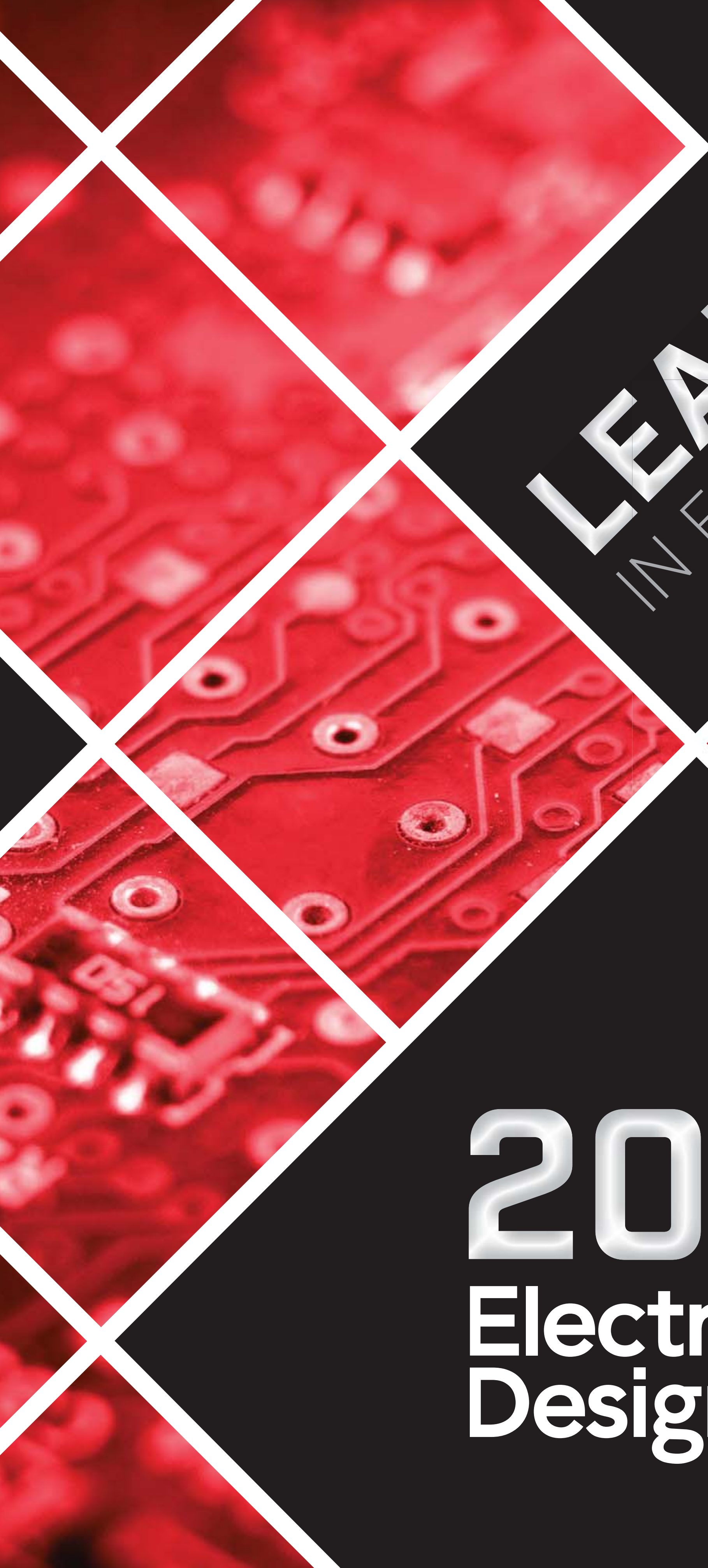

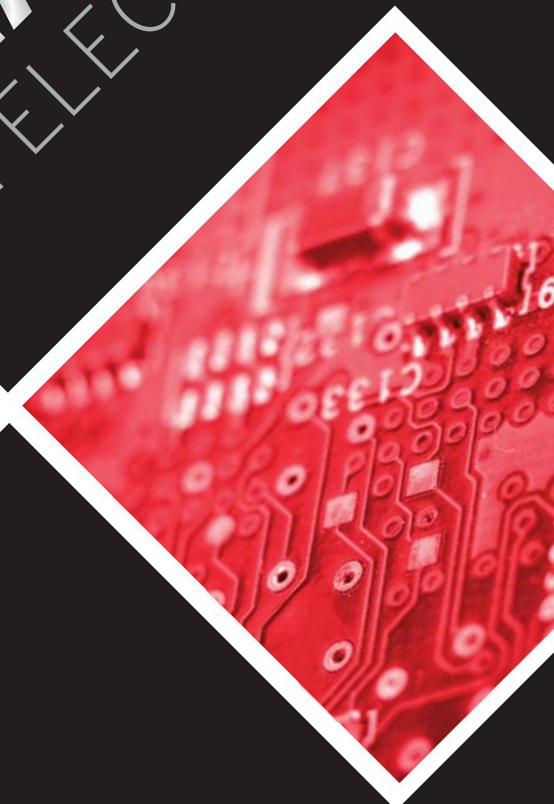

LEADERS IN ELECTRONICS

2021

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Altech Corporation is an established United States supplier of components and devices used in industrial control, instrumentation, medical and automation applications. Altech provides a very broad line of products that meet UL and international standards and are RoHS and REACH compliant. Altech's commitment to continuous quality management has been recognized since 1999 when they were awarded ISO 9001 certification.

Altech provides a multitude of services for customers. This starts with its employees, where product managers provide technical support and partner with customers in design assistance, ensuring the best solution for the application. Next, an efficient customer service department ensures that customers are informed with complete order information. Depending on the product, the versatile assembly department provides manufacturing, value-added, or customization services to expedite delivery. Altech's marketing department has been highly recognized for its catalogs, advertising, and website designs, while the sales department motivates the sales organizations throughout North America, ensuring product information is current and complete.

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Altech's products meet UL and international standards, and all are RoHS- and REACH-compliant. Altech's commitment to quality and continuous quality management had been recognized since May 27, 1999 when it was awarded the prestigious honor of ISO 9001 certification. Since then, Altech has successfully gone through the recertification process and complies with ISO 9001:2015.

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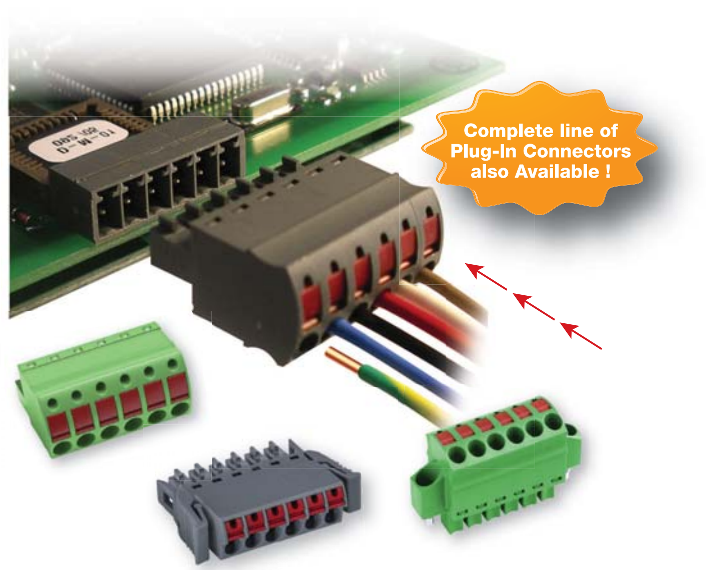

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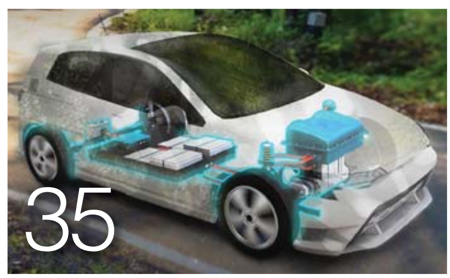

COLUMNS & DEPARTMENTS

Editorial

WILLIAM WONG | Senior Content Director

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Looking Forward to 2021

2020 was a year for the record books on multiple fronts, but what will 2021 deliver?

This year certainly hasn't been dull, given COVID-19 and the U.S. presidential election. On the downside, there have been a host of hurricanes, continuing human conflicts, famine, shootings, and multiple business sectors that were totally trashed. On the plus side, everyone is discovering the joys and hassles of video conferencing and virtual tradeshows. Likewise, the stock markets continue to rise and fall while the pace of new technology remains vigorous.

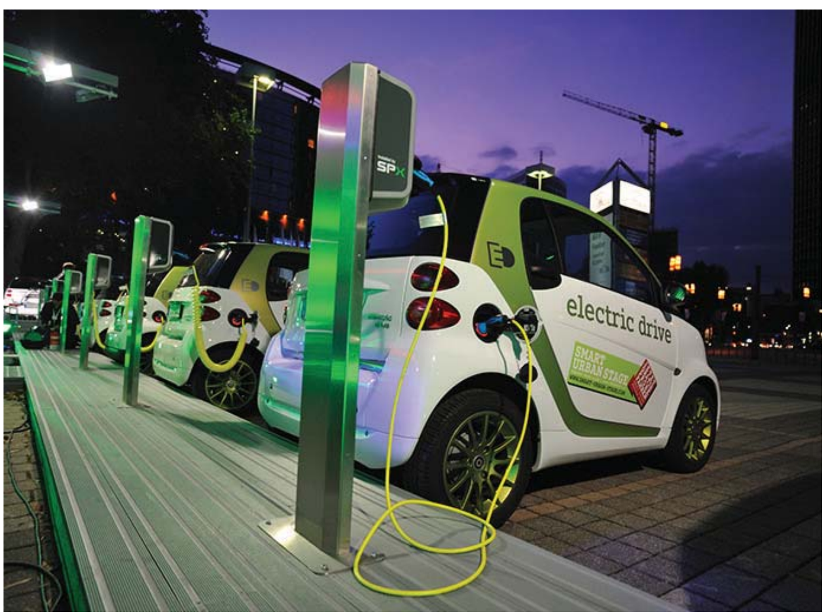
In many ways, 2021 will be like 2020 when it comes to technology. Artificial intelligence (AI) and machine learning (ML) will grow in importance and the number of hardware and software alternatives will make a designer's job that much harder given the number of tradeoffs involved. The opportunities are increasing as the ability to put AI/ML on the edge is becoming practical. It may be the start of a swing toward a personal assistant without the need to be connected to the cloud all of the time.

Even as the edge becomes smarter, the cloud and enterprise continue to transform what a server looks like. Disaggregation is allowing for easier build out, but also incorporation of technologies from SmartNICs to SmartSSDs is changing how storage, communication, and computation are done. Developers also need to pay attention to trends like the growth of RISC-V and FPGAs in almost every arena.

Of course, we cover a lot more than just the computation side of electronics. The latest changes with gallium nitride (GaN) and silicon carbide (SiC) on the power-management side of things are just as important, as they have proven useful in everything from electric cars to power distribution *(see figure)*. At the other end of the spectrum are battery-sipping solutions where low quiescent current (I_Q) and efficiency are critical design factors.

5G and other wireless technologies are having their ups and downs. 5G development and deployment moves onward, but many of the benefits will be in the future, given COVID-19 and the limits on congregation near 5G access points like stadiums. The additional time will help for IoT support, which is still in the works and different from the blazing speeds touted for streaming to smartphones and tablets. It may also allow Wi-Fi to make inroads. Wi-Fi mesh and even Bluetooth mesh will play a part in IoT's growth.

We will continue to deliver our coverage of these areas in print as well as online with special digital issues and ebooks. We look forward to bringing the best in-depth coverage in 2021. So stay safe—I look forward to interacting with everyone online and in print and hopefully in-person in the near future. ed



Electric-vehicle powertrains and charging are just some areas where new silicon is making a difference. *(Editor77 | Dreamstime.com)*

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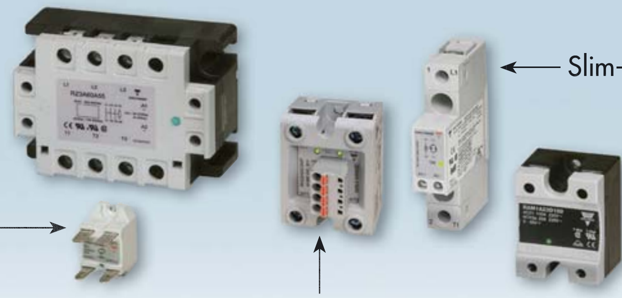

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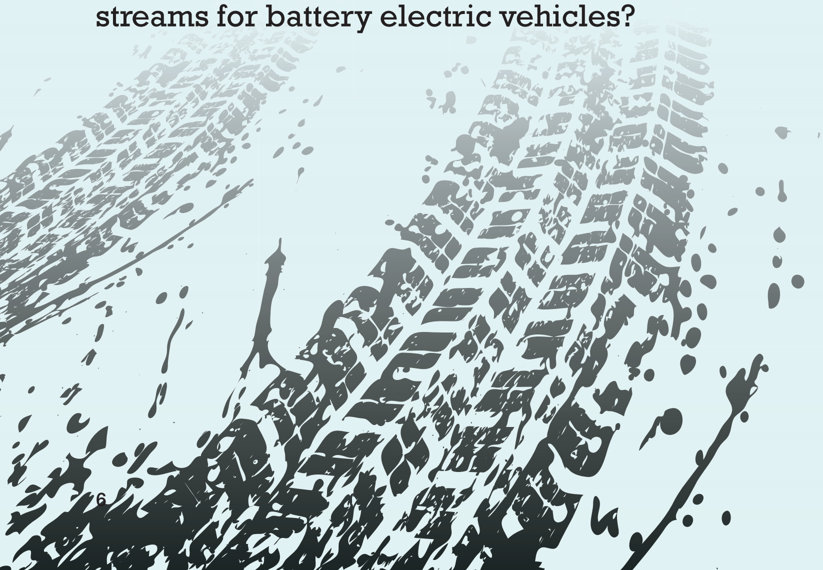
SUNIL KUMAR JHA | Content Writer, Global Market Insights Inc.

Heavy-Duty OFF-ROAD APPS Hold Key to BEV Success

With the rise in truck freight movement and millions of trucks on the road, heavy-duty vehicles are perceived as a likely roadmap to minimize emissions. What are the revenue streams for battery electric vehicles?



A disruption in the automotive industry has prompted automakers to streamline commercial and consumer transportation by eliminating or reducing the demand for fossil fuels. In this regard, the battery-electric-vehicle (BEV) industry has stepped up to the concerted efforts of governments and NGOs to reduce CO_2 emissions.

From low-power vehicles and unreliable charging to high-performance and convenient transport solutions, electric vehicles have taken considerable strides in techno-commercial development and innovation in battery technology.

With no potential alternative to BEVs, automakers have upped their investments in sophisticated technology and robust initiatives to propel consumer reach. Mobility has become one of the most holistic approaches as decarbonization of the automotive landscape using electric vehicles becomes a viable and efficient solution.

BEVs have emerged to surmount climate change as zero-emission vehicles such as EVs gain more traction. Battery electric vehicles are replacing the internal combustion engine (ICE)—they don't have fuel tanks, conventional engines, onboard electricity generation provisions, and tailpipes. Doing away with tailpipe has made the BEV a potential and viable candidate to achieve CO_2 reduction targets.

Li-ION BATTERIES

An upsurge in BEVs is largely due to the lithium-ion battery, which has higher energy density and better durability than lead-acid batteries. R&D has pushed Li-ions from around 100 Wh/kg a decade ago to 250 to 300 Wh/kg today. Current trends suggest a notable rise in battery capacity—BEVs are touted to reach an average driving range of 350 to 400 km in line with battery sizes of 70 to 80 kWh by 2030.

Seizing the opportunities will be Li-ion batteries for vehicles underpinned by favorable government policies. Of late, there's been a notable shift toward using lithium-ion batteries that provide increased density and longer cycle life, thereby offering same energy storage at lower weight.

Lithium-ion batteries are in high demand for BEVs because they can output high energy and power by unit of battery mass, enabling them to be lightweight and smaller. Such features

have made them the go-to battery in consumer electronics, including laptops, cell phones, portable game/audio players, and video and digital cameras.

Beyond their power density, Li-ion batteries are used extensively in the EV industry due to their ease of charging, safety, charging speed, longevity, and maintenance.

On another note, recycling has become a major issue as metals such as lithium, nickel, and cobalt are essential to producing lithium-ion batteries. Since the metals are distributed around the world, BEV manufacturers are wary of supply-chain disruption as well as their mining due to environmental concerns.

COMPELLING AVENUES IN HEAVY-DUTY VEHICLES

Due to their fuel consumption and emissions, heavy-duty vehicles and the notable rise in truck freight movement are receiving scrutiny and perhaps a key element in the roadmap to minimization of emissions. These vehicles have found on-road applications in buses, package delivery, and freight.

Heavy-duty off-road applications, including cargo-handling equipment, are being developed at seaports. Buses have become a major market in BEVs—according to a 2017 report from the American Public Transit Association, 538 out of 9,821 electrified buses were BEVs in U.S. transit fleets.

