, latency-sensitive applications.

To give designers an easy way to move into 10BASE-T1S, the company offers RMII and MII evaluation boards that fit on many Microchip MCU boards, or they can be in designs created by the user. Another evaluation board can be plugged into a USB host to make it a 10BASE-T1S node, and it's supplied with drivers for both Linux and Windows. In addition, the company's MPLAB Harmony Development Framework includes support to integrate 10BASE-T1S technology with its microcontrollers and microprocessors.

Summary

The release of IEEE's 802.3cg SPE standard could not have come at a better time, as Industry 4.0 begins to take shape. Industry 4.0 and the auto industry are racing toward simplifying their massive connectivity problem while also adding more sensors and other connectable devices every year.

Both 10BASE-T1S and 10BASE-T1L pave the way for extending the reach of Ethernet to the edge of the network, providing support for low-data-rate devices that have no need for gigabit speeds using simple two-conductor cables. In short, it has the potential to dramatically change the way these devices are connected in both industrial settings and every type of vehicle. ed

- Workshops
- Technical Lectures
- RFIC
- Bootcamp
- Three Minute Thesis
- IMS
- Panel Sessions
- Connected Future Summit
- Exhibitor Activities
- Focus Groups
- ARFTG

AT A GLANCE

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	Sunday 19-Jun-22	Monday 20-Jun-22	Tuesday 21-Jun-22	Wednesday 22-Jun-22	Thursday 23-Jun-22	Friday 24-Jun-22
Workshops	Workshops	Workshops				
Technical Lectures	Technical Lectures	Technical Lectures			Technical Lectures	
RFIC Plenary Session, Reception, Industry Showcase	RFIC					
Quantum Bootcamp	Bootcamp					
RF Bootcamp		Bootcamp				
RFIC Technical Sessions and Interactive Forum		RFIC	RFIC			
Three Minute Thesis		Three Minute Thesis				
IMS Plenary Session and Welcome Reception		IMS				
IMS Technical Sessions and Interactive Forum			IMS	IMS	IMS	
Panel Sessions		Panel Sessions	Panel Sessions	Panel Sessions	Panel Sessions	
Connected Future Summit			Connected Future Summit			
Exhibition			Exhibitor Activities	Exhibitor Activities	Exhibitor Activities	
MicroApps and Industry Workshops			Exhibitor Activities	Exhibitor Activities	Exhibitor Activities	
Amateur Radio Talk and Reception			Focus Groups			
Young Professionals Talk and Reception			Focus Groups			
Industry Hosted Reception				Exhibitor Activities		
Women In Microwaves Talk and Reception				Focus Groups		
IMS Closing Ceremony and Awards					IMS	
99th ARFTG						ARFTG

ROGER FRANZ | Engineering Systems Analyst and Project Manager, TE Connectivity
SIGRID ROTZER | Researcher, Fraunhofer Institute for Reliability and Microintegration IZM
PRATYUSH RAI | Founding Engineer and Chief of Research & Development, Nanowear Inc.
VLADAN KONCAR | Distinguished Full Professor (Classe exceptionelle), ENSAIT

New IPC Standards Help Engineers Weave Through the World of E-Textiles

Developing standards for the rapidly expanding e-textile industry has become more vital than ever. This article discusses the standards put in place by the IPC, and those that are under development.

Electronic designers rely on standards for device interoperability, design reuse, quality, lower product-development costs, and increased competitiveness on a level playing field of global collaboration *(see "Don't Underestimate the Value of Standards," www.electronicdesign.com)*. Even non-technical users of electronic goods benefit as well, probably without thinking about it. Unless, for example, in their new computer purchase, they see Wi-Fi specified as conforming to IEEE 802.11. IEEE standards may be the most familiar since there are some 1,300 of them.

Within the area of printed-circuit technology, IPC standards provide comprehensive coverage with more than 300 standards including both electronic design and manufacturing *(to see the IPC Standards Tree, go to https://www.ipc.org/media/2547/download)*. IPC.org is a global trade association dedicated to furthering the competitive excellence and financial success of its members, who are participants in the electronics industry.

In pursuit of these objectives, IPC devotes resources to management improvement and technology enhancement programs, the creation of relevant standards, protection of the environment, and pertinent government relations. IPC encourages the active participation of all its members in these activities and commits to full cooperation with all related organizations *(to participate, see link at the end of this article)*.

As a non-profit, member-driven organization and leading source for industry standards, training, industry intelligence, and public policy advocacy, IPC is the global association that helps OEMs, EMS, PCB manufacturers, and suppliers build electronics better. More than 3,000 companies around the world depend on IPC programs and services to further their competitive advantage and financial success. IPC members represent all facets of the electronics industry, including design, printed board manufacturing, electronics assembly, and testing.

Table 1: IPC E-Textile Standards

Standard	Title	(estimated) Release Date
IPC-8921	Requirements for Woven and Knitted Electronics Textiles (E-Textiles) Integrated with Conductive Fibers, Conductive Yarns and/or Wires	05/2019
IPC/JPCA-8911	Requirements for Conductive Yarns for E-Textiles Applications	Future
IPC-8952	Design Standard for Printed Electronics on Coated or Treated Textiles and E-Textiles	End of 2022
IPC-8971	Requirements for Electrical Testing of Printed Electronics E-Textiles	Mid 2022
IPC-8981	Quality and Reliability for E-Textiles	Early 2023

The Standards

In this article, we report on standard activities for e-textiles. These materials have been known by various names: ultra-flexible circuits, printed electronics, functional fabrics, technical textiles, wearable technology, smart fabric, smart textiles, and so forth. The currently published E-textiles Standard, IPC-8921, Requirements for Woven and Knitted Electronics Textiles (E-Textiles) Integrated with Conductive Fibers, Conductive Yarns and/or Wires, includes 20 new terms and definitions for e-textiles.

Table 1 is a summary of the IPC e-textile standards, including those being developed.

IPC-8921: Requirements for Woven and Knitted Electronics Textiles (E-Textiles) Integrated with Conductive Fibers, Conductive Yarns and/or Wires

As noted in IPC's press release:

Developed through input from 140 members of the IPC D-72 Textiles Materials Subcommittee, IPC-8921 establishes classifications and designations for e-textiles integrated with e-fibers, e-yarns, and e-wires, and standardizes key characteristics, durability testing, and industry test methods. Key characteristics include electrical resistance, electromagnetic immunity, thermal conductivity, coefficient of thermal expansion (CTE), specific heat capacity, thermal shock resistance, outgassing, T_g, and melting point.

IPC-8921includes 20 new terms and definitions for e-textiles and quality-assurance provisions and test frequency. It's the first baseline compilation that merges the textile industry and electronic performance attributes in one document. When used as a benchmark of e-textile performance, e-textile products can be analyzed and compared for use in any application. Development expectations and outcomes may be shared between user and seller for transparency.

A publicly available preview at the IPC.org website shows the Table of Contents of the complete standard document. Sections on Scope and Applicable Documents, General Requirements are followed by Key Characteristics Durability, Quality Assurance Provisions, and Packaging. The published standard is available at the IPC Webstore.

But this standard was only the beginning. Next, we highlight the current state of development of other upcoming standards.

IPC-8981: Quality and Reliability for E-Textiles Wearables

As the e-textile market continues to grow, comparable quality and reliability standards across the multitude of e-textile applications become a necessity. Thus far, there are no proper e-textile reliability standards, so e-textile manufacturers look to other, related fields where such standards already exist.

1. Textile-based medical monitor using a smartphone for Bluetooth wireless data. *(Courtesy of Nanowear Inc.)*

Faced with the unique challenge of combining two worlds—electronics and textiles *(Fig. 1)*—with often very different materials, properties, and requirements, those standards often fail to meet e-textile specific needs. This situation resulted in the efforts to establish the standard *IPC 8981 Quality and Reliability for E-Textiles Wearables,* starting back in 2019 with a survey among industry and research stakeholders.

This survey aimed at gaining insight into which quality and reliability characteristics (mechanical, e.g., bending or abrasion resistance; or exposure, e.g., temperature or UV resistance) were deemed important for different application areas for e-textiles (fashion, sports, medical, military). Based on the results of the survey, a five-task plan to develop the standard was conceived. The following is an overview of the tasks and progress achieved to date.

Task 1: E-Textiles Wearables Terms and Definitions

To determine the scope of the standard and clarify essential terms and concepts, e-textile, wearable, and e-textile wearable were defined at the start of the standardization process. Finding the definitions was not as straightforward as it may seem. Although many people working in the textile and electronics field do have an idea of what those terms mean, those ideas don't necessarily overlap, emphasizing the need for standardization.

Task 2: Establishment of Guidelines for Manufacturers

Conceived as an accompanying document to the main standard, the guidelines are intended to provide users with information relevant to the requirements presented in the standard. In addition, general information about e-textiles, applicable production tools and processes, as well as integration and contacting methods usable to combine electronic and textile components are provided.

The document aims at giving e-textile stakeholders coming from either the textile or electronics sector (or from an altogether different field) an overview of the respective other side necessary for the successful development of e-textile wearables. Especially for those wishing to newly expand their business toward e-textile manufacturing or start a new e-textile-related venture, the guidelines can be helpful.

Even though part of the IPC-8981 standardization effort, the guidelines will be able to function as a standalone reference document for those interested to get started with e-textiles.

Table 2: IPC E-Textile Product Classifications

Class	Name	Description	Example
1	General E-Textile Wearables	Includes products suitable for application categories where the major requirement is function of the completed assembly.	Fashion
2	Dedicated Purpose E-Textile Wearables	Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures.	Sports, low-risk PPE
2 – Single-Use/Short-Term Use	Dedicated Purpose E-Textile Wearables	Includes Class 2 products that are designed to be disposable after one-time or short-time use.	
3	High Performance/Harsh Environment E-Textile Wearables	Includes products where extended lifetime, high reliability, and performance or performance-on-demand are critical; equipment downtime cannot be tolerated; end-use environment may be uncommonly harsh; and the equipment must function when required, such as life support or other critical systems.	Military, PPE, critical medical, professional sports
3 – Single-Use/Short-Term Use	High Performance/Harsh Environment E-Textile Wearables	Includes Class 3 products that are designed to be disposable after one-time or short-time use.	One-time use smart bandage

Task 3: Classification for E-Textiles Wearables

Due to the large number of e-textile applications and resulting variety of products with a wide range of requirements, the implementation of different quality and reliability levels was necessary for the standard. While the initial survey grouped e-textiles according to fields of application, the approach for categorizing e-textiles within the standard is slightly different.

Using existing IPC product classifications for electronics as a basis, three main product classifications for e-textiles have been defined, with a subcategory applicable to classes 2 and 3. *Table 2* gives an overview of the categories and their descriptions.

At the time of writing, tasks 1 and 3 are finished, and the guidelines document exists as an extensive draft document.

Tasks 4 & 5: Creation of a Basic Standard and Establishment of Threshold Levels for Different Characteristics

The survey realized companies and organizations designing and manufacturing, or being interested in e-textiles, at the start of our committee's work, resulted in the establishment of the levels of importance for 22 different e-textile characteristics. The characteristics range from laundering, dry cleaning, water resistance, and stretching to biocompatibility, perspiration, and acid/alkali resistance in the function of the target product category, which are Fashion, Sports, PPE, Military, and Medical.

The survey helped us to define the main groups of characteristics important for e-textiles and define the structure of the IPC-8981 standard for Quality and Reliability for E-Textiles Wearables.

For instance, the mechanical stresses have divided into two groups: Mechanical I (IPC-8981 B series) and Mechanical II (IPC-8981 C series). The chemical, water, UV, microbes, and temperature stresses have been grouped into Exposure I (IPC-8981 D series) and Exposure II (IPC-8981 E series), and finally Cleaning (IPC-8981 F series) and Wearability & Comfort (IPC-8981 G series) groups were added *(Fig. 2 on page 24)*.

The General 8981 group (IPC-8981 A series) contains all of the testing procedures related to the general principles of measurement, the textile motherboard, sensors, electronic modules, and power-supply testing. Each specific stress type in a group corresponds to a testing method.

For example, *IPC-8981 B 01: Abrasion stresses* includes the testing method that should be applied to an e-textile product to test its resistance to abrasion. After testing, the e-textiles' electrical resistance is measured using the method defined in *IPC-8981 A 02: Textile motherboard,* and finally the master document is consulted to define the e-textile product class (1, 2, 2a, 3, or 3a).

To date, task 4 has been finalized and task 5 is focused on the creation of basic standards and establishment of threshold levels for the different characteristics. The structure of the IPC 8981 sub-standards is given in *Figure 2.* The drafts of test methods and the master documents are currently finalized.

The next step will be to send all necessary documents to academic and industrial laboratories worldwide that will validate our test methods and verify the threshold levels aiming at the definition of the products' classes. Laboratories will first have to identify what characteristics they're interested in. Then the corresponding test methods and master document will be sent to them by IPC to assess the quality and reliability of their products and verify that if they belong to the class where they would like to position them in.

Their feedback in the form of reports and a questionnaire will be sent back to IPC and will help improve the IPC-8981 Quality and Reliability for E-Textiles Wearables document.

The task group has a goal of completing this standard by the end of 2022.

IPC-8952: Design Standard for Printed Electronics on Coated or Treated Textiles and E-Textiles

Printed electronics on flex are at the heart of electronics devices prevalent in the fields of wearable monitoring devices, interactive consoles for entertainment and communication, solar cells, RFID tags and antennas for inventory tracking, OLED display screens, and lighting devices.

2. IPC-8981 Quality and Reliability for E-Textiles Wearables structure.

Textile is a ubiquitous material and a flexible substrate for fabricating printed electronics. Printed electronics on textile is an additional layer of functionality integrated into this ubiquitous material present in our apparel, upholsteries, and accessories.

The goal of the IPC-8952 standard is to establish specific requirements for the design of printed-electronics applications (design details, materials, test requirements, mechanical properties, physical properties, thermal management) on textile as a substrate. The standard also established the specifications for methodologies of component mounting and interconnecting structures on coated or treated textile substrates. It aims to introduce a common design language and guidelines for use between user and supplier for any given e-textiles with printed electronics.

While standards exist for flexible printed electronics, they don't consider the variations brought in by coated or treated textiles that are otherwise not seen in a standard flexible substrate. These variations are four-way stretchability, surface roughness, breathability, effects of moisture, coefficient of thermal expansion (CTE), edge effects due to textile manufacturing, and finishing process.

The list of design considerations and guidelines covered in this standard include applicable good design practices from the printed electronics on flexible substrate standards, such as IPC-2292 and IPC-9257. The standard drafting process is scheduled to finish in April of 2022 and then go for an industry review.

IPC-8971: Requirements for Electrical Testing of Printed Electronics E-Textiles

One of the main functionalities of printed-electronics e-textiles is the electrical function of the circuits in the printed electronics. The functionalities related to the printed conductive traces are electrical connectivity, electrical insulation between adjacent printed conductive traces, and leakage current through a given dielectric layer between adjacent printed traces. These originate from their trace width and thickness, distance between the adjacent traces, and the thickness of the dielectric layer.