Vehicle manufacturers have set sizable targets to electrify buses and cars as battery manufacturers witness a paradigm shift, such as major investments to boost production. Stakeholders, including charging hardware manufacturers, charging point operators, and utilities have upped investments in charging infrastructure.

With smaller batteries and lower driving ranges, BEVs hold an edge over fuel-cell electric vehicles (FCEVs). For instance, more Japanese OEMs are adopting battery-electric technology and doing away with hydrogen fuel cells.

THE SHIFTING LANDSCAPE

The who's who of the automotive industry have made their way into the BEV arena. For instance, General Motors Co. and Nikola Corp. announced a strategic partnership in which the former will reportedly engineer and manufacture Nikola Badger BEVs and FCEVs. With the shift toward battery electric vehicles, economic forecasts are strong for BEV manufacturers.

Building a competitive moat in the battery electric-vehicle landscape, prominent companies are likely to up the game in terms of business strategies. For instance, Tesla revealed plans to reduce electric battery costs and build a $25,000 battery electric vehicle within three years.

Forward-looking companies are looking to move away from costly cobalt and turn to nickel and iron formulations. Novel production methods, such as the use of dry powders rather than liquid slurries, will likely come to the forefront in the next five years or so.

Overall, the outlook will largely depend on the reduction of the size of battery plants and minimizing production steps. And the automotive industry faces the unique challenge of ramping up BEV charging points.

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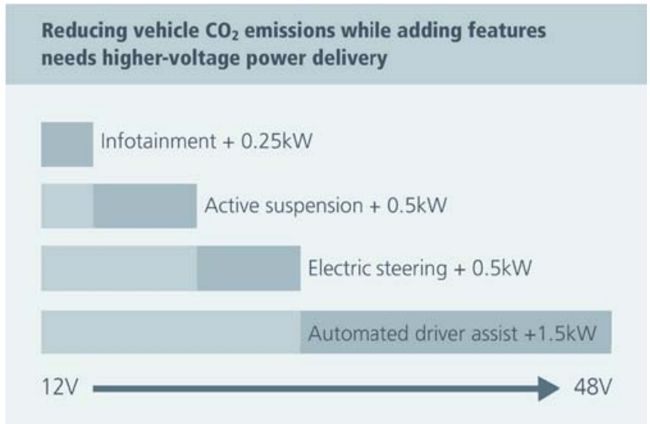
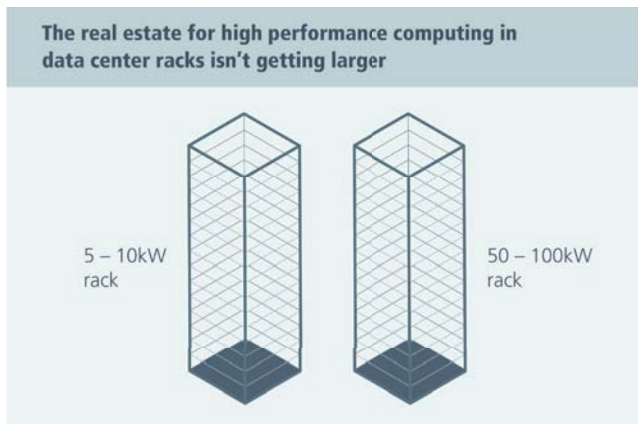
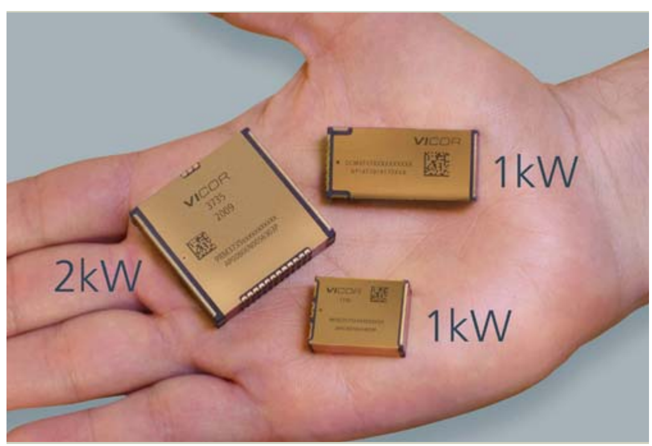






SOL JACOBS | VP and General Manager, Tadiran Batteries

Battery-Powered Remote Wireless Sensors Go to EXTREMES

Remote wireless apps in extreme environments demand long-life, industrial-grade lithium batteries. Engineers have a choice of primary (non-rechargeable) cells that can last up to 40 years or industrial-grade rechargeable Li-ions with a 20-year lifespan.

Indoor wireless applications have much different power requirements than remote outdoor locations. Indoor applications are generally more accessible for easy battery replacement, and moderate temperatures serve to maximize battery life, commonly enabling the use of inexpensive consumer-grade alkaline and lithium-ion (Li-ion) rechargeable batteries.

The opposite is true for remote wireless applications, particularly those connected to the industrial Internet of Things (IIoT) that experience prolonged exposure to extreme temperatures. These applications demand the use of robust, long-life, industrial-grade lithium batteries that can achieve extended battery life to reduce the total cost of ownership.

Some harsh environments are typical to remote locations, such as sweltering deserts, the Arctics, and pressurized undersea environments. However, extreme temperatures can also occur in more commonplace applications like automotive windshields, where the battery must perform reliably despite the severe temperature cycles that characterize car interiors.

That application requires the use of bobbin-type lithium-thionyl-chloride ($LiSOCl_2$) cells, uniquely designed to handle heat soak, which can rise to 113°C (according to SAE) when parked, then rapidly cool to room temperature *(see table)*. In cold weather, the opposite occurs: the battery must endure cold soak followed by a rapid rise in temperature.

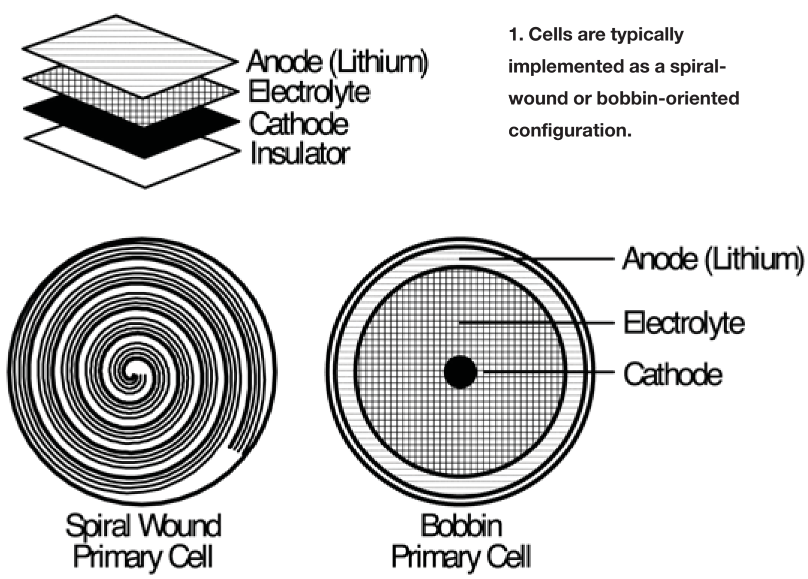
Primary cell	$LiSOCL_2$ Bobbin-type with hybrid layer capacitor	$LiSOCL_2$ Bobbin-type	Li Metal Oxide Modified for high capacity	Li Metal Oxide Modified for high power	Alkaline	$LiFeS_2$ Lithium iron disulfate	$LiMnO_2$ CR123A
Energy density (Wh/1)	1,420	1,420	370	185	600	650	650
Power	Very high	Low	Very high	Very high	Low	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	1.5 V	3.0 V
Pulse amplitude	Excellent	Small	High	Very High	Low	Moderate	Moderate
Passivation	None	High	Very low	None	N/A	Fair	Moderate
Performance at elevated temp.	Excellent	Fair	Excellent	Excellent	Low	Moderate	Fair
Performance at low temp.	Excellent	Fair	Moderate	Excellent	Low	Moderate	Poor
Operating life	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate	Fair
Self-discharge rate	Very low	Very low	Very low	Very low	Very high	Moderate	High
Operating temp.	-55 to 85°C, can be extended to 105°C for a short time	-80 to 125°C	-45 to 85°C	-45 to 85°C	-0 to 60°C	-20 to 60°C	0 to 60°C

The table compares popular primary cells.

This example illustrates how prolonged exposure to extreme temperatures can negatively impact ordinary batteries due to frozen chemicals, voltage drops, and accelerated self-discharge: environmental challenges that limit the choice of battery.

TWO TYPES OF LOW-POWER WIRELESS APPLICATIONS

Low-power remote wireless sensors and devices are increasingly utilized in applications such as asset and animal tracking, system control and data automation (SCADA), AMR/AMI utility metering, environmental and seismic monitor-



1. Cells are typically implemented as a spiral-wound or bobbin-oriented configuration.

ing, M2M, AI, and machine learning, to name a few.

The typical low-power device that draws average current measurable in microamps may be suitable for various primary (non-rechargeable) batteries, including iron disulfate ($LiFeS_2$), lithium manganese dioxide ($LiMNO_2$), $LiSOCl_2$, alkaline, and lithium metal oxide *(Fig. 1)*.

If the device draws average current measurable in milliamps, enough to prematurely exhaust a primary lithium battery, then it may call for some form of energy-harvesting device coupled with an industrial-grade, rechargeable Li-ion cell. Photovoltaic (PV) panels are the most common type of energy-harvesting device. However, certain niche applications also draw small amounts of current from equipment movement, vibration, temperature variances, and ambient RF/EM signals. Real-life examples are highlighted later in this article.

EVERY REMOTE WIRELESS APPLICATION IS UNIQUE

There are no one-size-fits-all solutions for battery-powered devices, as numerous factors affect the choice of battery chemistry. These variables include the amount of current consumed during active mode (including the size, duration, and frequency of pulses); energy consumed during "standby" mode (the base current); storage time (as normal self-discharge during storage diminishes capacity); thermal environments (including storage and in-field operation); and equipment cutoff voltage, which drops as cell capacity is exhausted or during prolonged exposure to extreme temperatures. Perhaps most critical is the annual self-discharge rate of the cell, which often exceeds the actual amount of energy consumed annually by the device.

As the lightest non-gaseous metal, with a high intrinsic negative potential that exceeds all others, lithium offers unique performance characteristics. They include the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all commercially available chemistries. Lithium cells operate within a normal operating current voltage (OCV) ranging from 2.7 to 3.6 V. Lithium chemistries are also non-aqueous, thus less likely to freeze in extreme cold.

If an ultra-long-life battery is required, the preferred choice is $LiSOCl_2$ chemistry. These batteries can be constructed in two ways—bobbin-type or spirally wound.

Spiral-wound construction delivers greater surface area contact between layers, resulting in higher energy flow potential with higher self-discharge. Conversely, bobbin-type battery construction offers higher capacity, higher energy density, plus a wider temperature range (–80 to 125°C), along with a glass-to-metal hermetic seal to help prevent leakage. With reduced surface area for chemical reactions to occur, bobbin-type $LiSOCl_2$ batteries can deliver an incredibly low self-discharge rate (under 1% per year for certain cells), enabling up to 40-year battery life.

UNDERSTANDING THE PASSIVATION EFFECT

Battery self-discharge is ubiquitous, affecting all cells, including those that are disconnected. This naturally occurring phenomenon is mainly influenced by the passivation effect.

Passivation develops when a thin film of lithium chloride (LiCl) forms on the surface of the lithium anode, creating a temporary separation between the anode and the cathode, reducing the chemical reactions that cause self-discharge. Whenever a current load is placed on the cell, the passivation layer offers initial high resistance, causing a temporary drop in voltage until the discharge reaction begins to dissipate the passivation layer. This process keeps repeating every time the load is removed.

The level of passivation can be variable based on a cell's current discharge capacity, the length of storage, storage temperature, discharge temperature, and prior discharge conditions. Partially discharging a cell and then removing the load tends to increase the amount of passivation relative to when the cell was new.

While passivation is extremely useful for minimizing battery self-discharge, too much of it can be problematic by blocking energy flow. The test of a

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battery manufacturer is to effectively control passivation to strike the ideal balance between energy flow and self-discharge.

A battery's self-discharge rate is also influenced by the cell's current discharge potential, its method of manufacturing, and the quality of its raw materials. As a result, a top-quality bobbin-type $LiSOCl_2$ cell can achieve a self-discharge rate of 0.7% per year, thus retaining 70% of its original capacity after 40 years. By contrast, an inferior quality bobbin-type $LiSOCl_2$ cell can have a self-discharge rate of up to 3% per year, thus losing as much as 30% of its capacity every 10 years, making 40-year battery life impossible.

Design engineers need to be fully aware that a battery's actual self-discharge may take years to become fully measurable, and theoretical test data tends to be far less reliable than actual in-field data. So thorough due diligence is required when evaluating competing battery suppliers.

2. Oceantronics redesigned the battery pack for its GPS/ice buoy, replacing 380 alkaline D cells with a far smaller, lighter, and economically designed battery pack using 32 bobbin-type $LiSOCl_2$ cells and four HLCs. The redesigned battery pack reduced size and weight by 90% (54 kg down to 3.2 kg), making the device far easier to transport via helicopter to icebergs near the North Pole. *(Courtesy of Oceantronics)*

THE INCREASING NEED FOR HIGH PULSES IN TWO-WAY WIRELESS CONNECTIVITY

More and more, remote wireless devices connected to the IIoT require periodic high pulses to power two-way wireless communications. To satisfy this added power demand, smart devices must incorporate a low-power communications protocol (i.e., WirelessHART, Zigbee, or LoRa) along with a low-power chipset and energy-saving components. Proprietary energy-saving techniques also are deployed to extend battery life.

Unfortunately, despite their incredible longevity, standard bobbin-type $LiSOCl_2$ cells aren't well-suited for delivering high pulses. However, that challenge can be easily overcome by adding a patented hybrid layer capacitor (HLC). The bobbin-type $LiSOCl_2$ cell serves to deliver low-power background current while the HLC acts like a rechargeable battery to store pulses of up to 15 A. The patented HLC also features a unique end-of-life voltage plateau that can be interpreted and then programmed to deliver "low battery" status alerts.

Supercapacitors are commonly used to store high pulses for consumer electronics. However, they're rarely used in industrial applications due to inherent limitations, including short-duration power; linear discharge qualities that don't permit full discharge of available energy; low capacity; low energy density; and a very high self-discharge rate of up to 60% per year. In addition, supercapacitors linked in series require bulky cell-balancing circuits that add cost and draw more energy to further shorten their operating life.

BOBBIN-TYPE $LiSOCL_2$ BATTERIES IN THE REAL WORLD

Below are some representative examples of applications in harsh environments that often benefit from the use of long-life bobbin-type $LiSOCl_2$ batteries:

Oceantronics

To solve the problem of transporting large, bulky scientific equipment across the Artic, Oceantronics redesigned the battery pack for its GPS/ice buoy. It replaced an oversized battery pack made up of 380 alkaline D cells with a far smaller, lighter, and more cost-efficient solution using 32 high-energy-density bobbin-type $LiSOCl_2$ cells and 4 HLCs *(Fig. 2)*.

3. Bobbin-type $LiSOCl_2$ cells reduce the size and weight of Southwire's line/connector sensors that monitor the temperature, catenary cables, and line current of electric power to warn the utility if power transmission lines go down. (Courtesy of Southwire)

By achieving a 90%+ reduction in size and weight (54 kg down to 3.2 kg), the redesigned battery pack was far easier to transport to icebergs located near the North Pole via helicopter. In addition, converting from alkaline to bobbin-type $LiSOCl_2$ chemistry multiplied potential battery life many times over.

Southwire

Minimizing size and weight is a major concern for utility line crews climbing up and down tall towers to install line/connector sensors that monitor the status of electric power transmission lines, including temperature, catenary, and line current. Southwire chose bobbin-type $LiSOCl_2$ batteries to enable the collection and aggregation of data that's transmitted via cellular network to warn a utility if a transmission line goes down.

Use of a bobbin-type $LiSOCl_2$ battery enables the line/connector sensor to be more compact and lightweight (3.5 lbs.), providing easier portability in extreme temperatures (−40 to 50°C). These batteries also deliver the high energy density and high capacity required to provide 45+ days of backup power in case no line current is detected *(Fig. 3)*.

> Minimizing size and weight is a major concern for utility line crews climbing up and down tall towers to install line/connector sensors that monitor the status of electric power transmission lines, including temperature, catenary, and line current.

Cryoegg

Beneath glaciers in Greenland and Antarctica lay water channels up to 2.5 km deep. Researchers are using wirelessly connected sensors to measure how climate change and rising sea levels are impacting these deep-water channels.