The IPC-8971 standard outlines the rules for determining adjacent printed conductive traces and type of adjacency using the CAD/CAM drawings of the printed circuit. Based on this determination, the testing requirements are defined using test methodologies such as resistive continuity or isolation, indirect isolation and continuity (by signature comparison of capacitance, RF, impedance), and testing of accessible midpoints. The end-product classifications for electronic devices—Classes 1, 2 and 3—also are considered for defining the test requirements.

The standard provides guidance on considerations for electrical test setup, test techniques, and test equipment. A template for Test Certificate of Conformance is included along with guidance on traceability and statistical process control (SPC) for electrical testing operations. The task group has a plan to complete this standard via ballot by summer 2022.

Looking to the Future

When e-textile circuitry is combined with flexible components enabled by 2D and 3D nanomaterials like graphene, nanowires, nano coils, and advanced printing techniques, we will see new applications beyond health and fitness sensors now entering the market. As this technology continues to develop, you will want to be aware, and make use, of the body of knowledge incorporated into the different standards.

The IPC D-70 standards committee on e-textiles has many activities underway besides those highlighted in this article. All interested parties are invited to participate. There's no cost or obligation to participate, and all of the groups meet primarily via web meetings to enable the most participation. You can get involved in the IPC E-Textiles initiative today. Read more, including how to sign up, at IPC E-Textiles Initiative - Get Involved Today *(https://www.ipc.org/solutions/ipc-e-textiles-initiative-get-involved-today)*.

AUTOMATION CRITICAL: CLEAN RELIABLE POWER IN A COMPACT PACKAGE

This white paper will discuss the critical state of providing DC power to the ever expanding needs of manufacturing automation, including plant floor equipment, robotics, the industrial internet of things (IIoT), and other enterprise resources.

Power management is a huge concern in industrial and manufacturing applications for everything from food and beverage machines to industrial control cabinets and more. Providing clean, reliable power under greater limitations can be challenging. As the lifeblood of automation—whether part of a packaging system, robot or cobot, conveyor system, or any other machine—DC power supplies today must be rugged, compact, efficient, and comply with multiple standards.

Designing for Compactness

Control and power supply equipment are designed to fit into cabinets that protect them from the varied environments equipment is often operated in *(see Figure 1).* These cabinets typically use a DIN rail system to provide quick and easy installation. It doesn't matter whether used in medical equipment, telecommunications, or transportation, the growth of control electronics, sensor systems, and IIoT interfacing means that the space inside a cabinet for additional functions is getting harder to come by.

Figure 1: *Power supplies are a critical component in a wide variety of applications, including telecommunications, industrial panels, water treatment facilities, and conveyors as illustrated here.*

As control cabinets become more tightly packed with electronics the need for systems that can withstand greater temperatures becomes important as well. All this leads to design engineers being continually on the lookout for the latest generation of small, efficient and rugged DIN rail power supplies to incorporate into their equipment. The key element of such supplies include availability, ease of installation, and performance reliability for long life cycles. Furthermore, with a global customer base, companies need a single product range that offers multiple certifications.

Greater Innovation

Design constraints based on these needs spurred innovation in electronic power components and power supply topologies. Switch mode power supplies using high-frequency electronics were able to dramatically boost efficiency, seeing power density rapidly climb together with efficiency and reliability. Advances in electronics like these have evolved through a new generation of power components—such as power transistors, inductors and transformers—which support increases in power density while improving voltage regulation, reducing electromagnetic interference (EMI), and boosting long-term reliability. All told, these advancements have allowed for products supplying 480 W to now fit into the space formerly occupied by 120 W power supplies *(see Figure 2)*.

Multiple Solutions

As such an important component in any piece of industrial equipment, Altech has designed and manufactured a series of ultra slim metal case DIN rail power supplies for industrial applications such as video inspection, auxiliary power, and machine tools. These components were designed to take up less than half the space that a current power supply would normally occupy on a DIN rail. If you consider the 120 W supply as mentioned above, a normal DIN rail version would take up about 2.5 inches of DIN rail space, whereas Altech's PSC-120 series needs only 1¼ inches of space *(see Figure 3)*. With this ultra-compact power supply, Altech makes it easier for customers to include additional functionality in the same space as well as for use in shallow cabinets—without increasing costs.

Figure 2: *This illustrates the size difference between a standard and compact power supply due to the power density technologies now available.*

Figure 3: *The Ultra-Compact PSC series is a rugged power supply for industrial use.*

These ultra-compact high efficiency units support 1+1 or N+1 redundancy and built-in current sharing functions. Regardless of power supply output, every product in the series has an input requirement of 85-264 VAC/127-360 VDC. Output specifications for the PSC series power supplies are from 12 VDC to 48 VDC and up to 480 Watts. The PSC series is rugged for industrial use, offers high efficiency operation with a wide adjustment range, are lightweight and compact.

The company's PSD series of compact DIN rail power supplies also share the input requirements of 85-264 VAC/127-360 VDC as the PSC series of products *(see Figure 4)*. The difference is that the PSD series power supplies cover wattages from 15 W up to 100 W. Standard voltages for these supplies include 5, 12, 15, 24 and 48 VDC. These high efficiency supplies are designed for a wide range of industrial applications as well as consumer applications such as elevators, escalators, and other building systems.

Features for both product lines include 100% full load burn-in, low voltage and current ripple, Class II isolation, and overload, overvoltage, overtemperature and short-circuit protection.

Figure 4: *The PSD series of power supplies provide a low profile for use in tight spaces such as equipment enclosures.*

These supplies provide users efficiencies of over 90% for lower power dissipation and enhanced thermal performance. They also feature conformally coated PCBs to provide greater protection against contamination and humidity.

Worldwide Capabilities

The Flex line of DIN rail power supplies designed and manufactured by Altech is based on semi-resonant switching power supply technology to provide dynamic output power efficiencies to 93%. Used for electronic loads, motor loads, PLCs, sensors, and other common industrial loads, one unit can cover most input voltage options. The wide range of input voltages enables these products to operate in any part of the world.

The company's PSA and PSB lines are DIN Rail mountable for ease of installation and maintenance. As compact, robust and reliable units, they also offer IP20 protection. Both the PSA and PSB units are designed to provide 1, 2, and 3-phase input up to 600 W with current ratings ranging to 25 A, and power flexibility that reaches 50% of the rated current In *(see Figure 2)*. These specifications are meant to provide solutions for industrial application that are in constant evolution, which makes them remarkably flexible. These series of products offer a declared ambient temperature operations field that ranges from -25oC to 70°C. Besides offering 1-phase, 115-230 VAC units, the company also offers 2-phase, 230-500 VAC units, which allows customers to be able to use and store only one product.

These product lines are also equipped with three short-circuit overload protection features. The hiccup mode is a default factory setting for each product in the FLEX line of power supplies. In case of a short-circuit or overloading, the output current is interrupted. The device will try again to

Model	Output Current A @ 40oC	Input Voltage VAC	Output Voltage VDC
PSA-6024	3	110-230	24
PSA-12024	5	110-230	24
PSA-18024	7.5	110-230	24
PSA-36024	14	110-230	24
PSA-60024	25	110-230	24
PSB-12024	5	230-400-500	24
PSB-18024	7.5	230-400-500	24
PSB-36024	14	230-400-500	24
PSB-60024	25	400-500 3-phase	24

Figure 2: *This chart shows the product range available from the PSA and PSB flexible power supply line.*

re-establish output voltage and normal conditions about every two seconds until the problem has been cleared. A manual reset is available to the operator as well. In order to restart the output after an overload or short-circuit has interrupted the output, it is necessary to switch off the input circuit for about one minute. This approach is offered where safety procedures specifically require that reset be carried out by an authorized person only. The units also offer a continuous output mode where the output current is kept at a high value with near zero voltage during a short-circuit or overload condition. In this case, the current can reach up to three times the rated current. This mode is used to meet the requirements of demanding loads such as motors, solenoid valves, lamps, PLCs with highly capacitive input circuits, and other loads with marked transient overload behavior.

Certifications

In order for equipment to be sold and operated in various parts of the world, it is important that companies adhere to the certifications needed for their specific applications. As power supplies are such an integral part of every system, having proper certification is a critical requirement. Products mentioned here offer a number of key certifications, including UL, CE and CSA approvals. Others include UL508 listed for USA and Canada, 89/336/EEC EMC directive, 006/95/EC (low voltage), IEC 61000-6-4 for emissions, and IEC 61000-6-2 for immunity. Also note that the units offer safety approvals including EN60204-1, EN60950, and military standard MIL-HDBK-217F. In addition, the PSD low profile units are UL62368-1 recognized as well.

Conclusion

Power supplies are critical components to the industrial automation landscape. They must be reliable, robust, highly efficient, and compact in order to fit today's needs. Through the use of DIN rail systems and the latest power density designs, the latest power supplies provide thousands of hours of operation as well as savings in installation time and overall cost. Altech offers several lines of power supply products to fit most applications with the clean, reliable, and high-performance they need for worldwide distribution of systems.

ElectronicDesign 70 YEARS
Technology Report
STEPHEN OXLEY | Business Development Engineer, Fixed and Variable Resistors, Sensors and Specialist Components Division, TT Electronics

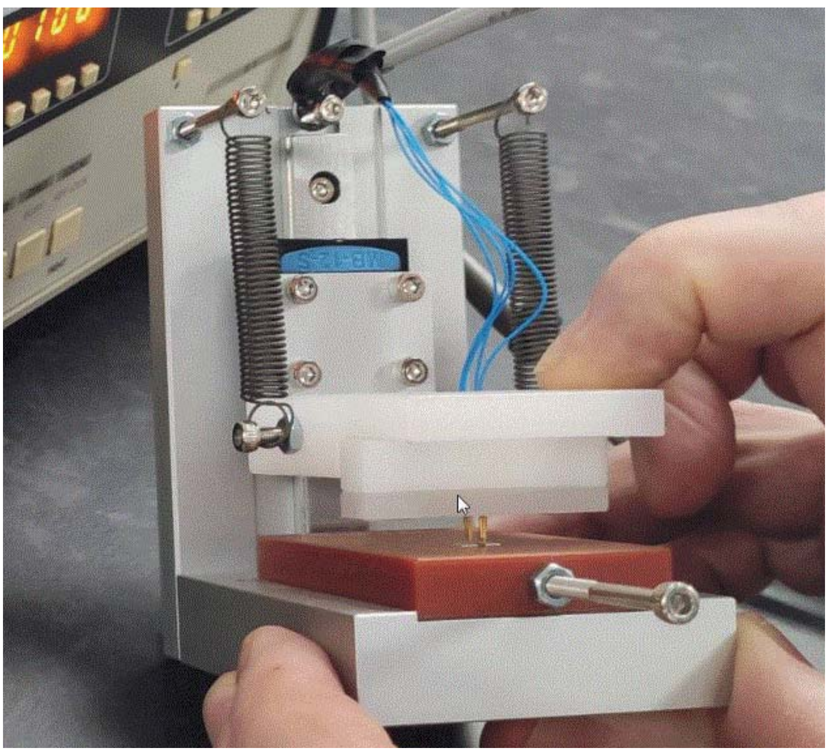
11 Myths About Low-Value Shunt SMD Resistors

Challenges often arise with the relatively common low-ohmic-value resistors during the design and manufacturing phases, leading to an array of misconceptions about them. TT Electronics' Stephen Oxley sets about to debunk the myths.

While low-ohmic-value resistors may appear alongside standard chip resistors in a typical bill of materials, they present unique challenges at every step of the design and manufacturing process. Debunking these myths will help designers better understand sub-milliohm characteristics and the need for specialist knowledge and techniques.

1. It's easy to check unmounted resistor values.

In general, resistors are the simplest of components to check prior to mounting. It requires a simple ohmmeter measurement, with 2-terminal connections for higher values and 4-terminal (Kelvin) connections for lower values or higher precision. But resistors with values around 1 mΩ or less require special equipment and great care in fixturing *(Fig. 1)*.



1. Fixturing is often overlooked. Manual probing doesn't provide the required accuracy needed. Therefore, a fixture is essential to ensure the probe tips are at the X and Y spacings stated on the datasheet or otherwise advised by the manufacturer.

The measurement system itself needs to be capable of measuring ohmic values in the 100-µΩ to 1-mΩ range with a level of uncertainty that's small compared to the component tolerance. This may be achieved with a specialist micro-ohmmeter or with a separate programmable current source and millivolt meter. Thermal drift can be an issue, so it's a good idea to leave the measurement system for at least an hour between switch on and use.

But it's the fixturing that's often overlooked. Manual probing will simply not give the accuracy needed. Thus, a fixture is essential to ensure the probe tips are at the X and Y spacings stated on the datasheet or otherwise advised by the manufacturer. The probe contact pattern should be centered on the component—being off-center in either the X- or Y-direction will affect current-flow patterns and hence the ohmic-value readings.

The fixture will require maintenance to replace worn probe tips and to ensure no misalignment arises. A repeatability and reproducibility study should be performed to ensure that measurement variation with repeated use and alternative users is acceptable.

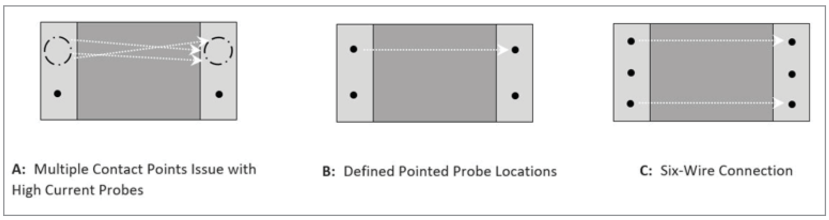
2. High-current probe tips are best for the current contacts.

While measurement currents in the region of 5 to 10 A are commonly used, it would seem appropriate to use a high-current sprung probe for the current connections. However, such probes tend to achieve their low contact resistance by having multiple contact points to the termination surface, typically in a circular ring or star shape.

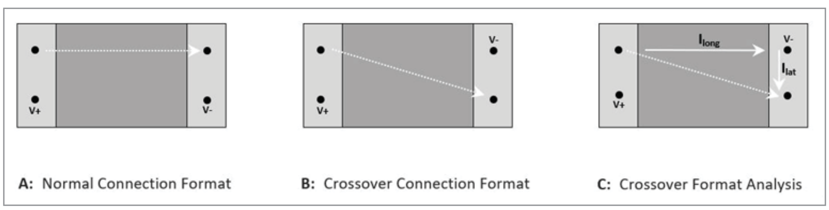
Figure 2A illustrates how such a probe has unpredictable and variable contact locations. They can differ with each application of the probes, giving rise to small but significant variations in the direction of current flow through the component.

That, in turn, leads to variations in the measured ohmic value. For this reason,it's advisable to use single sharp-point probes for the current as well as for the sense contacts *(Fig. 2B)*. It will set up a precisely defined current flow through the component, and repeatable ohmic-value measurements.

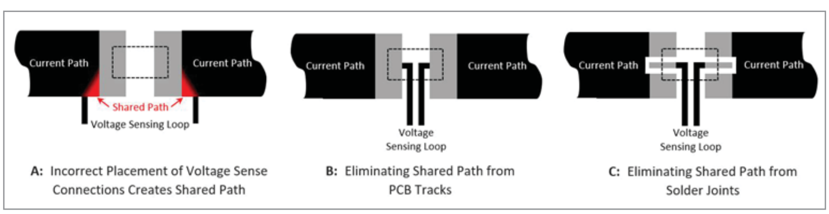
If the current requirements are simply too high to allow for the use of single sharp-point probes, then two probes may be employed for each current connection. This six-wire arrangement *(Fig. 2C)* has the additional benefit of setting up a symmetrical current-flow pattern closer to that seen in operation on a PCB.