To support this research, the "Cryoegg" was developed by Cardiff University. This innovative device measures and transmits data regarding temperature, pressure, and electrical connectivity via underwater radio signals, eliminating the need for bulky and expensive cables that can become broken or disabled by glacial movement. Bobbin-type $LiSOCl_2$ cells were chosen for their high capacity and energy density, extended temperature range, and

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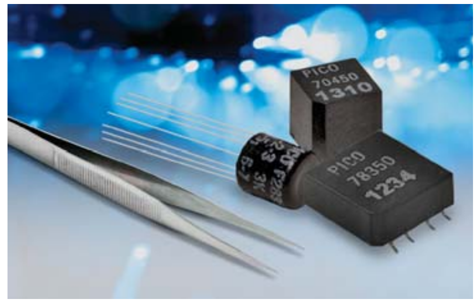

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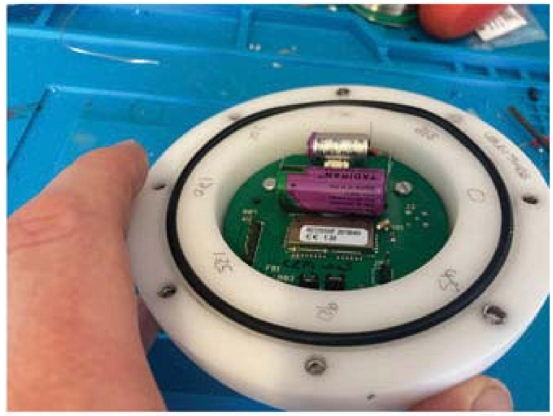


4. Bobbin-type $LiSOCl_2$ batteries feature higher capacity and energy density, an annual self-discharge rate as low as 0.7% per year to permit up to 40-year battery life, and the widest possible temperature range (–80 to 125°C).

ability to generate periodic high pulses to transmit data twice each day for approximately two years *(Fig. 4)*.

The Cryoegg utilizes the same 169-MHz Wireless M-Bus radio technology that's powered AMR/AMI utility meter transmitter units (MTUs) for nearly 40 years. Virtually all MTUs are powered by ultra-long-life, bobbin-type $LiSOCL_2$ batteries that reduce the potential for costly system-wide battery failures, thereby reducing the potential for chaotic disruptions to normal billing systems as well as disabling remote start-up/shut-off capabilities.

> Siolar-powered devices require PV panels and rechargeable batteries large enough to power the device for five to seven days in case there's no sunshine.

HIGHER ENERGY DEMAND MAY REQUIRE ENERGY HARVESTING

As previously noted, certain wireless applications that draw milliamps of current may demand the use of an energy-harvesting device in combination with Li-ion rechargeable batteries.

Consumer-grade rechargeable Li-ion cells are too short-lived for most industrial-grade applications, with a limited operating life of five years and 500 recharge cycles, restricted to use in moderate temperatures (0 to 40°C). Consumer Li-ion rechargeable batteries are also unable to deliver the high pulses required for two-way wireless communications.

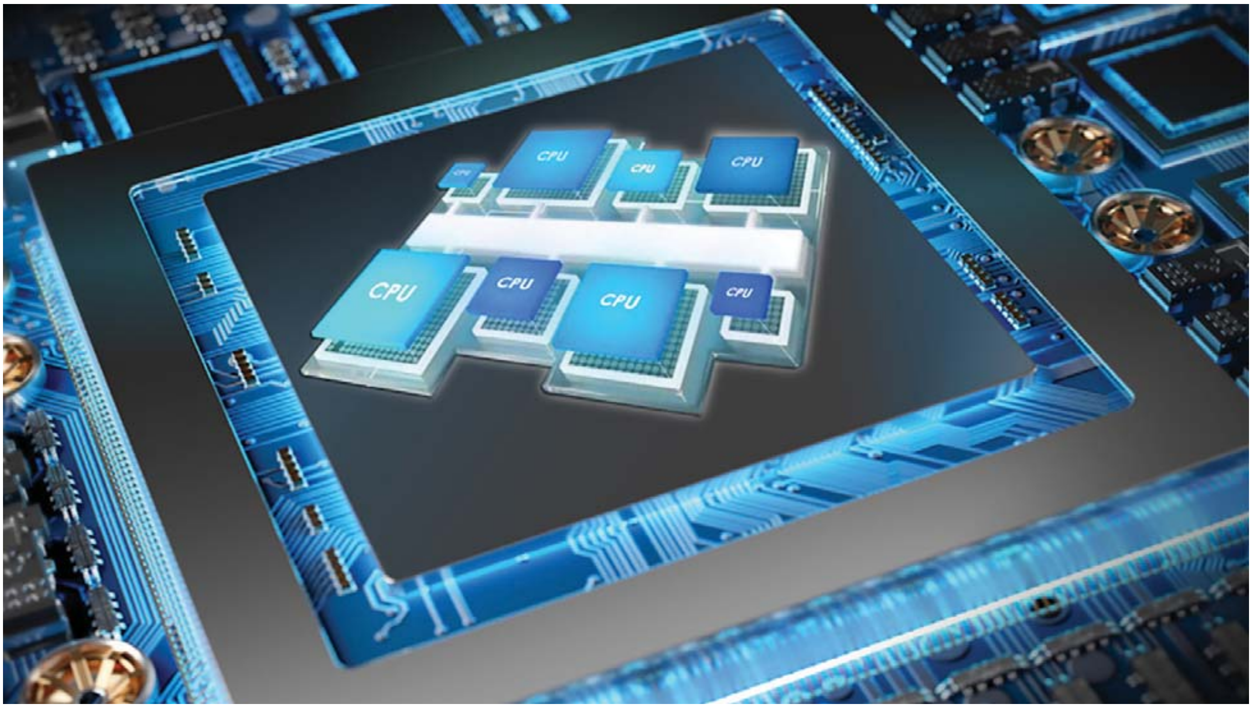
By contrast, industrial-grade Li-ion batteries can operate for up to 20 years and 10,000 full recharge cycles at an expanded temperature range (–40 to 85°C), along with the ability to deliver periodic high pulses to power two-way wireless communications.

One prime example involves the use of small solar (PV) panels and industrial-grade Li-ion batteries to power collars that remotely monitor and communicate the health, location, and safety of animal herds. Similarly, solar/Li-ion hybrid systems are powering parking-meter fee-collection systems equipped with AI-enabled sensors to identify open parking spots.

Solar-powered devices require PV panels and rechargeable batteries large enough to power the device for five to seven days in case there's no sunshine. While this scenario may rarely occur, the power supply must be overdesigned to cover any shortfall. Incorporating a primary $LiSOCl_2$ cell can create a backup solution for charging the Li-ion cell to compensate for a prolonged period of no sunshine. This backup solution permits the use of a smaller PV panel and fewer or smaller Li-ion batteries, thus saving money while aiding in product miniaturization.

Rapid expansion of the IIoT is creating dynamic opportunities for industrial-grade, long-life primary and rechargeable Li-ion batteries that improve product reliability and reduce the total cost of ownership. If your application requires a battery that can last as long as your device, then do your due diligence and challenge potential battery suppliers to supply well-documented long-term test results, comprehensive in-field performance data (under similar conditions), and numerous customer references. ed

JEFF HANCOCK | Senior Product Manager for Mentor Embedded Platform Solutions, Siemens Digital Industries Software



What's Best for Your Multicore Design— a Hypervisor or Multicore Framework?

Multicore embedded systems generally need some overall supervisory software that provides control of boot order and inter-core communication and security. There are two main options: a hypervisor and a multicore framework.

Today's multicore system-on-chip (SoC) hardware offers the promise of being able to pack more into your embedded project than ever before. Designers no longer have to segregate software domains into separate devices. Multicore processing clusters within the same device can lower bill-of-materials (BOM) costs and help shorten design times through tighter domain integration.

However, for more complex systems, it remains the task of the systems architect and software designers to correctly configure the application domains, keep important data separate and secure, and effectively manage how the overall system will communicate. One critical decision should be made early in the process: What's the best domain manager for your multicore system? Is a hypervisor required, or is a multicore framework a better solution?

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MULTICORE SYSTEMS

In a multicore SoC, facilitating functional segmentation of a project results in designs being configured as asymmetric multiprocessing (AMP) systems. An AMP system may be constructed from any combination of core architectures. All of the cores may be identical (homogeneous) or there may be a rich mixture of core types that includes conventional processing units as well as specialized cores; for example, (heterogeneous) digital signal processors (DSPs).

Each core executes independently in an AMP architecture, with or without an operating system. In addition, each core's operating system may be selected on the basis of the required functionality.

An AMP design comes with unique challenges:

- An inter-core communication facility is most likely required.
- There may be safety/security issues that require the cores to be protected from one another.
- Boot order—the sequence in which the software on each core starts—may be important to avoid synchronization and security issues.

Debugging the different workloads running on the potentially heterogeneous cores can be quite challenging.

Although the cores in an AMP system are independent, these challenges indicate that some overall control facility is necessary. Broadly there are two options:

- *Hypervisor:* A complex software component that runs across all the cores.
- *Multicore framework:* A software component that allows enablement for AMP systems, which runs on each core.

It should be noted that multicore applications can be implemented using a symmetric multiprocessing (SMP)-enabled operating system. However, that approach doesn't allow for independent workloads to be executed on different cores, and it doesn't support heterogeneous cores.

HYPERVISORS

A hypervisor is a fairly complex, versatile software component that provides a supervisory capability over a number of operating systems, managing CPU access, peripheral access, inter-OS communications, and inter-OS security. A hypervisor may be used in a number of ways. For example, multiple operating systems can be run on a single CPU to protect an investment in legacy software. But, with the growth of multicore processors, this is becoming rarer.

Alternatively, hypervisors can be used in embedded applications in AMP designs, where supervision of inter-core communication and allocation of peripherals to specific cores is needed. A hypervisor can also take care of the boot sequence and manage shared peripheral access.

One of the main advantages of using a hypervisor is that if an operating system "crashes," it will not affect execution of workloads on other cores.

One of the main advantages of using a hypervisor is that if an operating system "crashes," it will not affect execution of workloads on other cores. In some cases, the hypervisor can even reboot that operating system without requiring a reboot of the device. It is, of course, very advisable to utilize a hypervisor that's specifically designed for use in embedded applications for better performance.

Although it's possible to develop a hypervisor that will enable all of the required separation and virtualization features in software, it's quite difficult and unusual these days. Today hypervisors are designed to use underlying virtualization features present on most multicore processors.

PROS AND CONS OF HYPERVISORS

Hypervisors have advantages and disadvantages compared with other solutions.

Pros

- Great flexibility enables efficient resource sharing, dynamic resource usage, low latency, and high-bandwidth communication between virtual machines (VMs)
- Strong inter-core separation
- Enables device virtualization and sharing
- Ability to assign ownership of peripherals to specific cores

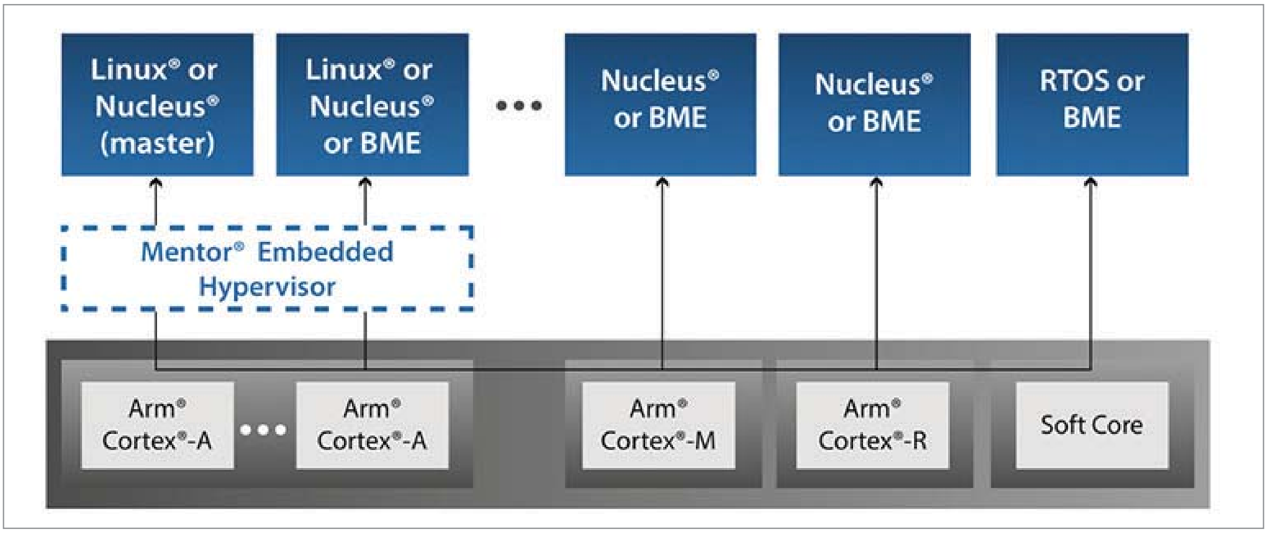
Cons

- Only work on a homogenous multicore device (i.e., all cores are identical)
- Significant code footprint
- Some execution overhead
- Require hardware virtualization enablement in the processor

MULTICORE FRAMEWORKS

Because of their separation, management, and sharing capabilities, hypervisors have far more functionality than many embedded designs demand—and they can be overkill. To address this issue, a few embedded runtime vendors developed an alternative that was specifically engineered to support an AMP multicore system: the multicore framework.

Frameworks are designed very specifically to support the multicore application, providing just the key functionality: boot order control and inter-core communications. The



1. The Mentor Embedded Hypervisor is a proprietary implementation of the OpenAMP standard.

result is that a framework loads a system with a much lower overhead and can be run on much more basic systems. Although each core in an AMP design probably runs an operating system, one or more cores may be "bare metal"—i.e., running no OS at all. A multicore framework can accommodate this possibility.

INTER-PROCESSOR COMMUNICATION (IPC)

Once the remote processor OS and application stack are running, many use cases will require communication with other parts of the system. The Mentor Embedded Multicore Framework provides a clean-room implementation of a remote processor messaging framework feature called rpmsg to establish a communications channel between the master operating system and the remote operating systems. In this way, data can be passed back and forth between the two in an inter-processor communication channel.

The transport layer that enables both remote processor lifecycle management and inter-processor communication is VirtIO. VirtIO is a virtualization standard for high-performance input/output device drivers widely adopted in virtualized Linux environments.

REMOTE PROCESSOR LIFECYCLE MANAGEMENT

Assuming control over a remote processor, and then starting or stopping an OS and/or application stack within that remote processor, is referred to as remote processor (remoteproc) lifecycle management. The Linux community has adopted a remote processor framework for managing this scenario. Remoteproc allows a master operating system to bring up other operating systems on other cores.

The remoteproc feature within the Mentor Embedded Multicore Framework enables remote processor interoperability between Mentor Embedded Linux, Nucleus RTOS, and Bare Metal Environments (BME) and Linux and RTOS products from other vendors. A key benefit to remote processor lifecycle management is reduced power consumption. The remote core stays in a low-power state when not in use. Only after remoteproc is used to bring up the remote core and deploy the necessary firmware does the remote core draw any notable power.

PROS AND CONS OF MULTICORE FRAMEWORKS

Multicore frameworks have advantages and disadvantages compared with other solutions.

Pros

- Provides the minimally required functionality for some applications
- Modest memory footprint
- Minimal execution time overhead
- Can work on heterogeneous multicore devices (i.e., all cores needn't be identical)
- Supports bare-metal applications

Cons

- The core workloads aren't isolated from each other
- Can be more difficult to control boot sequence, and to debug

OpenAMP

Although some multicore frameworks are proprietary, some standards have been proposed that govern their functionality, interfaces, etc. A popular example of such a standard is OpenAMP.

There are two key functionalities in OpenAMP:

- Lifecycle management using remoteproc. This facilitates control of boot order, etc.
- Inter-core communications using RPMsg.

A current reference implementation of the OpenAMP standard is available

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on GitHub. Mentor Embedded Multicore Framework (MEMF) and Mentor Embedded Multicore Framework Cert are proprietary implementations of the OpenAMP standard. Extensions to the standard include additional functionality to support Linux as a Remote, Large Buffer, Zero Copy, Proxy support for Ethernet, and additional development tools *(Fig. 1 on page 23)*.

MIXED SAFETY-CRITICALITY SYSTEMS

A mixed safety-critical system is a system that requires the execution of several applications of different safety integrity levels (SILs) or different criticalities, such as safety-critical and non-safety critical, on a single SoC. Both a hypervisor and a multicore framework can support this type of configuration.

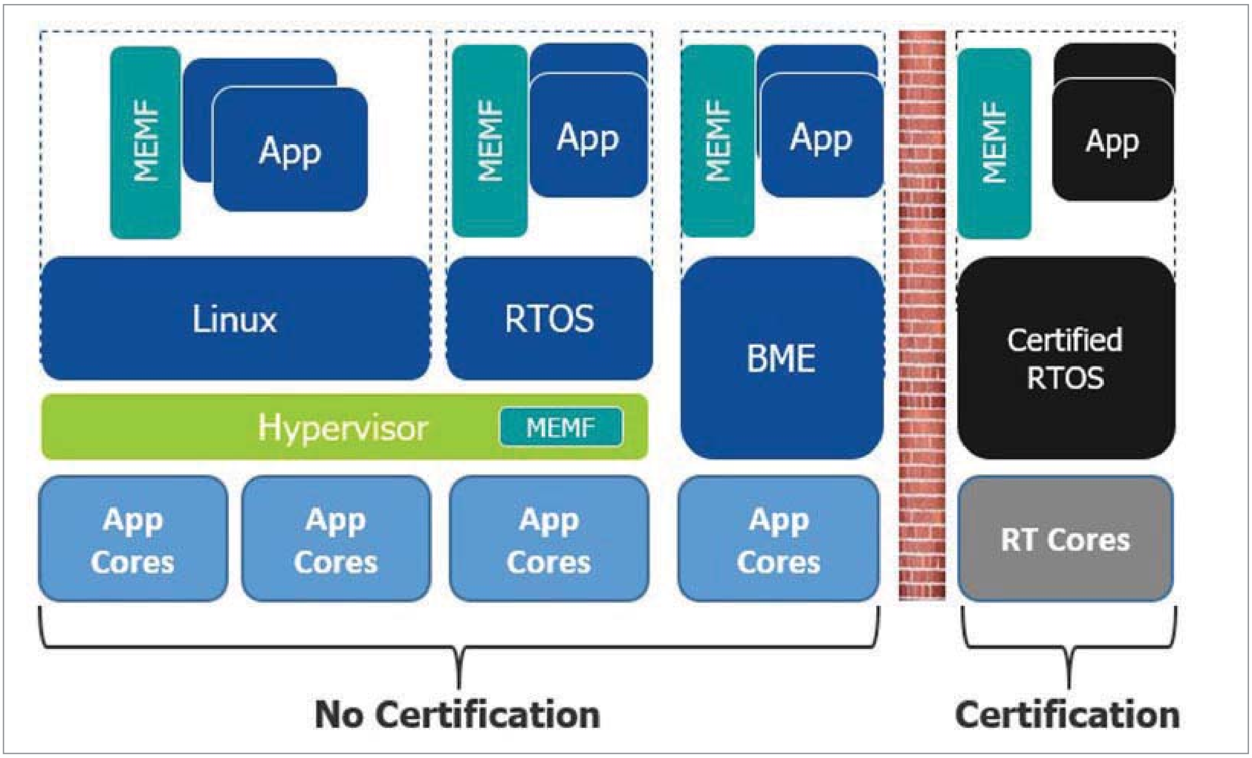
A hypervisor does this by certifying the hypervisor itself. The virtual machines can then have different criticality levels running with the certified hypervisor. The separation is provided by the certified hypervisor, which typically uses underlying hardware virtualization and separation features on the SoC.

A multicore framework leverages other hardware-assisted separation capabilities provided by some SoC architectures to obtain the required separation between the safe domain and non-safe domain. This includes the separation of processing blocks, memory blocks, peripherals, and system functions. The multicore framework provides enhanced bound checking to ensure the integrity of shared-memory data structures. It also provides interrupt throttling and polling mode to prevent interrupt flooding. It's even possible to use a non-safety certified hypervisor along with a mixed criticality-enabled multicore framework *(Fig. 2)*.

CONCLUSIONS

Deciding to use a hypervisor or a multicore framework, or both, to control and manage a multicore system is a critical architecture decision. The final choice will depend on the specific application requirements and the use case for the device. The options should be considered as complementary solutions that can unlock the power of a multicore SoC, enabling the management of the various project domains, and ultimately allowing designers to focus on the unique IP of their projects.

Deciding to use a hypervisor or a multicore framework, or both, to control and manage a multicore system is a critical architecture decision.



2. A multicore framework can provide enhanced bound checking to ensure the integrity of shared-memory data structures, allowing a non-safety certified hypervisor to work with a mixed criticality-enabled multicore framework.

BENOIT de LESCURE | CTO, Arteris IP

DON'T DO IT: Design Your Own On-Chip Interconnect

SoC apps have rapidly changing needs that must be addressed through the on-chip interconnect, but most interconnects developed in-house aren't user-friendly. Given the huge fixed development costs, doing a few chips a year usually makes no economic sense.

System-on-chip (SoC) technology is quickly evolving as the market demands higher computing power, faster speeds, scalability, and better reliability. SoC devices are currently being deployed in a diverse range of applications commonly found in embedded systems once dominated by microcontrollers.

Network-on-a-chip (NoC) provides a full functioning subsystem vital to SoC technology *(Fig. 1)*. Having the right intellectual property (IP) interconnects to enable the

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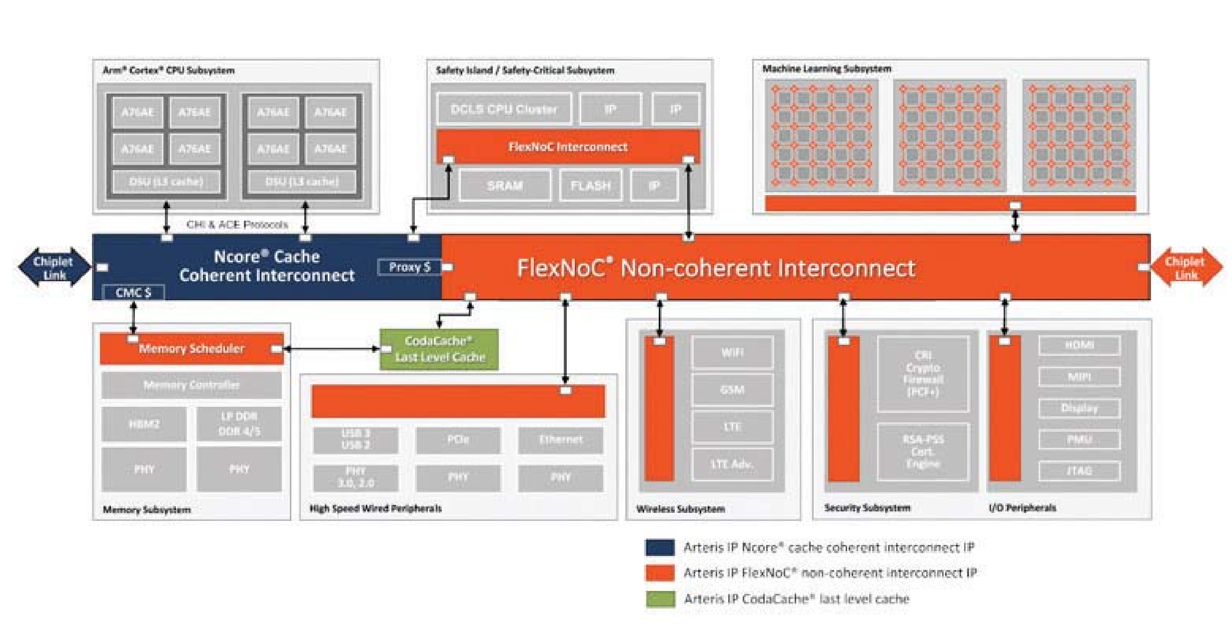


1. Licensing NoC IP from a commercial provider that already has a history of tackling cutting-edge issues, such as functional safety for autonomous vehicles, can help accelerate the time-to-market while providing a better technical solution than could be built through internal IP development. *(Source: Arteris IP)*

required scalability and performance of today's NoC and SoC designs is critical. However, an ongoing discussion among the design architecture community centers on whether it's better to purchase SoC interconnect IP from experts or build and maintain interconnect IP in-house.

EFFECTIVE INTERCONNECT IP SOLUTIONS

SoC applications have rapidly changing requirements that must be quickly addressed through the on-chip interconnect, but most interconnects developed in-house weren't developed to be user-friendly. Given the huge fixed development costs, doing a few chips a year usually makes no economic sense.

Most design teams have adopted a platform approach where one design is adapted for multiple markets and use cases by quickly creating derivative chips. The interconnect is critical to creating these derivative semiconductors. Failure to have a world-class interconnect IP slows down the ability to adapt to new chip requirements and severely limits a company's ability to respond to market changes.

Interconnect technology is challenging to create and support because of the low power, latency, data path, and security parameters that all must be optimized. In the highly competitive and rapidly changing IC market, companies have better ways to use their talent and money.

Given the complexities, regulations, evolving requirements, and cost, it's almost always better to license commercially developed interconnect IP. Buying proven technology helps to avoid being stuck supporting IP through multiple iterations and generations. IP experts exclusively focus on creating interconnect IP. These IP packages also allow for custom configuration.

NOC DESIGN: A TRICKY ROUTE

If chip companies are still tempted to move forward with their own interconnect IP program, consider what it takes to develop NoC interconnects.

> Interconnect technology is challenging to create and support because of the low power, latency, data path, and security parameters that all must be optimized. In the highly competitive and rapidly changing IC market, companies have better ways to use their talent and money.

NoC technology is a communication subsystem between modules on an SoC chip. NoC essentially connects IP design blocks on the SoC. The benefits of using a NoC interconnect include its packetized approach, wire reduction

Today's chip market is changing more rapidly than designers can adapt—as soon as one NoC is done, new requirements come into play. Teams must start the next chip iteration to meet new requirements for performance, bandwidth, cache coherence, arbitration, latency, quality of service, power management, and security.

leading to less chip real estate, and a significant power demand reduction. NoC also provides a more standardized way to add or replace IPs when designing an SoC.

The most challenging aspect of this process is designing the NoC so that the packets reach their destination at the time they need to arrive—without blowing up the area and/or power. This requires three completely separate skillsets:

- The networking expert to break down packets, channels, and quality of service.
- The semiconductor expert needed for design, verification, and Verilog expertise to design down to the gate level.
- The software expert who creates the IP configuration cockpit that turns chip architects' system requirements into synthesizable NoC RTL, testbenches, SystemC performance models, IP-XACT data, and other deliverables required of all commercial semiconductor design IP.

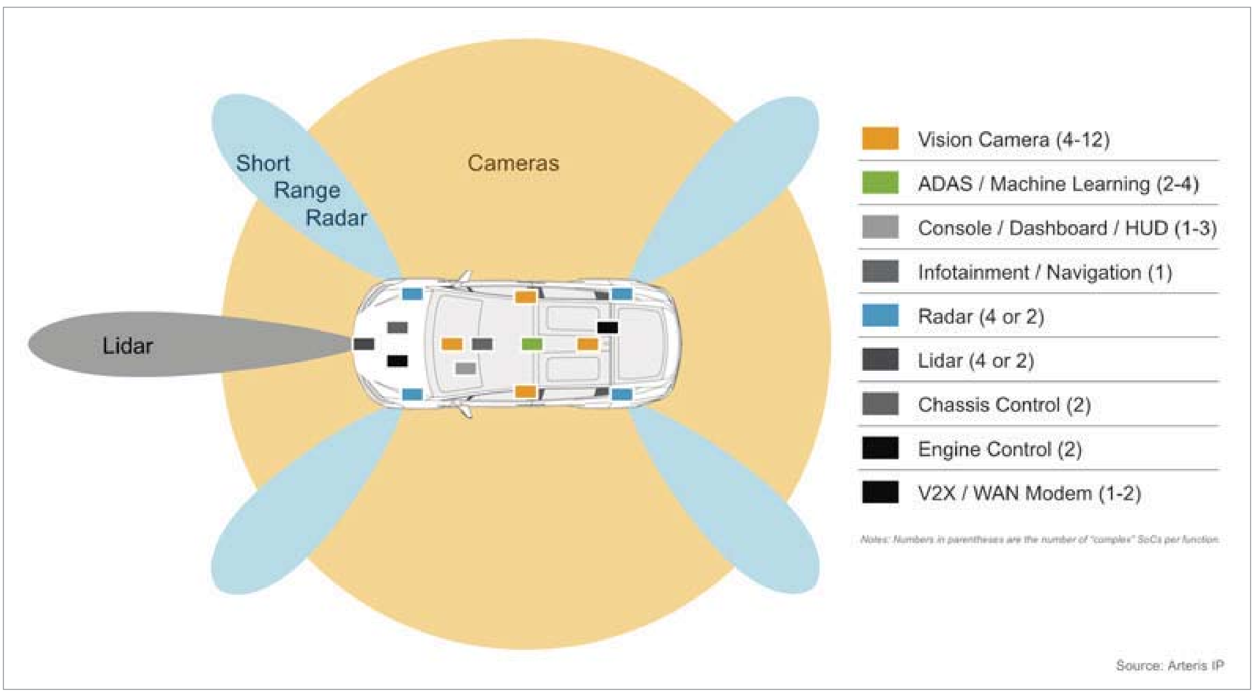
THE RAPIDLY EVOLVING SoC MARKET

Today's chip market is changing more rapidly than designers can adapt—as soon as one NoC is done, new requirements come into play. Teams must start the next chip iteration to meet new requirements for performance, bandwidth, cache coherence, arbitration, latency, quality of service, power management, and security.

Nowhere is this as accelerated as in vehicle design, where the shift toward autonomous vehicles sees advances in sensing, communications, and artificial intelligence *(Fig. 2)*.

A new interconnect could take over a year to define and implement in league with the rest of the IC design team, and that's too long—the competition would have already made it to market.

Selling into automotive, medical, or automation markets, safety accessors are going to look closely at how the IC has been built. This means the interconnect team needs traceability, proper verification, and documentation—lots of documentation, or no one will buy the chip.



2. Autonomous vehicles represent the tip of the spear in IC architecture and design, as well as safety. *(Source: Arteris IP)*

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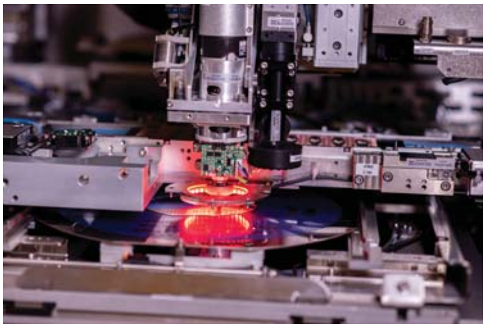

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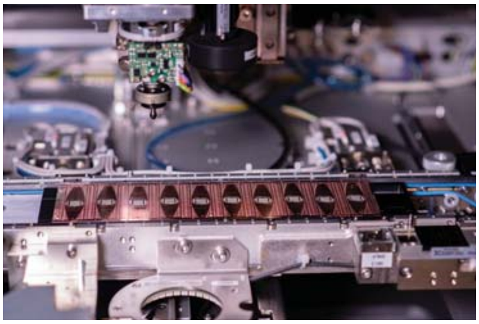

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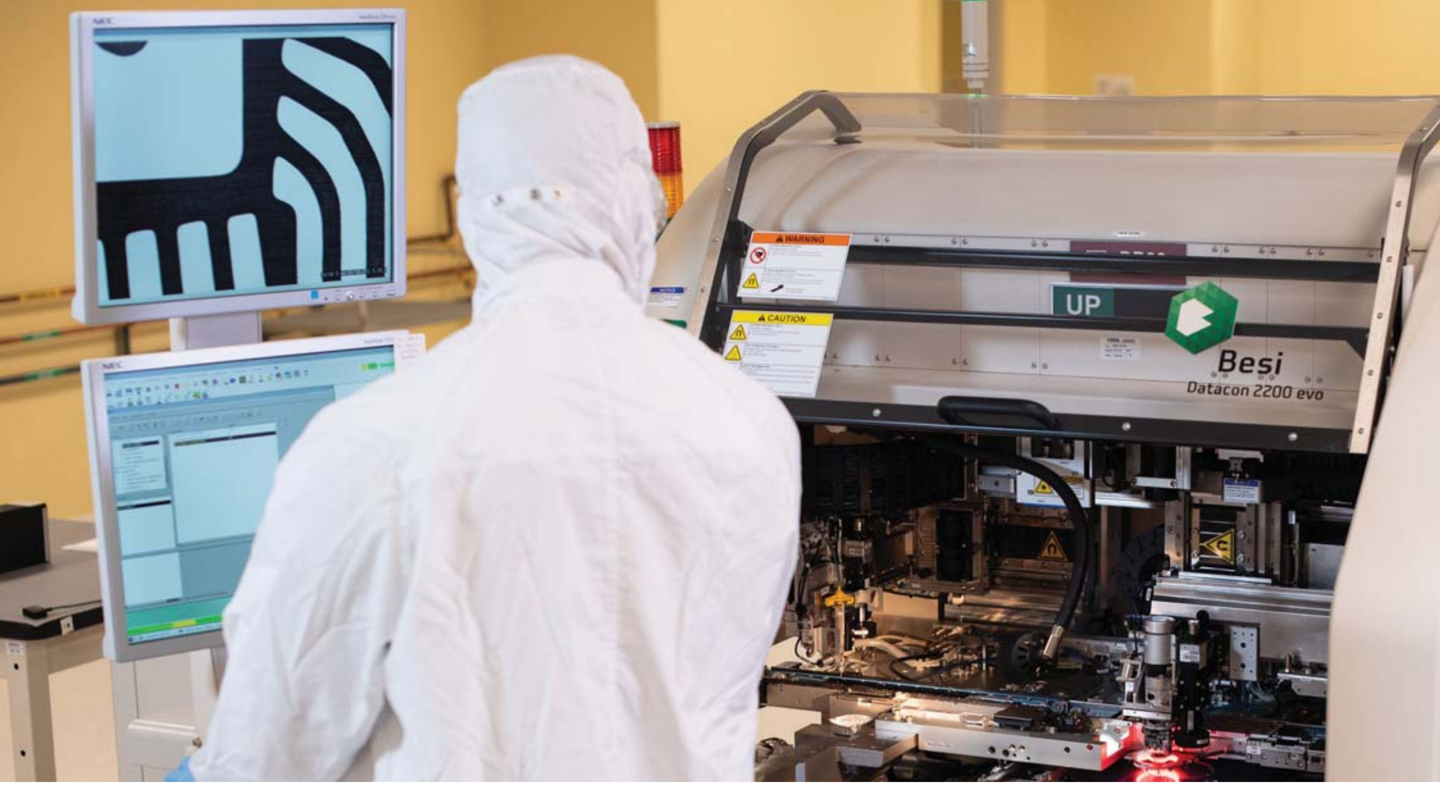

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There are many possible safety mechanisms within the interconnect providing diagnostic coverage and managing recoverability and reboots. Among them is the creation of safety islands that have high diagnostic coverage metrics to enable system-level ISO 26262 ASIL D compliance *(Fig. 3, again)*.