2. Unpredictable and variable contact locations give rise to small but significant variations in the direction of current flow through the component (A). Single sharp-point probes for the current as well as for the sense contacts set up a precisely defined current flow through the component, and repeatable ohmic-value measurements (B). The six-wire arrangement (C) demonstrates two probes used for current connection, creating a symmetrical current-flow pattern closer to that seen in operation on a PCB.



3. The connection format also should be specified and usually involves current contacts on one side of the chip and voltage-sense contacts on the other (A). A crossover format (B) may also be used; for a given set of location point spacings, this will result in a lower ohmic-value reading. This becomes clear when we consider how the diagonal current-flow path may be resolved into a longitudinal and a lateral component (C).



4. Minimizing the conductive path shared between the current path and the voltage-sensing loop increases both the effective ohmic value and the TCR of the mounted part (A). This may be achieved by connecting the voltage-sense tracks to the inner edges of the solder pads (B). When the voltage-sense pads are split from the current-path pads, the solder joints themselves also are removed from the shared path (C).

3. It doesn't matter whether current contacts are directly or diagonally opposite.

The connection format also should be considered; usually, current contacts are on one side of the chip and voltage-sense contacts on the other *(Fig. 3A)*. A crossover format *(Fig. 3B)* may be used, too, and for a given set of location point spacings, it will result in a lower ohmic-value reading. This is clear when we consider how the diagonal current flow path may be resolved into a longitudinal and a lateral component *(Fig. 3C)*.

The longitudinal component is associated with most of the voltage drop, which is picked up by the sense terminals with the expected polarity. But the lateral component that gives rise to a smaller voltage drop is picked up by the sense terminals with inverted polarity, and therefore reduces the measured value.

4. PCB pad and track design is straightforward.

The PCB layout design around a very-low-value resistor is critical to its performance. The most important aspect of this is the fact that four, rather than two, tracks must be provided to form a Kelvin connection, even when the component itself has only two terminals.

The aim is to minimize the conductive path shared between the current path and the voltage-sensing loop *(Fig. 4A)*, which would increase both the effective ohmic value and the TCR of the mounted part. This may be achieved by connecting the voltage-sense tracks to the inner edges of the solder pads *(Fig. 4B)*.

You also can take this a step further and split the voltage-sense pads from the current-path pads, so that the solder joints themselves also are removed from the shared path *(Fig. 4C)*. With this method, it's possible to approach the accuracy obtained from a true 4-terminal resistor.

Another source of error where high currents are ac or changing dc is due to the voltage-sensing loop linking with changing magnetic fields. This can induce a noise signal superimposed on the desired voltage-sense signal.

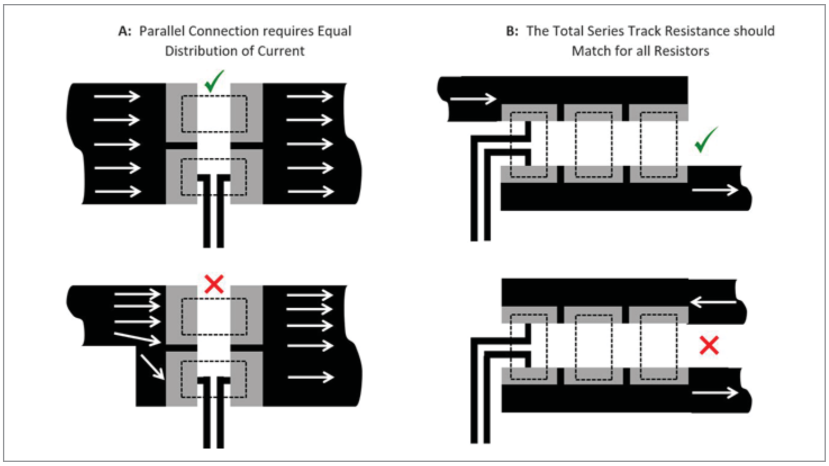
To reduce it, the loop area contained within the sense resistor, the two voltage-sense tracks, and the sense circuit input should be minimized. This means keeping the sense circuitry as close as possible to the sense resistor and running the voltage-sense tracks close to each other. A good way to keep these tracks especially close is to superimpose them in different PCB layers.

5. You can easily join shunts in parallel for lower values or higher ratings.

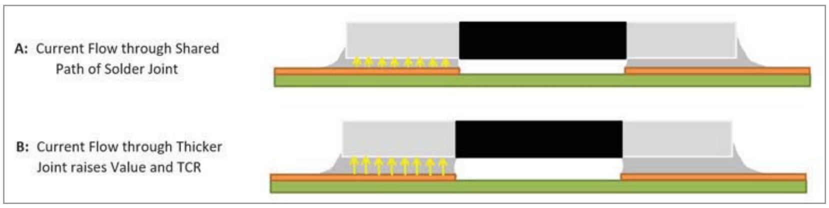
Designers are sometimes forced to use more than one current-sense resistor connected in parallel, either to meet a high power or surge rating, or to achieve an ohmic value lower than the minimum available. This is possible but not easy, and it needs careful layout design. Resistors may be connected in parallel with voltage-sense connections made to just one of the resistors, provided the track layout ensures equal distribution of current between all resistors.

For example, the position in the current trace where the resistors are placed should be well clear of bends or constrictions that could affect the distribution of current density *(Fig. 5A)*. The goal is to ensure that the total track resistance in series with each resistor is the same *(Fig. 5B)*, so that the sensed resistor carries the required fraction of the total current.

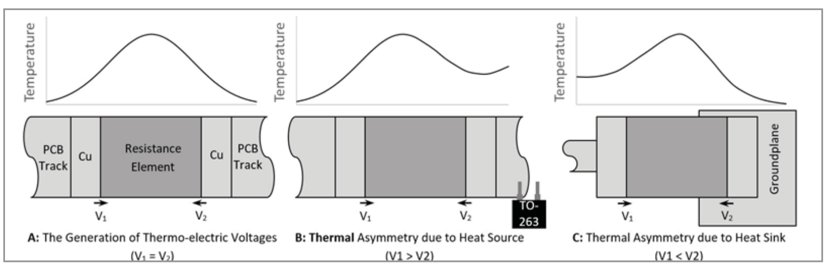
Moreover, it ensures that the proportion of the total current carried by the sensed resistor doesn't vary with temperature. This would occur with unequal series track resistances due to the high TCR of the copper PCB tracks.



5. Parallel connection requires equal distribution of current (A). The total series track resistance should match for all resistors (B).



6. The thickness of solder in the finished solder joint has a direct bearing on the mounted ohmic value. That's because the vertically resolved component of current flow through the solder joint (A) is in a shared path with the voltage-sense loop, which connects at the upper surface of the copper PCB pad. It therefore follows that increased solder thickness (B) will result in an increase mounted value.



7. Shown is a balanced state in which the thermal voltages V1 and V2 are equal (A); and an example of imbalance due to the external influence of a heat source and a heat sink (B and C), respectively.

6. The mounted value will equal the unmounted measurement.

The unmounted ohmic value measured in the manner specified by the manufacturer may still be different from the value obtained when the part is mounted on the recommended pad layout. This happens for two reasons.

First, the current flow through the resistor will not be the same when using one or two point contacts at each terminal, as when using a solder joint that connects to most of the lower termination surface. Second, the voltage-sense separation for unmounted measurement needs to be somewhat greater than the minimum theoretically possible, thus allowing for tolerance in the location of probes relative to the resistor. For a mounted part, by contrast, the voltage-sense solder joints will always connect to the innermost points of the termination surfaces.