Having a licensed NoC from a partner tightly coupled with key IP vendors is a safer and faster route.

Once the decision is made, licensing the NoC IP from a specialized interconnect developer is the better route from both a technical and business perspective.

SPECIALIZATION IN FUNCTIONAL SAFETY

Functional safety is the perfect example of a value-add at the IC level for autonomous-vehicle and robot designs, and one that requires training, knowledge, and manpower to complete accurately. It's better handled by a specialty NoC provider who has worked closely with processor IP providers such as Arm *(Fig. 3)*.

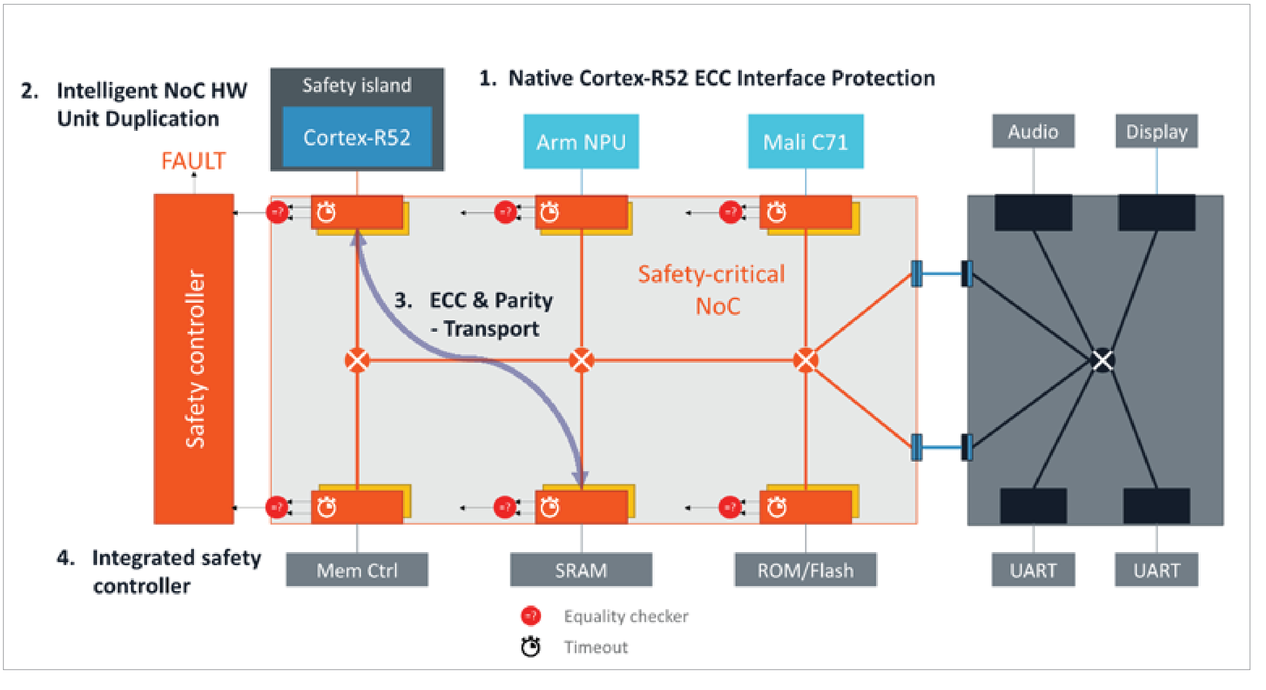
There are many possible safety mechanisms within the interconnect providing diagnostic coverage and managing recoverability and reboots. Among them is the creation of safety islands that have high diagnostic coverage metrics to enable system-level ISO 26262 ASIL D compliance *(Fig. 3, again)*.

These safety islands aid in ensuring fail-safe modes, while ECC and parity transport minimize errors. Much work goes into redundancy and path optimization, as well as subsystem reset and reboot, while avoiding catastrophic failure.

CONCLUSION

Effective interconnect IP design requires extensive technical expertise in several disciplines. Engineering SoC interconnects in-house will require tens of engineers and prolonged design time, extensive internal verification, and the ability to rapidly address company-wide support concerns and numerous other issues that will only worsen as SoC technology continues to evolve.

The alternative to in-house interconnect design is simple: Seek out companies that focus on engineering and licensing the state of the art in NoC interconnect IP. ed

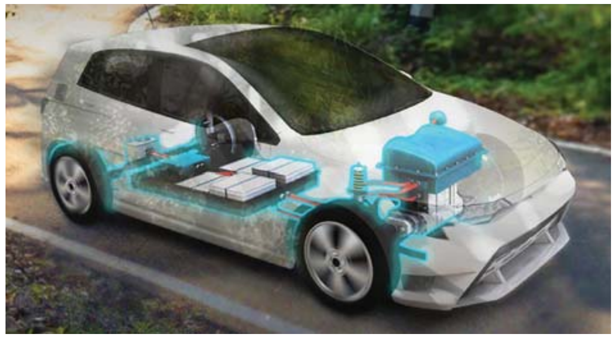


3. Creating safety islands; generating, transporting, and checking error-correcting codes (ECC) and parity bits; and providing integrated built-in self-tests and reporting are some of the NoC IP benefits that have been developed with key IP providers. *(Source: Arteris IP, Arm)*

MURRAY SLOVICK | Contributing Editor

Automotive GaN FET Features Integrated Driver

The device, developed by Texas Instruments, is said to double power density and boost efficiency in automotive onboard chargers.



TI's integrated GaN solution can help hybrid-electric and electric vehicles charge faster and drive farther. *(Source: TI)*

Wide-bandgap semiconductors are an attractive material for power devices due to low losses, improved temperature capability, and high thermal conductivity. Compared to silicon (Si), with a larger bandgap, higher breakdown field, and higher electron saturation velocity, power devices can have higher breakdown voltage and operate at higher frequency.

In the automotive space, GaN FETs can help significantly reduce the size of electric-vehicle (EV) onboard chargers and dc-dc converters compared to existing Si solutions. As a result, engineers are able to achieve extended battery range, increased system reliability, and lower design cost.

Texas Instruments' (TI) new 650- and 600-V automotive-qualified GaN FETs aim to power on-board charging systems in electric vehicles while reducing power losses by 50%. The parts are further said to help engineers deliver twice the power density, achieve 99% efficiency, and reduce the size of power magnetics by 59% compared to existing solutions.

One key advantage of GaN is fast switching, which enables smaller, lighter, and more efficient power systems. TI's LMG342xR030 integrates a silicon driver that enables switching speed up to 150 V/ns. This integration, combined with a low inductance package, is said to deliver cleaner switching and minimal ringing in hard-switching power-supply topologies.

The integrated driver solves a number of other challenges in GaN applications. It ensures the device stays off for high drain slew rates. The driver also helps protect the GaN device from overcurrent, short-circuit, undervoltage, and overtemperature conditions with fault indication.

What's more, the GaN FETs include adjustable gate-drive strength for EMI control, digital temperature reporting, and TI's ideal diode mode. The latter maximizes efficiency by reducing third-quadrant losses via adaptive dead-time control and automatically realizes a fast synchronous FET operation without external circuitry.

Traditionally, when designing GaN FETs, engineers must solve the tradeoff between switching speed and power losses. TI's ideal diode mode aims to reduce third-quadrant losses by up to 66% compared to discrete GaN and SiC MOSFETs. Third-quadrant operation can be defined as follows: When the GaN device is turned off and negative current pulls the drain node voltage to be lower than its source, the voltage drop across the GaN device during third-quadrant operation is high.

This integration, plus the high power density of GaN technology, enables engineers to eliminate more than 10 components typically required for discrete solutions, according to TI. In addition, each of the new 30-Ω FETs can support up to 4 kW of power conversion when applied in a half-bridge configuration.

The converter requires only a single surface-mount power inductor and output bypass capacitor. It's designed to use a 4.7-μH inductor and a 2.2-μF output capacitor.

One aspect of a GaN converter is the reverse-recovery characteristic, which helps to avoid losses and other associated problems. Unlike Si MOSFETs, there is no p-n junction from source to drain in GaN devices. That's why the GaN device can offer zero reverse recovery and a low output capacitance, enabling higher efficiency in bridge-based topologies.

GaN's fast switching speed increases efficiency, which in turn reduces the burden on cooling in automotive vehicles. With packaging that allows engineers to use smaller heat sinks while simplifying thermal designs, the new devices provide thermal design flexibility with the ability to choose from either a bottom- or top-side-cooled package. In addition, the FETs' integrated digital temperature reporting enables active power management. As a result, engineers can optimize system thermal performance under varying loads and operating conditions.

Pre-production versions of TI's four new 600-V GaN FETs are available now in a 12- × 12-mm, quad flat no-leads (QFN) package. Pre-production versions of the new LMG3522R030-Q1 and LMG3525R030-Q1 650-V automotive GaN FETs and evaluation modules are expected to be available in the first quarter of 2021. ed

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For applications requiring extended storage life followed by high current drain, Tadiran offers TLM Series lithium metal oxide batteries. Packing powerful amounts of energy into small spaces, TLM Series batteries are utilized in medical applications such as portable defibrillators. They also allow battery-operated surgical drills to be smaller and more ergonomic to reduce fatigue while at the same time delivering the high torque required for efficient drilling cycles. TLM Series batteries also provide an lower cost COTS solution for military applications. For example, TLM batteries enable more miniaturized guided munitions to be periodically tested for system readiness whereas legacy reserve/thermal batteries are bulkier and do not permit system readiness testing without exhausting the battery.

ALIX PAULTRE | Editor, *Evaluation Engineering*

TI's New GaN FETs for Automotive and Industrial: An Insider's Perspective

Next-gen 600- and 650-V gallium-nitride FETs developed by Texas Instruments double the power density and achieve 99% efficiency.

Texas Instruments recently expanded its high-voltage power management portfolio with next-generation 650- and 600-V gallium-nitride (GaN) field-effect transistors (FETs) for automotive and industrial applications. Integrating a 2.2-MHz integrated gate driver, the devices can enable twice the power density, achieve up to 99% efficiency, and reduce the size of power magnetics by up to 59% compared to existing solutions.

Developed using proprietary materials and processing with a GaN-on-silicon (Si) substrate, these GaN FETs can address applications from driving electric-vehicle (EV) onboard chargers to empowering hyperscale and enterprise computing platforms. To get a better handle on what this represents for the engineering community, we sat down with Steve Tom, who manages the GaN product line within TI's High-Voltage Power business unit. Steve joined TI after graduating from the University of Michigan with BSEE and MS IOE degrees.

Let's start with the trends in wide-bandgap power electronics, because in this case, talking about the trends is a good place to start.

I think sometimes we take power management for granted because everything needs power. And that's why we're so focused on it—it's that important. We want our customers to make the most differentiated products. The way we've architected this is that we've identified power topics as things that our customers really care about, things that have been important, things that are emerging in places where we see we can add a significant advantage of differentiation.

Everybody's been talking about power density and efficiency, but let's talk about something we don't often see, and that's TI touting the isolation and low noise of these parts.

I spent a lot of time myself personally addressing power density, but the key is the isolation technology. If you've got to shift domains in the voltage, you have to have an isolation barrier. I live on the high-voltage side of the transformer; you have to be able to cross over the appropriate way to get to whatever you're trying to power.

So, isolation's important for that. It's also important in a lot of the topologies we do with GaN. The reason GaN can provide the power density and efficiency is because we use new topologies. Those topologies also require isolation, so that's the place we're able to merge in with different technologies.

Thanks for addressing that, because the two things you most often hear are power density and how the frequencies are so high. They're so astronomically high that your magnetics can be the size of a match head. That's all you hear. You know what I mean? And it's nice to hear other aspects of the advantages of the technology.

You have to talk about low noise and precision. To get the performance, you're pushing a lot of power, and you can deliver that efficiency. But if you can't control it with precision, you can't get the right switching waveforms. If you're just blasting the device, it's going to lead to trouble. The key is, you have to get those ideal waveforms because if you get clean square waveforms, you're not burning efficiency and seeing parasitic ringing.

We focused on integrating the driver to get the highest DVT, because if you have slow DVT, you're just burning power. By putting a silicon driver with our GaN FET, you get that brawn of GaN, but you also get the brains and the precision of a silicon driver, so you're getting the best of both worlds. When thinking about power, if you want to optimize and deliver properly, having analog high-precision circuits to give you that low-noise capability allows you to get the most out of what you're trying to deliver. And hence the reason for TI's focus in this direction.

Which brings me to the next point, because packaging is a significant issue when it comes to wide-bandgap semiconductors. Between the parasitics and the design and all, the current generation of passive and transistor packaging does not hold up to the performance that wide bandgap promises. In your release, you talk about your ultra-cool packaging. So, you're also thinking about thermal as well as parasitics.

It's a hobby of mine, because without the packaging, you can't get the power. And I think if you look at the power levels, the power levels aren't new. People have always been trying to push one, five, 10 kilowatts, or more. Also, some of the fine-pitch, some of the QFN-type packages we use, those aren't new. They've been used in low voltage for a long time.

The high-speed nature has been done for a long time as well. The challenge is, can you get the high power, the high speed, and that fine-pitch packaging, and do it all at the same time? That's what's really new and differentiated with what we're doing. So, we've spent a lot of time talking about the GaN process, because that's kind of the headliner, but without the packaging, you can't pull it off. We never had a TO-220 type of package. We know those big leads at that speed, it's just an inductor. It's just not going to work. We knew that we had to get a different type of package.

That's why we've gone with this kind of QFN style—this low inductance—but at the same point, designed so that you can get the thermal mechanics. You've got to get the right size pads. You've got to be able to distribute the power where you must get it off the board. You've got to get the heat thing.

We're trying to also come up with packages so that our customers are doing new things. They're having to find ways to think about how to integrate these in, but that's what's exciting about what we're seeing with some of our new parts.

You say reference designs are coming, but what about evaluation kits? I see you have this daughtercard available. Can you talk a little bit about that aspect, what's coming in the way of designs and kits and the like?

We want to get our customers up and running as soon as possible. GaN is almost exclusively used in a half-bridge, the high-side and low-side device, so you're taking advantage of the fact that GaN has zero reverse-recovery targets. That allows you to switch fast, which is a big advantage. We focus on the half-bridge. We want to make it so you can basically plug it in. We want to make it versatile. On that daughtercard, we have the two devices, so you have everything you need to get up and running. We optimize the layout; the waveforms are clean.

It basically gives the end user flexibility for any type of motherboard they're working on. If they want to do totem-pole PFCs, or any number of multilevel typologies, or more higher-power advanced typologies, that's your basic sub-building blocks you can plug in. And because the way it was optimized on a car, it gives you flexibility if you need to wire it to do different areas. That was our intent there.

Is the industrial device simply a version of the automotive device, or does it do things differently?

There's a couple of differences. The first is the voltage level. In the automotive device, there's a trend and oftentimes requirement to get to that higher voltage, that 650-V level, versus industrial, where 600 V makes sense when a lot of the offline power is power supplies. Both have similar power levels, power delivery.

One of the bigger differences is, as I mentioned before, in the automotive version we put the power pad on top, so you can implement it with a cold plate. The device for industrial use sits in a 1U rack for a telecom or an enterprise PSU. You can put it on a daughtercard and stand it up.

One of the things the release brings up is in integrated high-speed protection and digital temperature reporting for active power management and thermal monitoring. Now, are you using an open-source thing, like a PMBus kind of thing, or is this a proprietary command bus?

There are two specific features. One is the digital temperature reporting. We actually kept it pretty simple for this one—it's just a simple PWM out, you could run that directly into a micro. It's proportional to the temperature.

Very straightforward.

We talk about active power management. There's also another feature here. I mentioned we can send the voltage a current, which is useful. So, like a synchronous converter, your current is going to reverse and we can sense that reversal. Whether it's a MOSFET or other GaN FETs, that device will passively conduct current of the reverse direction, but you get that body die out and you burn a lot of power.

If we're testing that current, we just turn the FET back on automatically. And suddenly that power dissipation dropped to near zero because your FET is now back on. The turn on assist, we can call it ideal diode mode or other different ways, but it's that optimal sensing and turn on that you're able to get. Reduce your power dissipation and push your system that much harder.

Is there anything you feel we haven't touched on that you think is important to leave with the audience?

What I would say is it's exciting to see what the technology can do. The end performance—whether it's the power density, whether it's the efficiency, whether it's just reducing thermals—if you can get the efficiency up, you can remove fans in your set of cooling fans. Therefore, you just get an overall simplified system.

That benefit is what's really exciting, and that's what I enjoy seeing as people find different ways to use the parts. I'm just excited that we can be part of it. The implementation we're doing, we take that GaN FET and integrate a high-performance silicon driver to optimize the performance of FET, and we put it in an advanced package that allows you to get thermals out efficiently without compromising electrical performance.

Pricing has become very aggressive—it's being able to be competitive with existing technologies. So, when we look at it, there's really no reason not to move over to GaN and take advantage of what it can bring in. ed

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WILLIAM G. WONG | Senior Content Director

The Continuing Adventures of Ohm

Find out about Georg Ohm from his creator, Dr. Ray Ridley, and the impetus behind the series.

These days are challenging times for many reasons, including COVID-19. We were lucky enough to have some humorous and insightful cartoons from Dr. Ray Ridley, CEO of Ridley Engineering, creators of the RidleyBox and RidleyWorks design tools. Ohm Confinement is now a regular weekly series on *Electronic Design*. We had a short chart with Dr. Ridley about his cartoon series.

Why a cartoon?

At the beginning of the COVID lockdown in March, my wife and I shuttled our work necessities to the house to set up shop. Our employees did the same. Knowing that it could be weeks or months in a home-based work environment, we adapted as quickly as possible. Memories of raising our four children while working from home in the early days (1990s) kept us laughing through the trauma. These fun memories soon evolved into a cartoon series.

How did it get started?

It started as Ohm Confinement with our main character, power electronics engineer Georg Ohm, attempting to work from home with three children (Meg, Mic, and Milli) to supervise. Meanwhile his wife, Dr. Tera Ohm, is quarantined in her hospital office. The cartoon series became *Adventures of Ohm* as the lockdown eased. Ohm and his family experience many triumphs and setbacks together—achievement, praise, creative mastery, unemployment, devastation, peace, and ultimately, unexpected laughter and quality time with family.

Our introduction to Ohm started here. The new scopes that you can buy have ever bigger screens, but even the best of them is no match for my notebook PC. When you're trying to look at detailed waveforms with maybe eight traces on a screen, it becomes very difficult. We have always used the HDMI output on a scope (make sure it has one!) to put the waveforms on a monitor to share with course attendees. Recently, TV prices have plummeted, and the refresh rates are fast enough to use a TV for a computer monitor. That changed a lot of things for us. Our 28-in. screen become a 34, then a 48, 54, and finally an 80-in. monitor for our conference screen. A 55-in. monitor sits on my bench in the lab with a scope, FRA, and multiple windows for development work. It's a real game changer. At the same time, of course, you can watch movies and your favorite sports events.

Where do you get your material from?

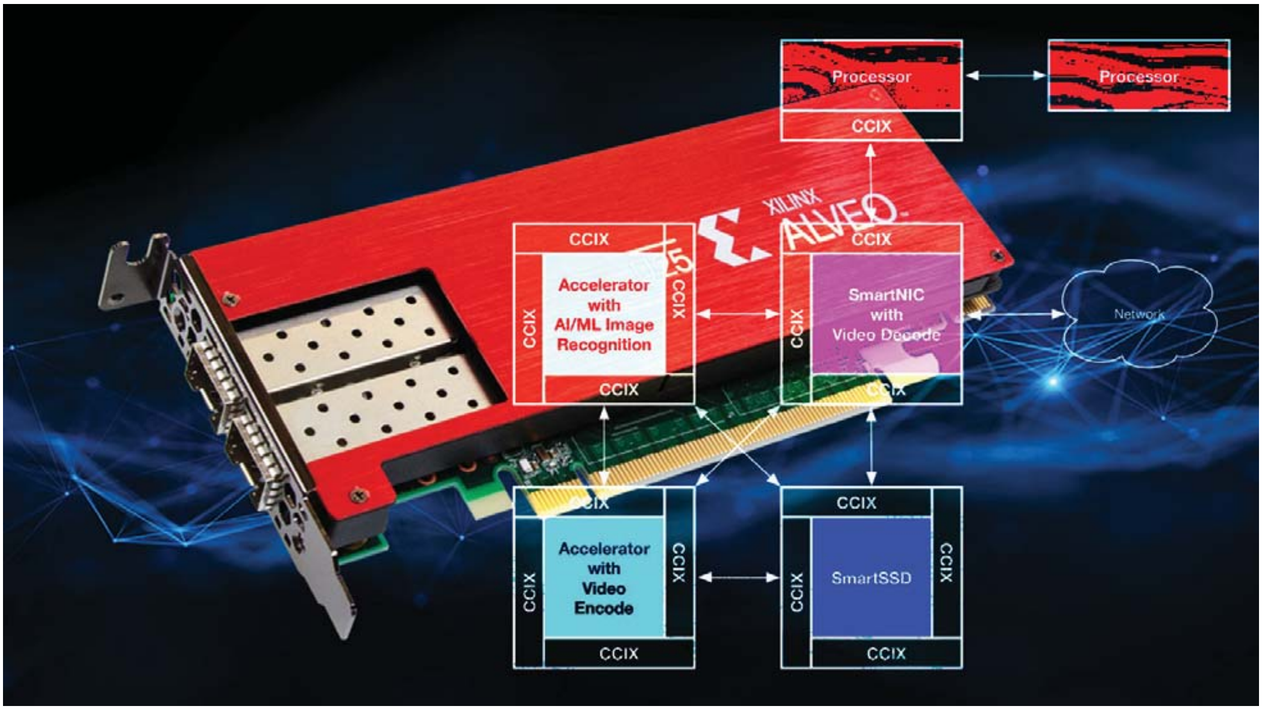
Much of the material is based on real experiences, whether ours or engineers we know. The growing menagerie of animals reflect the realities of the Ridley household. Although it seems like an oxymoron—Engineers and Humor—we find fellow engineers to be quite a comedic bunch. They just think differently.

Do you work with anyone to create the series?

My wife and business partner, Denise Ridley, who is COO of Ridley Engineering Inc., works with me as well as Aya Shaheen, a young and talented artist, who is the illustrator. ed

TO CHECK OUT the Ohm Confinement cartoon series in its entirety, go to Media Gallery section on *Electronic Design's* homepage at *www.electronicdesign.com.*

SCOTT SCHWEITZER | Technology Evangelist, Xilinx

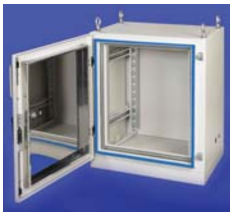


How PCIe 5 with CXL, CCIX, and SmartNICs Will Change SOLUTION ACCELERATION

To go beyond being a generic NIC, SmartNICs will demand more from the PCIe bus. Fifth-gen PCIe and protocols like CXL and CCIX are stepping up to the task. Soon we'll be sharing coherent memory, cache, and establishing multi-host peer-to-peer connections.

We've jumped many chasms over the past three decades of server-based computing. In the 1990s, we went from single-socket standalone servers to clusters. Then with the millennium, we first saw dual-socket and later multicore processors. As we turned another decade, GPUs went far beyond graphics, and we witnessed the emergence of field-programmable gate-array (FPGA)-based accelerator cards.

As 2020 draws to a close, SmartNICs (network interface cards), also known as DPUs (data processing units), are coming into fashion. They boast huge FPGAs, multicore Arm clusters, or even a blend of both, with each of these advances bringing significant gains in



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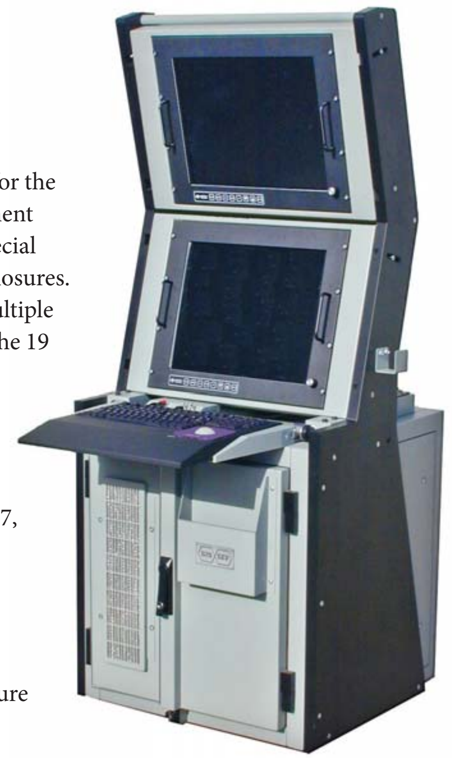

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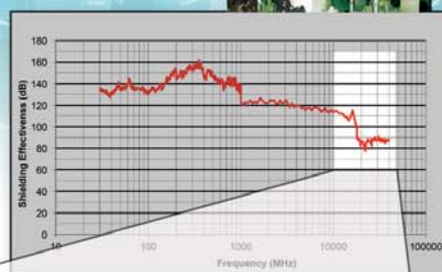

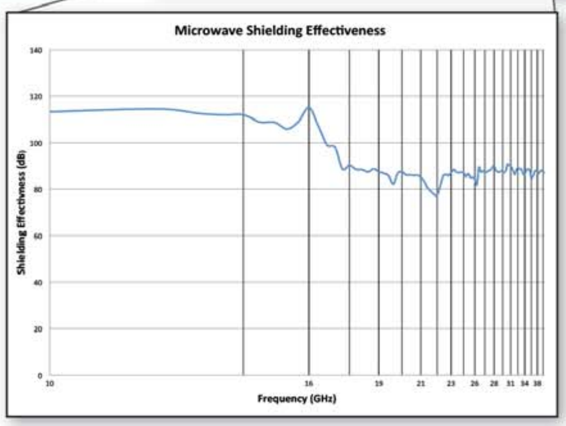

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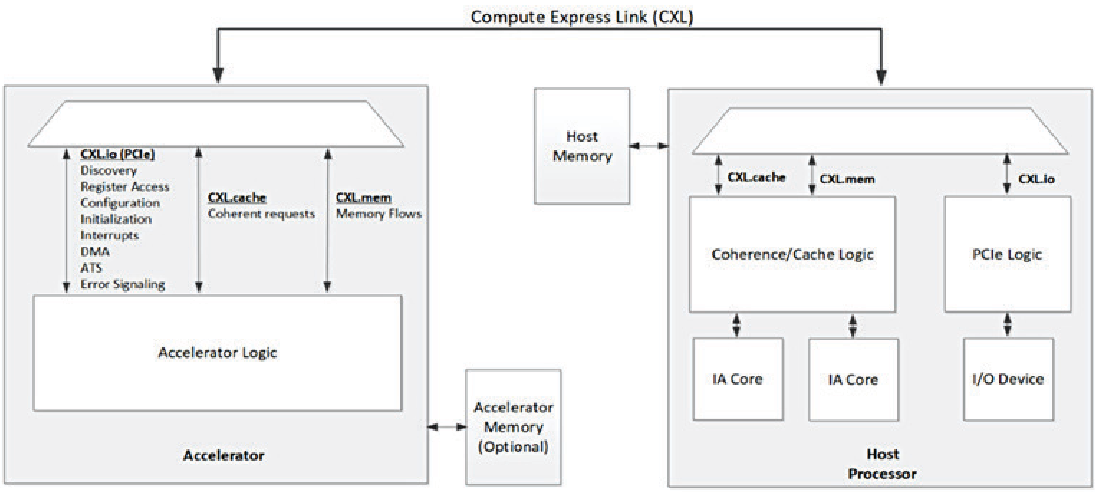


1. This is a conceptual diagram of an accelerator attached to a processor via CXL. *(Source: "Compute Express Link Specification July 2020," Revision 2.0, version 0.9, page 31)*

solution performance. From trading stocks to genomic sequencing, computing is about getting answers faster. Under the covers, the roadway has been PCI Express (PCIe), which has undergone significant changes but is mainly taken for granted.

PCIe EVOLUTION

Peripheral Component Interconnect Express, or PCIe, first appeared in 2003 and, coincidentally, arrived just as networking was getting ready to start the jump from Gigabit Ethernet (GbE) as the primary interconnect. At this point, high-performance computing (HPC) networks like Myrinet and Infiniband had just pushed beyond GbE with data rates of 2 Gb/s and 8 Gb/s, respectively. Shortly after that, well-performing 10-GbE NICs (network interface controllers) emerged onto the scene. They could move nearly 1.25 GB/s in each direction, so the eight-lane (x8) PCIe bus couldn't have been timelier.

The first-generation PCIe x8 bus was 2 GB in each direction. Back then, 16-lane (x16) slots were unheard of, and server motherboards often had only a few x8 slots and several x4 slots. To save a buck, some server vendors even used x8 connectors, but only wired them for x4—boy, that was fun.

Like me, most people, OK nerdy architects, know that with every PCIe generation, the speed has doubled. Today, a fourth-generation PCIe x8 slot is suitable for about 16 GB/s, so the next generation will be roughly 32 GB/s. If that's all the fifth generation of PCIe brought, that would be fine. However, it also comes with an Aladdin's Lamp filled with promise in the form of two new protocols, Compute Express Link (CXL) and a Cache Coherent Interconnect for Accelerators (CCIX), to create efficient communication between CPUs and accelerators like SmartNIC or co-processors.

COMPUTE EXPRESS LINK

Let's start with CXL. It provides a well-defined master-slave model where the CPU's root complex can share both cache and main system memory over a high-bandwidth link with an accelerator card *(Fig. 1)*.

This enables the host CPU to efficiently dispatch work to the accelerator and receive the product of that work. Some of these accelerators have sizable high-performance local memories using DRAM or high-bandwidth memory (HBM). With CXL, these high-performance memories can now be shared with the host CPU, making it easier to operate on datasets in shared memory.

Furthermore, for atomic transactions, CXL can share cache memory between the host CPU and the accelerator card. CXL goes a long way toward improving host communications with accelerators, but it doesn't address accelerator-to-accelerator communications on the PCIe bus.

In 2018, the Linux kernel finally rolled in code to support PCIe peer-to-peer (P2P) mode. This made it easier for one device on the PCIe bus to share data with another. While P2P existed before this kernel update, it required some serious magic to work, often requiring that you had programmatic control over both peer devices. With the kernel change, it's now relatively straightforward for an accelerator to talk with PCIe/NVMe memory on the PCIe bus or another accelerator.

As solutions become more complex, simple P2P will not be enough, and it will constrain solution performance. Today, we have persistent memory sitting in DIMM sockets, NVMe storage, and smart storage (SmartSSD) plugged directly on the PCIe bus, along with a variety of accelerator cards and SmartNICs or DPUs, some with vast memories of their own. As these devices are pressed to communicate with one another, our expensive server processors will become costly traffic lights bottlenecking enormous data flows. This is where CCIX comes in—it provides a context for establishing peer-to-peer relationships between devices on the PCIe bus.

CACHE COHERENT INTERCONNECT FOR ACCELERATORS

Some view CCIX as a competing standard to CXL, but it's not. CCIX's approach to peer-to-peer connections on the bus is what makes it significantly different *(Fig. 2)*. Furthermore, it can take memory from different devices, each with varying performance characteristics, pool it together, and map it into a single non-uniform memory access (NUMA) architecture. Then it establishes a Virtual Address space, enabling all of the devices in this pool access to the full range of NUMA memory. This goes far beyond the simple memory-to-memory copy of PCIe P2P, or the master-slave model put forth by CXL.

As a concept, NUMA has been around since the early 1990s, so it's extremely well understood. Building on this, today, most servers easily scale to a terabyte (TB) or more expensive DRAM memory. In addition, drivers exist that can map a new type of memory called persistent memory (PMEM), also known as storage class memory (SCM), alongside real memory to create "huge memory." With PCIe 5 and CCIX, this should further enable system architects to extend this concept using SmartSSDs.

COMPUTATIONAL STORAGE

SmartSSDs, also known as computational storage, place a computing device, often an FPGA accelerator, alongside the storage controller within a solid-state drive, or embed a compute function inside the controller. This enables the computing device in the SmartSSD to operate on data as it enters and exits the drive, potentially redefining both how data is accessed and stored.

Initially, SmartSSDs are viewed as block devices, but with the appropriate future driver installed in the FPGA, they could be made to look like byte-addressable storage. Today, SmartSSDs are produced with multiple terabytes of capacity, but capacities will explode. Therefore, SmartSSDs could be used to extend the concept of huge memory, only via NUMA, so that both the host CPU and accelerator applications can access many terabytes of memory, across numerous devices, without rewriting the applications using this memory. Furthermore, SmartSSDs can provide better TCO solutions by enabling in-line compression and encryption.