For these reasons, we can say that two standard methods are able to measure ohmic values of sub-milliohm resistors. The first is to mount the part onto a defined Kelvin connected test PCB, the definitive way to establish ohmic value. The second is to use probed connections, as described previously. In addition, determine a standard mounting offset, normally negative, which is summed with the probe measured value to indicate the predicted mounted value:

Mounting offset = mounted value – probed value

This offset will vary depending on the termination dimensions, which in turn can be a function of the nominal ohmic value. Therefore, it should be regarded as product-specific.

7. The resistance alloy TCR is a good guide to the shunt's TCR.

The datasheets for low-value shunt resistors may quote two values of TCR. One relates to the resistance alloy TCR and is typically in the ±10- to ±40-ppm/°C range. The other is the actual TCR of the component, taking into account the contribution of the copper terminations.

The two figures are only the same for a true Kelvin shunt in which the current path and voltage-sense loop are separate in the terminations and meet only within the resistance element. Such a construction is relatively costly, so in most cases the actual shunt TCR is greater in magnitude than the resistance alloy TCR. It also depends on the ohmic value, increasing as the value falls.

For example, for 500 μΩ, a shunt TCR in the range of ±100 to ±400 ppm/°C is typical, which is 10X greater than the resistance alloy TCR. If a datasheet has only one TCR value, that should be the shunt TCR. When comparing products, it's clearly important to know which TCR definition applies to which figures.

8. If the layout design is correct, mounting the shunt won't affect its TCR.

The importance of layout design with the correct Kelvin configuration to achieve the minimum TCR has already been described. But the thickness of solder in the finished solder joint also has a direct bearing on both the mounted ohmic value and TCR. That's because the vertically resolved component of current flow through the solder joint *(Fig. 6A)* is in a shared path with the voltage-sense loop, which connects at the upper surface of the copper PCB pad. It therefore follows that increased solder thickness *(Fig. 6B)* will increase the mounted value and associated TCR.

This sensitivity to solder joint thickness can be reduced by using parts with wide area terminations. Such designs aim primarily to lower thermal impedance to the PCB, but reduction in solder thickness sensitivity is an added advantage. Furthermore, the sensitivity also may be eliminated by choosing a 4-termination style shunt. It needn't be a true Kelvin shunt, because the connection between current path and voltage-sense loop may be made within the termination copper.

9. Shunt temperature rise is just thermal impedance times power.

For a normal resistor, the hotspot temperature rise for a given power dissipation is easily calculated. It's simply the thermal impedance of the part in °C/W multiplied by the dissipation in W. This can be added to the ambient temperature to give the hotspot absolute temperature.

The situation for very-low-value resistors is more complex because significant dissipation in the shunt implies significant current levels in the PCB tracks. This means that the PCB tracks themselves will contribute to the total temperature rise.

If it's possible to establish the track temperature rise, then that can be added in to give the actual hotspot temperature. However, if detailed thermal modeling is unavailable, it may need to be determined empirically. But it must be accounted for somehow, otherwise the maximum temperature will be underestimated, with implications for both the thermal design and accuracy calculations.

10. The sensed voltage will be zero if no current is flowing.

Ohm's law presents an ideal resistor with current in direct proportion to voltage. All resistors deviate from linearity because of finite TCR, but in very-low-ohmic-value parts, the voltage-current curve may not even pass through the origin. A copper terminated-metal-element chip resistor contains at least two boundaries between dissimilar metals. These act as thermocouples and generate a thermoelectric voltage in the presence of a temperature gradient *(Fig. 7)*.

Now these thermocouples are connected in series and, because of the symmetry of the component, are of opposite polarity when the resistor element itself is the main heat source. As a result, if the temperature distribution across the chip resistor is symmetrical, any generated thermoelectric voltages will be cancelled out *(Fig. 7A)*.

However, there may be asymmetry due to the external influence of a heat source *(Fig. 7B)* or a heat sink *(Fig. 7C)*, respectively. This leads to a finite value of V1 – V2, which sums with the measured sense voltage and creates a source of error. In particular, it may give a false indication of current flow when currents are at or near zero.

11. A low-value SMD shunt is "just another resistor."

By now, it should be obvious that, although it may be listed alongside standard chip resistors in a bill of materials, a 0.5-mΩ SMD shunt, for example, requires specialist knowledge and techniques at every stage in the design and manufacturing process. This includes component selection, layout design, the inspection of incoming components, and soldering process control.

As a result, it may be advisable to think of low-value SMD shunts as a separate class of component, and expect to invest more time and attention on them with the support of a specialist supplier. ed

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The Importance of Low Iq in Energy-Harvesting Systems

This article discusses one of the most important IC performance characteristics needed for energy-harvesting applications: A low standby quiescent current, typically less than 6 µA but even as low as 350 nA typical.

Energy-harvesting-based wireless sensor networks (WSNs) are the result of enabling WSN nodes with the ability of extracting energy from the surrounding environment. There's no one single wireless technology or standard on which WSN works. However, numerous wireless standards help in the success of WSN systems. The most popular among these are Bluetooth, ultrawideband (UWB), and Zigbee wireless standards as per IEEE 802.15.4.

What is a WSN?

The main component in any WSN network is a WSN transceiver. The transceiver houses both the RF transmitter and RF receiver. The WSN transceiver complies with any of the WSN wireless standards, one of them being IEEE 802.15.4

Low Iq PMICs

Power-management ICs (PMICs) usually integrate many of the following: low-dropout regulators (LDOs), dc-dc regulators, sequencers, supervisors, load switches, built-in self-test (BIST) ICs, along with logic components in a single IC. These devices are easily configured with hardware and serial communications.

A PMIC needs to handle loads spanning from microamps to hundreds of milliamps and must be able to distribute power to devices employed in an energy-harvesting system. The PMIC will provide efficient system management for loads ranging from fractions of a microamp to a few hundred milliamps. It will typically operate over a 2.2- to 5-V input range.

Sleep Mode

If an energy-harvesting network becomes overly active, excess nodes must be kept in a sleep mode until it's necessary for coverage and connectivity, especially in the event of failures in other neighboring system nodes.

Some energy-harvesting systems can draw all of their power from the surrounding environment, typically from either light or vibrational energy. Such devices could serve as platforms for running environmental or other types of sensors in remote locations.

Nanopower

Nanopower applications can make the best use of energy harvesting as their prime power source. Applications include smart homes, smart thermostats, smart locks, smart doors and windows, and even fitness bands, sports watches, and activity trackers.

Hard-to-reach remote applications will really benefit from energy harvesting. Instead of sending out a technician every month or year to replace batteries, these types of applications will now run without a battery and virtually last forever.

Most energy-harvesting components, like solar panels or piezoelectric devices, can produce only a few milliwatts (one-thousandth of a watt) or even microwatts (one-millionth of a watt) every hour. Even though small, such amounts, when

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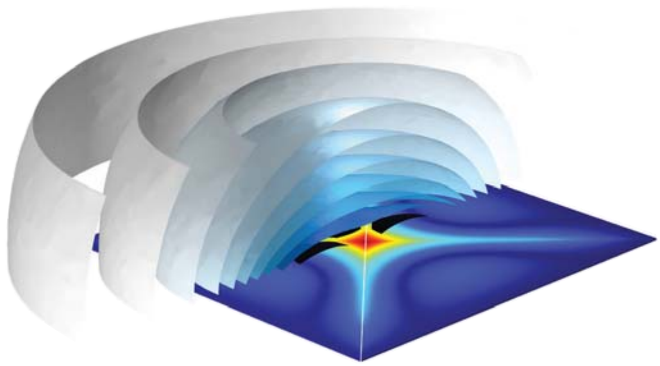
Designing Piezoelectric Acoustic Transducers with Simulations

Piezoelectric transducers generate and receive acoustic signals in applications that range from small speakers to medical devices and sonar arrays. The trend to miniaturize these devices presents significant challenges. For example:

- Piezoelectric devices within mobile speaker applications need to be able to generate high-quality sound.
- Many noninvasive medical diagnostic devices operate at highly specific frequencies. Thus, the piezoelectric devices must operate at a precise frequency.
- Sonar applications often require that piezoelectric devices generate high-power signals to propagate long distances without attenuating below detectable levels.

In each case, product design engineers must develop designs that meet the required specifications within ever-smaller packages.

These electroacoustic transducers are inherently multiphysics in nature. Thus, designers must have a platform that allows them to calculate the multiple physics within their products, such as multiphysics simulation.



Multiphysics simulation has the features needed for developing product designs more effectively and simulating the designs within operating conditions. In addition, the simulations may include the entire ecosystem, from the control circuit to the piezoelectric transducer to the surrounding acoustic environment.

In this presentation, guest speakers Kyle Koppenhoefer and Joshua Thomas from AltaSim Technologies will discuss the development of an acoustic device that operates on piezoelectric transducers within an underwater environment. The webinar will also include a live demonstration using the COMSOL Multiphysics® software, as well as a Q&A session.

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SPEAKER:

Kyle Koppenhoefer is the president of AltaSim Technologies. He and his business partner founded AltaSim 20 years ago. He works with customers to identify how computational analysis can be used to provide solutions to their products and manufacturing processes. Prior to cofounding AltaSim, Kyle worked for the Department of Defense and the Edison Welding Institute. He holds a PhD in civil engineering from the University of Illinois.

SPEAKER:

Josh Thomas is a senior engineer at AltaSim Technologies. He has provided consulting and training support in COMSOL Multiphysics® over the last 10 years. He is a lead instructor in many of AltaSim's classes and has worked extensively with structural mechanics problems and multiphysics problems involving thermal and structural analysis. Josh received his bachelor's degree in aerospace engineering and master's degree in mechanical engineering from The Ohio State University.

banked, can power small systems due to recent improvements in lower-powered microcontrollers and transmitters. Using such self-powering systems, sensor networks could be set up where it wasn't formerly feasible to do so in the past, due to the inability to deliver power (by replacing batteries or running a power line) to the sensors.

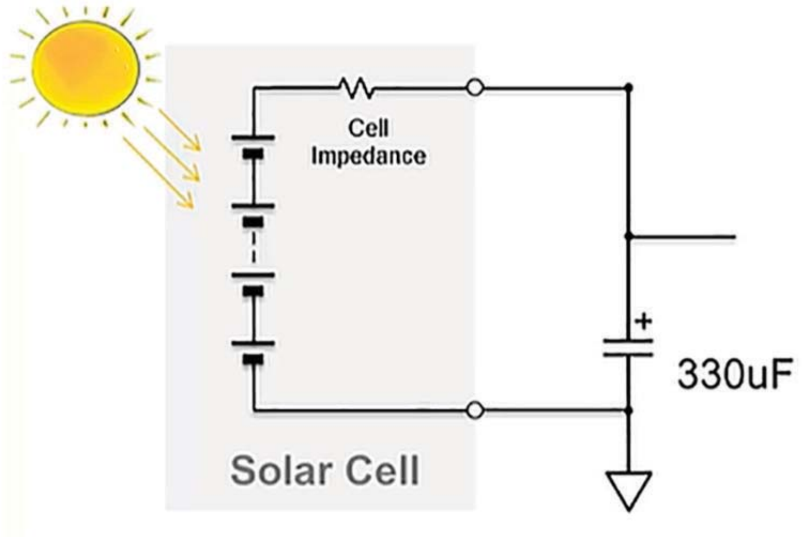
Even implantable medical devices in the human body can use energy-harvesting techniques. These kinds of applications run at low data rates and low duty cycles while running on nano average power.

Sources such as light, electromagnetic (EM) waves, vibrations on bridges, or even the heat generated by the human body, are viable energy sources. Light produces the most power per unit area by far. Solar-harvesting applications can sometimes use a low-Iq buck converter in the design as well.

Solar-Power Energy Harvesting

So, how can designers use solar energy to transmit via a radio?

If we have solar cells receiving sunlight and they're arranged in series to create a higher voltage, we still will not have enough energy in those cells. The solution is to store that energy in something like a capacitor. In this way, we can now use a nanopower, low-Iq, buck dc-dc converter to create a core rail needed to power a radio IC *(see figure)*.



Solar energy is harvested, stored in a capacitor, and then fed into a low-quiescent-current buck converter. *(Image from Reference 1)*

Wireless Switch Using Energy Harvesting

The switch in this design is built like a linear dynamo and will transform its mechanical energy into electrical energy. This electrical energy is optimally harvested.

Since the switch is wireless and cableless, it increases the flexibility and uptime when mechanical vibration or a chemically aggressive environment might render wires impractical.

Kinetic energy is the energy generated via the motion of an object. In this case, the object is a magnet in the switch that moves back and forth inside a coil. It changes the magnetic field and induces a voltage in that coil. This principle is well known as electromagnetic induction, or Faraday's law.

Energy-harvesting switches are quite suitable when lower maintenance and installation costs, increased flexibility, and system uptime are needed and when wiring would be impractical. These switches are a potential solution particularly in explosive-proof applications. That's because their inherent low-power operating characteristics enable the design to avoid the usage of intrinsically safe barriers, encapsulation, or other costly protection methods.

This kind of design targets applications that require on-off signals for machine start and stop control, presence and position sensing, counting, alarm signaling, and other desired digital inputs.

In this example, a buck converter regulates the rectified and doubled signal coming from the switch, feeding the output voltage to a 32-bit Arm Cortex-M3 multiprotocol, 2.4-GHz wireless MCU with 128 kB of flash. A voltage doubler is used at the input of the buck converter to charge capacitors from the switch output voltage and switch these charges in such a manner whereby exactly twice the voltage is produced at the output than at the input. All of these devices consume very low Iq.

Summary

Engineers have harvested energy for hundreds of years, first with water and windmills, then hydroelectric dams, solar panels, and geothermal plants. Now, in today's advanced electronics environment, engineers can use tiny solar panels and thermoelectric generators to access power from seemingly insignificant temperature differences—piezoelectric devices that convert small mechanical vibrations into power to create electricity.

The amount of power can be small—measured in microwatts—and the devices don't usually generate power 24/7. But the ambient energy sources they use, including light, heat differentials, vibrating beams, transmitted RF signals, and others, provide that small amount of power for free. Low quiescent currents help make this possible. ed

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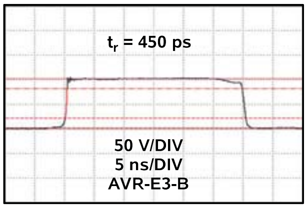

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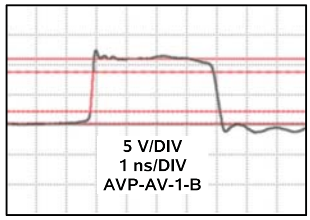

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40 V	150 ps	1 MHz	AVP-AV-HV3-B
50 V	500 ps	1 MHz	AVR-E5-B
100 V	500 ps	100 kHz	AVR-E3-B
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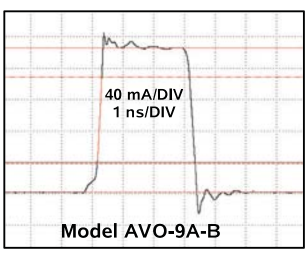

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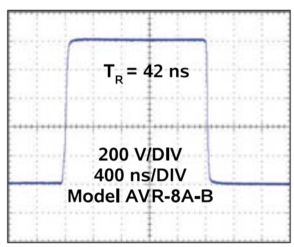

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WILLIAM G. WONG | Senior Content Director

70 Years of Semiconductors

A brief glimpse at semiconductor history, from SCRs and TRIACs to NVIDIA's 80-billion-transistor Hopper GPU.