ENTER SmartNICs

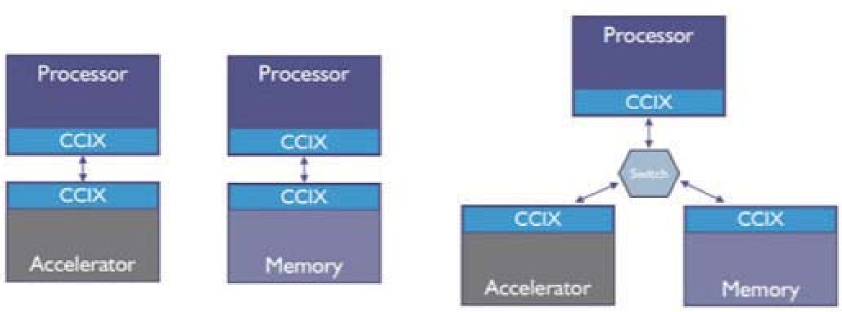
How exactly does a SmartNIC fit into this architecture? SmartNICs are a special class of accelerators that sit at the nexus between the PCIe bus and the external network. While SmartSSDs place computing close to data, SmartNICs place computing close to the network. Why is this important? Simply put, server applications rarely concern themselves with network latency, congestion, packet loss, protocols, encryption, overlay networks, or security policies.

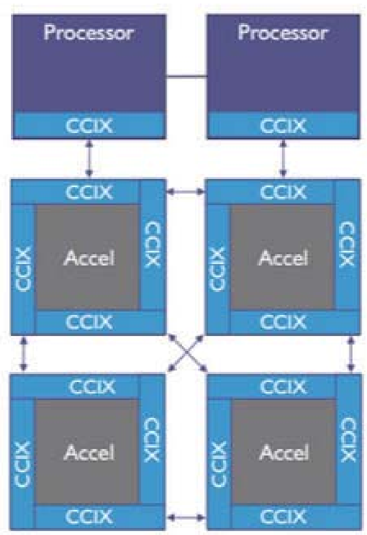
To address these issues, lower-latency protocols like QUIC were created to improve latency, reduce congestion, and recover from packet loss. We've crafted TLS and extended that with kernel TLS (kTLS) to provide encryption and secure data in-flight. We're now seeing kTLS being added as an offload capability for SmartNICs.

To support the orchestration of virtual machines (VMs) and containers, we created overlay networks. This was followed by technologies like Open vSwitch (OvS) to define and manage them. SmartNICs are starting to offload OvS.

Finally, we have security, which is managed through policies. These policies are expected to be reflected in the orchestration framework in forms like Calico and Tigera. Soon these policies will also be offloaded into SmartNICs using programming match-action frameworks like P4. All of these are tasks that should be offloaded into these specialized accelerators called SmartNICs.

With CCIX, an architect would then be able to build a solution where multiple accelerators can directly access real memory and the storage inside





2. The three sample CCIX configurations include direct attached, switched topologies, and hybrid daisy chain. *(Source: "An Introduction to CCIX White Paper," page 5)*

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SmartSSDs as one huge-memory space with a single virtual address space. For example, a solution could be constructed using four different accelerators *(Fig. 3)*.

The SmartNIC could have a video decoder loaded into it so that as video arrives from cameras, it can be converted back into uncompressed frames and stored in a shared framebuffer within the NUMA virtual address space. As these frames become available, a second accelerator running an artificial-intelligence (AI) image-recognition application can scan these frames for faces or license plates. In parallel, a third accelerator could be transcoding these frames for display and long-term storage. Finally, a fourth application running on the SmartSSD removes the frames from the frame buffer once the AI and transcoding tasks are successfully completed. Here we have four very specialized accelerators collaboratively working together to become known as a "SmartWorld" application.

The industry started adding more cores to offset the issues around Moore's Law. Now there's an abundant number of cores, but not enough bandwidth to the CPU from the external devices such as NICs, storage, and accelerators. PCIe Gen5 is our next hop, and it enables a much bigger conduit to open up high-performance computing on CPU.

For example, a typical CPU core can handle 1 Gb/s+, but if you have dual 128-core CPUs, then PCIe Gen4x16 isn't enough. Cache coherency provided by the CXL and CCIX protocols offers tremendous benefits for applications demanding tight interaction between CPU cores and accelerators. Primary application workloads such as databases, security, and multimedia are now starting to leverage these advantages.

ORCHESTRATION

The final piece of the puzzle is orchestration. This is the capability whereby frameworks like Kubernetes can automatically discover and manage accelerated hardware and mark it in the orchestration database as online and available. It will then need to know if this hardware supports one or more of the protocols mentioned above. Subsequently, as requests for new solution instances come in and are dynamically spun up, those container instances that are aware of, and are accelerated by, these advanced protocols can use this hardware.

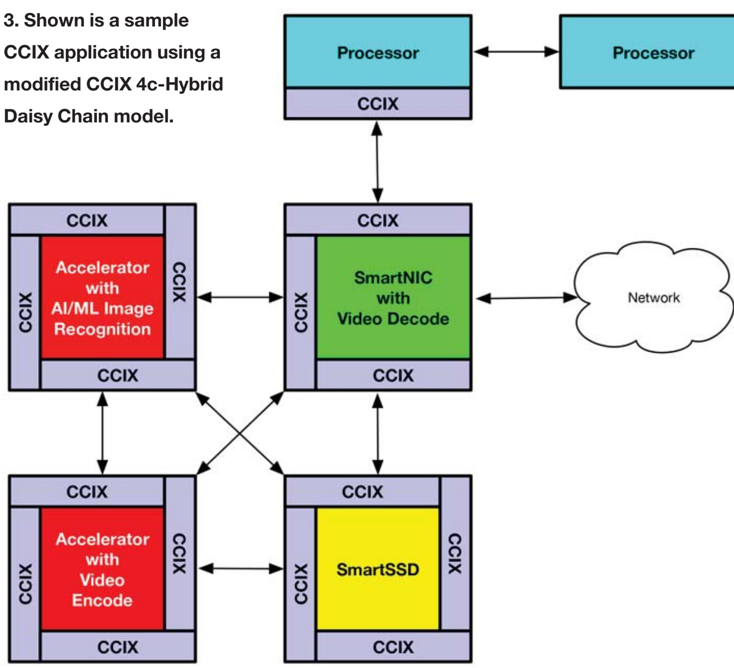
Xilinx has developed the Xilinx Resource Manager (XRM) to work with Kubernetes and manage multiple FPGA resources in a pool, thereby improving overall accelerator utilization. The result is that newly launched application instances can be automatically dispatched to execute on the most appropriate and performant resources within the infrastructure while remaining within the defined security policies.

SmartNICs and DPUs that leverage PCIe 5 and CXL or CCIX will offer us richly interconnected accelerators that will enable the development of complex and highly performant solutions. These SmartNICs will provide compute-intense connections to other systems within our data center or the world at large. It's even possible to envision a future where a command comes into a Kubernetes controller, running natively on a SmartNIC resource, to spin up a container or pod. The bulk of computation for this new workload might then be occurring on an accelerator device somewhere else within that server, all without ever getting the server's host CPU directly involved.

For this to function correctly, we'll need additional security enhancements that go well beyond Calico and Tigera. We'll also need new accelerator-aware security frameworks for extending security contexts, often called secure enclaves, across multiple computational platforms. This is where Confidential Computing comes in. It should provide both the architecture and an API for protecting data in-use across multiple computational platforms within a single secure enclave.

Much like a sensitive compartmented information facility (SCIF) can be an entire Department of Defense building, a secure enclave within a computer should be capable of spanning multiple computational platforms. Exciting times ahead. ed

3. Shown is a sample CCIX application using a modified CCIX 4c-Hybrid Daisy Chain model.



Electronic Design.

DAVID MALINIAK | Senior Editor

2020 Salary & Career Report

Here's an overview of the state of continuing engineering education as revealed by responses to our 2020 Annual Salary and Career Report survey.

CONTINUING EDUCATION

"Technologies are ever evolving, and competent engineers must keep up with the changes that come." That statement from a respondent to our 2020 Salary & Career Report survey sums up the feeling engineers have about continuing their engineering educations. In our survey, we asked you to update us on your current level of education and how you prefer to learn about new technologies and skills. Does your employer encourage continuing education by footing the bill, and if so, in what modes? And how does the coronavirus pandemic figure into the picture? In this article, we'll look at these topics with facts, figures, and anecdotal responses.

EDUCATION LEVELS HOLD STEADY OVERALL

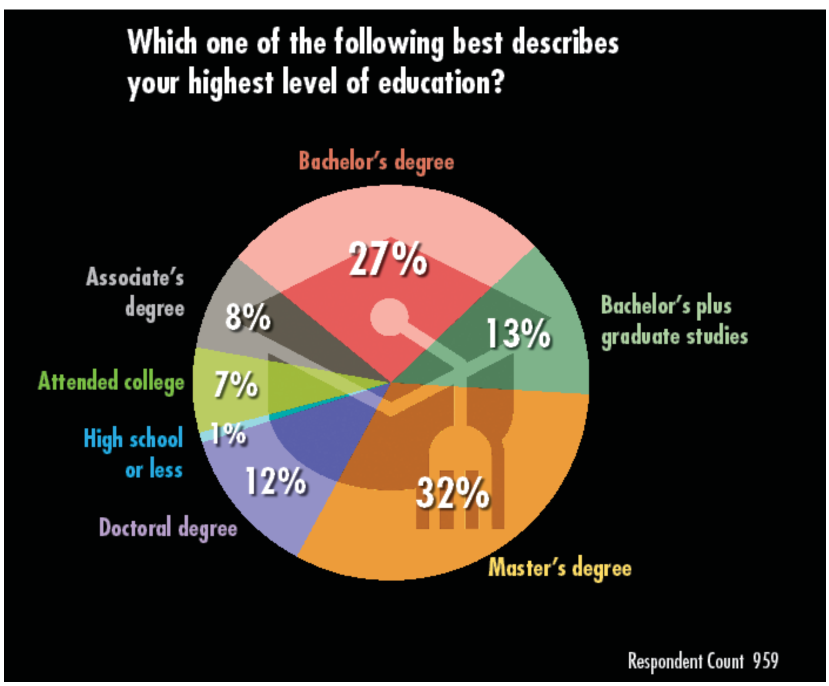
First, let's look at where you stand with your respective highest levels of education and see how that compares with the 2019 survey responses. The leading response was a master's degree (32% vs. 33% in 2019), followed by a bachelor's degree (27% vs. 30%). Last year, 9% of you reported holding a doctorate; this year, that number jumped up to 12%. Also, the number of respondents who have bachelor's degrees and then followed that up with at least some graduate studies are holding firm at 13%. So, these survey results suggest that the levels of education among you are more or less on balance year on year compared to 2019.

SO MANY WAYS TO LEARN

It's good to see that the general level of education among engineers seems to be on the rise. But we also asked, "What are some of the ways in which you continue your engineering education?" The leading category this year: 65% report relying on engineering/technology publications for keeping up with trends. That's followed by 60% who lean on webcasts and 58% who consume engineering videos.

Vendors to the OEM electronics industry have always done a great job at cranking out videos, white papers, and webcasts to educate engineers on their latest and greatest innovations. All of those mediums are free to consume, and webcasts can usually be viewed on demand if you've missed the live events.

Most in-person modes of continuing education—things like in-classroom college courses, seminars, user group meetings, and meetups—are down a few percentage points from last year's results. Only 26% attended trade shows or conferences, and just 21% have been to engineering association-sponsored meetings.



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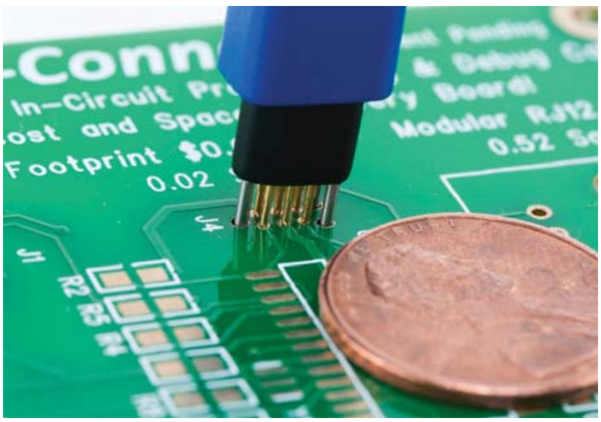

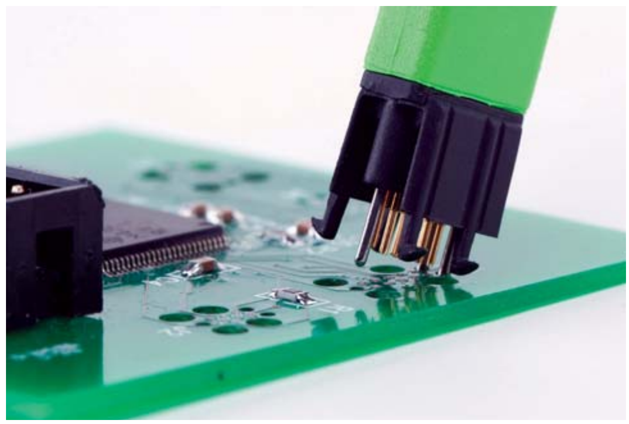

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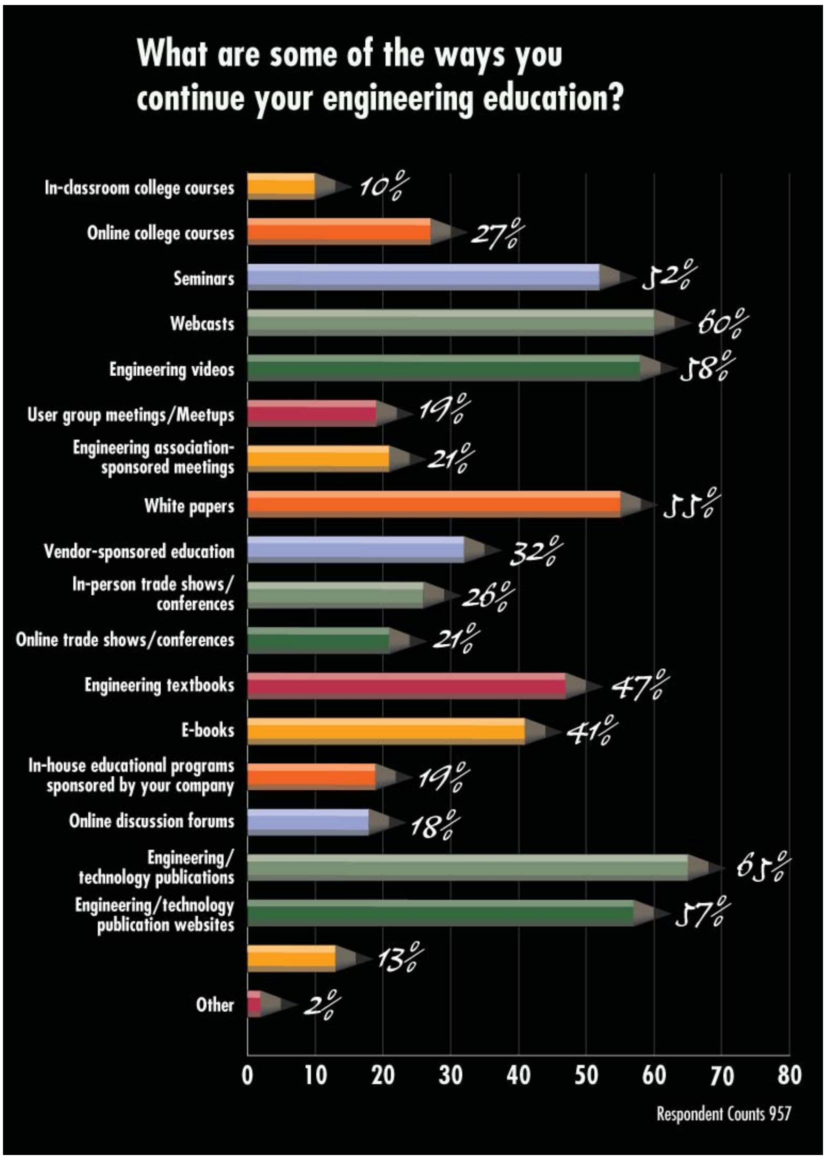
Curiously, online learning is basically on par with last year and even down in some categories. You've been reading fewer e-books (41% vs. 44% in 2019), participating less in online college courses (27% vs 31%), and visiting online engineering discussion forums at a lower clip (18% vs 22%). Given the pandemic's stifling of most away-from-home activities since earlier this year, this is a surprising result. It's even more surprising given that a number of you called out COVID-19 as among the biggest challenges you face in staying current with relevant engineering information.



IMPEDIMENTS TO LEARNING

Yet, the pandemic isn't the most prevalent barrier to gaining knowledge. In their written responses to the question of challenges in maintaining their engineering educations, far more respondents cited lack of time in various guises: "Too much work, not enough time for self-training and hunting for resources," goes a typical plaint.

This is, of course, not a new finding in the years of surveying our audience on career-oriented issues. Work-life balance is important to everyone, and not everyone wants to take training materials or extracurricular reading home. Lots of you would rather do it on company time, but it's just not possible. "It's hard to balance the intake of new information with working on active projects," according to one respondent.