Electronic Design has been around a bit longer than I have worked in the industry—but not by much. Having lived through it, you might think I had a good handle on how the technology progressed. However, so much has happened over the years that's been amazing even to me.

Silicon and germanium transistors have been around since the 1950s when vacuum tubes were king *(see figure)*. There were metal-oxide-semiconductor field-effect transistors (MOSFETs) in 1959, starting with p-type MOS (PMOS) and n-type MOS (NMOS) logic and eventually complementary metal-oxide-semiconductor (CMOS).

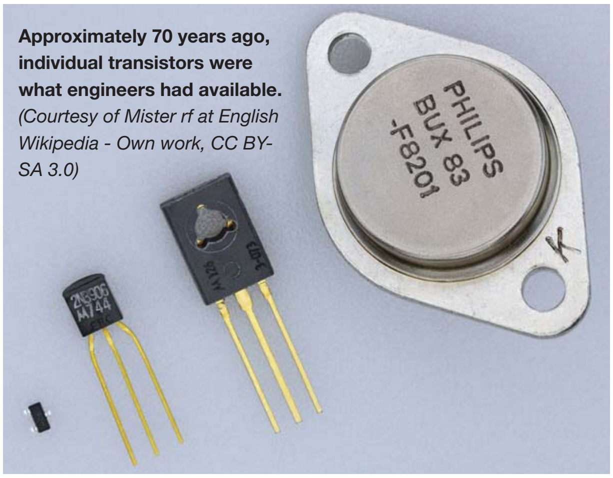
Silicon has been the mainstay since the early '60s, bumping germanium out of the way over time. There also are some very broad areas, including digital, analog and power, when it comes to semiconductors. Optoelectronics should be in the mix, too, but that's yet another area of discussion.

To give an idea of the growth of semiconductors over the years, just take a look at the number of transistors being packed into a single die:

- 1960: small-scale integration (SSI): < 100 transistors
- 1964: medium-scale integration (MSI): 100-1,000 transistors
- 1972: large-scale integration (LSI): 1,000-100,000 transistors
- 1980: very-large-scale integration (VLSI): > 100,000 transistors
- 1989: ultra-large-scale integration (ULSI): over one million transistors
- 2022: No acronym: NVIDIA Hopper H100 GPU, 80 billion transistors, 4-nm process

I haven't been able to track down what year it might be, but more transistors are packed into one NVIDIA Hopper than were produced in the entire world at one point.

The progression on the analog and power side is no less impressive. In addition to transistors, we have devices like thyristors, silicon-controlled rectifiers, and TRIACs that build on the advances in semiconductor technology.



Approximately 70 years ago, individual transistors were what engineers had available. *(Courtesy of Mister rf at English Wikipedia - Own work, CC BY-SA 3.0)*

Integration and advanced semiconductor technology led to the Fairchild µA741 operational amplifier (op amp) in 1968. It simplified analog system design while providing flexibility and ease of configuration. Op amps remain a primary tool in analog designers' kits.

The release of Signetics' NE555 timer in 1972 was yet another stepping stone along the way to more powerful analog semiconductors. It changed the way engineers thought about timing. CMOS versions are still in use today.

Wide-bandgap (WBG) semiconductors include silicon carbide (SiC) and gallium nitride (GaN). GaN started a bit late, around 1969. The first GaN metal semiconductor field-effect transistors (GaN MESFETs) were developed in 1993. A 1-kW dc-dc converter the size of a postage stamp is possible now because of GaN FETs. Applications like electric vehicles and cloud data centers are pushing the limits for WBG technology.

More Modern Movement

LEDs and optoelectronics are yet another semiconductor technology area that has seen rapid change. They drive computer displays rather than the CRTs and vacuum light bulbs that illuminated our lives of the past. Our fiber communication systems are lit by this technology.

Semiconductor production technologies like bulk substrate, metal-organic vapor phase epitaxy, and molecular beam epitaxy have helped to deliver more compact, more powerful solutions. The demands on the production side have led to large foundries moving even large companies to being fabless suppliers.

Likewise, chip packaging also has radically changed over time. Mixing different technologies is now more common, and it's occurring at the die level with various architectures for stacking, packing, and connecting dies within the same package.

Keeping track of what has happened in the semiconductor market in the last few months keeps me busy and amazed to the point where I often forget how much has changed over the years. It's taken an enormous effort to get where we are today, with many fantastic products and technologies requiring millions of people to deliver. We continue to move faster as the tools and infrastructure augment what individual designers and engineers can build. Where will we be in another 70 years? ed

Ad Index

Every effort is made to ensure the accuracy of this index. However, the publisher cannot be held responsible for errors or omissions.

WILLIAM G. WONG | Senior Content Director

Remembering Electronic Designs

As *Electronic Design* celebrates its 70th year, we're creating an assortment of special article series that look back at how our industry has evolved over the past seven decades.

At 70 years, *Electronic Design* has been around longer than I have, although I'm close. We plan on being around for another 70. If the amount of change in just our industry is any indication of what's coming up, then we're in for a whirlwind ride. Even 70 years ago, electronics had changed the world, doing things that were never possible before.

Usually, my Lab Bench articles look at a new dev kit or product. This time, though, I wanted to highlight some of the online and print articles that are looking back and forward. These include:

- What Computer Had the Biggest Impact on You?
- Series: Then and Now
- Do You Recognize These?

You can always leave comments online for these articles. However, with the "What Computer Had the Biggest Impact on You?" series, you can provide additional feedback, which I've turned into slideshows based on your input.

The "Series: Then and Now" is a collection of articles that are appearing in each print issue of *Electronic Design*. These cover a very large swath on some target topic like processor technology.

Finally, there's the "Do You Recognize These?" series, where I provide a hint and a close-up image about a technology or product. I follow up with the full image and a description. Sometimes I give a little history, since most of these are items I've worked with.

It's worth putting our latest technology into context. Take the transistor radio, which would have been around when *Electronic Design* started publication *(Fig. 1)*. It had about half-a-dozen individual transistors. It ran off a 9-V battery. We now have smartphones that have multiple chips with transistor counts in the millions using 5-nm silicon technology. They have foldable, hi-res screens plus multiple hi-res cameras that can capture and store video internally.

Think of where we would be without early chips like the NE555 timer. We've had many Ideas for Design articles based on this part alone.

Anyone remember the IMSAI 8080 with 8-in. floppy disks used in the movie *WarGames* (*Fig. 2*)? Its S-100 bus was used in dozens of pre-IBM PC platforms.

These days, multiple platforms currently out there are smaller and more powerful, like Arduino *(Fig. 3)* and Raspberry Pi.

By the way, anyone remember how to solder or wire wrap? ED

1. Transistor radios in the 1950s had half-a-dozen transistors (left). The Samsung Galaxy Z Flip has a folding AMOLED screen with 2636 × 1080 resolution and a 64-bit, 8-core system-on-chip with gigabytes of storage (right). *(Courtesy of Joe Haupt from USA (left), and Samsung (right))*

2. The IMSAI 8080 is housed an Intel 8080 microprocessor with S-100 cards providing peripheral and memory support. *(Courtesy of Wikipedia, Don DeBold)*

3. The Arduino Uno WiFi uses a module to provide wireless support.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