Another oft-cited issue is the sheer volume of material to be sifted through and prioritized. "The problem is focusing on the relevant issues. The available information is vast and overlapping," said one respondent. Meanwhile, another laments that "sometimes the amount of information is too much, and sometimes too little." Still others cite the combination of the pace of change in the industry and the number of topics to keep abreast of.

CONTINUING EDUCATION AS A BENEFIT

Finally, we asked whether your employer invests in its engineering staff by reimbursing you for the cost of continuing education. On this front, the comparison to the 2019 survey results is a mixed bag. More of you report that your employers pick up the tab for things like trade show/conference fees (46% vs. 44% in 2019), professional certifications (26% vs. 25%), and, importantly, online training (31% vs. 26%).

But when it comes to some other avenues of continuing education, employers have become a bit stingier. They're footing the bill less often for seminars (39% vs. 45% in 2019), engineering textbooks (25% vs. 27%), and college tuition costs (30% vs. 32%). More of you say your employers don't cover continuing education costs at all (26% vs 23%). Clearly, in some instances, employers have reined in their investments in employees, perhaps ultimately to their own detriment.

As Henry Ford once said, "Anyone who stops learning is old, whether at twenty or eighty. Anyone who keeps learning stays young." And to that, let's heed the words of Bob Dylan: "May you stay forever young." ed

LOU FRENZEL | Technical Contributing Editor

HEATHKIT: An Employee's Look Back

Lessons of a successful electronic business—an interview with Chas Gilmore, former Heath executive.

For those of you who do not know or remember, Heath Company was the largest kit company in the world. Heath designed and put practically every type of electronic product into kit form. Its products, called Heathkits, were exceptionally popular and many are still in use today.

Over the years, *Electronic Design* has published many Heathkit-related articles and blogs. Recently, I had a chance to talk with Chas Gilmore, who was a Heath executive. For those of you who fondly remember Heathkit and miss its products, here's a look back at this amazing company and the lessons it offers.

Chas, what was your affiliation with Heath?

A recent physics graduate, I joined Heath in 1966 as an engineer in the Scientific Instruments department. This was a new group designing laboratory instruments supporting the Malmstadt/Enke, Electronics for Scientists program. The kit business was making great strides.

The audio department was about to introduce the AR-15 FM receiver/amplifier. It had rave reviews, putting Heath in the top tier of the Audio/HiFi market. At the same time, the Ham (amateur radio) department was updating the phenomenally successful SB-line of an HF SSB receiver, transmitter, and transceiver, and modernizing the popular $99 single-band SSB transceiver line *(Fig. 1)*.

1. The Heathkit line of low-cost, high-frequency SSB receivers, transmitters, and transceivers used vacuum tubes. *(Source: https://www.qsl.net/sp5btb/vintage.html)*

My career at Heath had two parts. From 1966-1977, I progressed to Engineering Manager, Product Line Manager (Kit and Assembled) for Instrumentation, and Director of Engineering before joining another division of Schlumberger (then-parent company of Heath), and then starting a software company. I returned in 1984 as VP of Engineering and Marketing, eventually becoming General Manager. By then, Heath was owned by Zenith. I left Heath in 1993 after we closed the kit business.

Is it Heath or Heathkit?

Good question. The legal name was Heath Company. Heathkit was the primary registered trade name. The two names are often used interchangeably—even by those of us who worked there.

Did Heath also offer some products in non-kit form?

Yes, from time-to-time certain kits were offered "Wired" or "Assembled" (we used both terms). Prior to the demise of the kit business in the early '90s, kit products were always the dominant business.

Why did Heath's kit business fade away?

The original Heath Company kit business phased out in 1992. The reasons for Heathkit's demise are more extensive and complex than reasons speculated by folks from the outside, who typically focus on two reasons: Heath could not incorporate modern parts like surface-mount devices, and reduced assembly costs for electronic goods eliminated savings from building a kit. Although these were factors, they are far from being the only reasons.

- Heath accommodated many changes: from point-to-point wiring to printed circuit boards (PCBs); vacuum tubes to transistors; transistors to ICs; and the ever-increasing complexity of electronic circuits. There were plans afoot to make use of surface-mount technology, which would have addressed the first factor.
- Decreasing manufacturing costs took a substantial chunk of "savings" out of building a kit, especially when equivalent assembled products became high volume. One workaround was to focus on products where eliminating the manufacturing labor for an assembled unit remained significant. For example, linear amplifiers for ham radio. Pretty hard to build those with automated production.
- Heath had significant assembly manual development expense, and the manuals were a great part of Heath's success. This was a product cost that manufacturers of assembled products didn't have *(Fig. 2)*.

2. Heathkits came with extensive documentation and detailed schematics.

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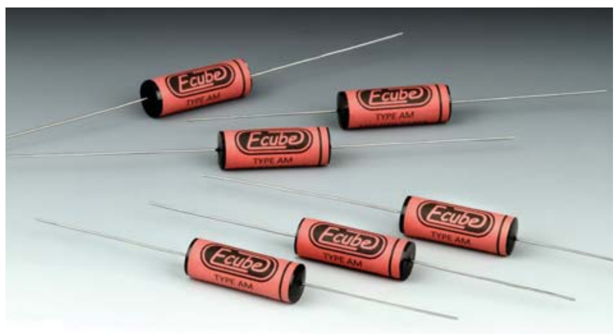

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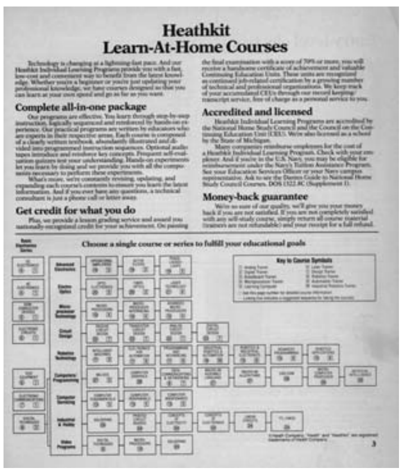
A lot of the reason for building a kit version of a product was beyond saving labor. The educational value in kit building, satisfaction of building something on your own, the ability to service/maintain the product, and, of course, the satisfaction of successfully building the unit and placing it into operation were all positive forces.

In addition to technology and cost, there were also multiple more subtle factors:

- In the late '70s and the '80s, demands on discretionary time increased substantially, limiting the time "Dad" (it was almost 100% a male hobby) could spend on a non-family-oriented hobby. Many popular "big" kits (TVs, HiFi receiver/amplifiers, ham transceivers, etc.) required substantial assembly time—many well over 100 hours. The use of assembled and tested subassemblies reduced build time and increased success on complex products, but eventually even that was too much to meet the demand for instant gratification.
- The rapid growth of personal computers siphoned away many of the "early innovators" (who were a large part of the Heath customer base). These customers were attracted to computer software and enjoyed exploring the infinite possibilities presented by computer programs.
- Electronic products became pervasive—everybody had multiple electronic products, where before a household might have a single radio. As consumer electronic products became extremely popular—HiFi, TV, CB Radio, etc.—increased volumes resulted in lowered costs and removed the "wow factor" associated with having such a product and being able to say "I built that myself."
- As Heath evolved, it became a subsidiary of large corporations and corporate overheads and expectations grew. As a result, Heath became less nimble (it's tough to make rapid changes as a part of a large corporation) and found it difficult to achieve corporate expectations of profitability in a market where high-volume consumer electronics set expectations. Management and financial constraints imposed as a division of a large public corporation; Zenith Electronics added additional financial pressure.

In 1993, kits were phased out, leaving Reflex lighting and Heathkit Educational Systems *(Fig. 3)*. These businesses were sold to investors in the following years. In 2012, Heathkit Educational Systems filed for bankruptcy and the assets, including the kit-related assets, were purchased, including the name, trademarks, and copyrights.



3. Heathkit Educational Systems developed "teach yourself" training materials for a range of electronic technologies and systems.

Under the new ownership. Heath is still a concern. Not the Heath of old, but an entirely new business. The Reflex Heath/Zenith product line had multiple owners, and now as a part of Ferguson, is sold through big-box stores.

Why were Heathkits so successful for so long?

Certainly, popularity of electronic products and fascination with electronics were huge forces. A big driver in the 1950s was the large number of WWII veterans who, during the war, received electronic training. When reentering civilian life, they wanted to continue to work with electronics.

Commercial equipment was very expensive; Heathkits eased the expense burden substantially. Many early kits followed the 80% rule. That is, they provided 80% of the functionality and specifications at 20% of the price.

User experience was also a driver. As the market expanded from the trained GIs, the manuals became more comprehensive, moving to step-by-step assembly instructions with many detailed illustrations. This enabled interested customers with less electronic experience to successfully build kits. Quickly, Heath adopted the "We will not let you fail" slogan and supported it with a robust Customer Service department, who helped many, many customers achieve the ultimate rush of finding a problem and successfully placing their product in operation.

Was Heath strictly a mail-order business?

Yes and no. From the inception of the electronic kit business in 1947 until the early 1960s, Heath's sole outlet was through mail order—catalogs/flyers, trade shows, and magazine advertisements. In 1961, Heath experimented with retail stores. These became popular and by the mid-1970s, there were over 60 Heathkit retail stores.

Do DIY hobbyists still want kits?

Yes, electronic kits are quite popular today. The kits are very different from the Heathkits of the past. Many are simply circuits on a PCB, leaving final packaging to the customer. Typically, kits from any one company focus on a single product area. Many are quite inexpensive and few offer Heathkit-level manuals.

Why do you think the original Heath is so well remembered?

Multiple reasons. For a long time (1950s through the mid-1970s), they were the only game in town. Heathkits resulted in a working packaged product. The assembly manuals were the best by far, leading to a very high success rate and providing a great deal of practical electronic theoretical education and assembly skills. Again, the emotional high from completing the kit was great. Many, many Heathkit customers were repeat customers.

Did Heathkit have any real competition? Who?

In the 1950s and 1960s, there were multiple competitors. Two had similarly broad product lines: Knight-Kit (Allied Radio) and EICO. Both had product lines including test instruments, HiFi, ham, and miscellaneous electronic products. Radio Shack appealed to hobbyists, but Heath didn't see them as a major competitor. They weren't a kit company and sold a wide range of fully assembled imported products. Probably the main competition was from their very popular TRS80 personal computer, which went up against Heath's kit computers.

What were the main product lines at Heath, and which was the largest?

Over the long haul, ham and test instruments vied for the largest. There were times when audio contended for the largest and TV did as well, especially when there were large bulk sales to the home-schooling institutions such as Bell and Howell. It used Heathkits to provide hands-on instruction, with the building of a kit TV being the course cap-stone project.

In the mid-1970s, Heath introduced its own line of instructional products. These became a significant product line for Heath under the trade name Heathkit Educational Systems and were the last remaining Heath product line in the mid-1990s. They had significant sales into secondary and post-secondary education.

When kit personal computers were introduced in August 1977, they soon became by far the largest product line.

Is it true that Heath's original products were test instruments?

Yes, the "first" Heathkit was the O-1 Oscilloscope. This product was originally introduced in the July 1947 issue of *Radio News* magazine at $39.50—complete.

What was the best-selling test instrument?

No question—the VTVM. The product started as the V-1. It underwent minor modifications over the years; however, the basic circuit remained essentially the same for its entire life. The last VTVM was sold in 1989.

In 1955, Heath tried a great experiment with the V-7—the introduction of the PCB. There were many at Heath who questioned this move, concerned a PCB would "ruin" the kit building experience. Clearly this wasn't the case, as VTVM volumes were neck-and-neck with the Cantenna for Lifetime Volume leader and PCBs were part of nearly every kit thereafter.

What was the best-selling ham radio product?

My guess would be the SB-200 Linear Amplifier for Lifetime Dollars *(Fig. 4)*. It was introduced in 1968 (the model number changed to SB-201, making 10-meter band coverage available only with proof of a ham license) and discontinued in 1983. The Heathkit HN-31 "Cantenna," a 50-Ω dummy load, was introduced in 1961 and remained in the product line until 1991. Likely this accessory outsold any other ham-radio product in sheer numbers, and was my daughter's first solo build.

4. The SB-200 Linear Amplifier was one of Heathkit's top selling kits.

Describe the Heath Product Development organization.

Engineering consisted of two major groups: Design Engineering and the Manual department, each about 80 people out of some 700 in total at Heath. Engineering consisted of Ham, Instruments (kit), General, Scientific Instruments, Audio, and TV departments supported by Component Engineering and Drafting. The Manual Department consisted of Writers, Editors, Illustrators and a support group.

I quickly learned a typical kit design took approximately an equal number of Design Engineering and Manual Department hours—no wonder those manuals were so good. Engineering was a major driver of product innovation. Many product ideas originated from Heath engineers.

A marketing/product-planning group with multiple PLMs (product line managers), often coming from engineering, shepherded each product from concept to end-of-life.

Additionally, the Service and Technical Correspondent Departments were staffed with people with strong technical backgrounds. Everyone involved was a user of Heath products and worked together to bring products to market.

It sounds like Heath may have had a unique product-development process to ensure successful kits. What was it?

Indeed, the process was quite unique—as is the kit business. Once the product was defined and approved, work started in Design Engineering. Development was assigned to an engineer who was often part of a two-person team consisting of the engineer and a technician. Occasionally, with larger products like a TV or one of the newer ham transceivers, multiple engineers made up the team.

Engineering development proceeded as do most electronic products with the exception that, from the start, a top-of-mind topic was assembly by a customer at home with minimal laboratory equipment, or even none at all for a non-technical product such as a TV or audio receiver. When a final prototype was in hand and passed the functionality and specification requirements, the engineer turned a prototype and five sets of parts along with a draft circuit description and other assembly information over to the assigned manual writer.

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As I noted earlier, writing the manual often took as many hours as the electronic/mechanical design. In the process, the manual writer consumed one or two sets of parts building the product to write and check out the assembly process. Additionally, illustrators prepared the detailed and often expanded-view drawings to accompany the assembly step-by-step instructions.

Early on, Heath discovered drawings conveyed much more information than photographs and the drawing could delete clutter that might appear in a photograph. The manual writer also wrote detailed circuit descriptions and troubleshooting guides.

When the manual draft was complete, a phase known as pre-proof began. Three sets of parts were packed as in production. Employees from the manual department, engineering, and product management built the product according to the draft manual. Engineering tested the completed products and the manual writer compiled all manual markups. Suggested changes and comments were reviewed, and a revised final manual was created.

Was that the main manual test?

No. The next phase was proofbuild. Proofbuilds involved acquiring 25 sets of parts packed according to the final packing instructions. When ready for the proofbuild, 20+ employees were selected from a pool of interested people to build the kits. Like the pre-proof, there was a proofbuild manual review.

Depending on the extent of the proofbuild comments and manual revision (and any engineering revisions revealed by building 20+ proofbuilds), one of two phases occurred. If the proofbuild went relatively well, the product moved to production and was scheduled for a catalog release. If not, a post-proof was scheduled

You mention the engineer always kept buildability in mind. Did this result in unique aspects of the kits?

Yes it did. This became especially true as the kit customers expanded from very technical customers to the more general customer. By the early ’60s, the product volume and breadth of the customer base added multiple unique features to the kits—most derived from customer experience. Two key additions were supplying solder to ensure the use of rosin core solder vs. damaging acid core solder (90% of build problems were associated with soldering) and adding the “Nut Starter” to most kits.

With the introduction of more complex consumer-oriented kits such as color TVs, when a meter was needed to align the product and the customer was unlikely to own a meter, Heath supplied, in kit form, a very simple VOM. With other kits, such as FM receivers, the tuning meter was converted into a meter for alignment purposes.

The advertisement for the very first Heathkit, the O-1 Oscilloscope, used the term “Complete.” That set the tone for the next 45 years. Heathkits didn’t presume the customer would supply any critical items. If they needed it, it was in the kit.

Can you explain how the Heath personal-computer business was conceived?

The personal-computer line is an excellent example of how product concepts came about at Heath. In this case, I had been working with mini-computers as part of our Scientific Instruments products, and had become quite interested in the hobbyist/kit potential for a personal computer. Lou Frenzel was managing the Heathkit Educational Systems business and had been a personal-computer hobbyist/enthusiast for some time. We were good friends and discussed this potential frequently.

Additionally, Heathkit Educational Systems was in the process of introducing a course and accompanying trainer based on the Motorola 6800, and in Engineering we were looking at the Intel 4004 for possible inclusion in a Heathkit. All of these factors came together at the right time.

What was the deciding factor?

The trigger was the *Popular Electronics* January 1975 issue. Lou and I sketched out some concepts for a Heathkit computer kit. Shortly thereafter, Lou presented the concept at the weekly PDC (Product Development Committee) meeting, chaired by the head of the Product Management group and attended by the president, along with the heads and managers of all major Heath organizations. They were the folks to be sold.

It was a very long and drawn-out meeting, with many, many skeptics. “What would someone do with a kit computer—balance their checkbook?” Finally, after a lot of selling, we left the meeting with development authorization for the H-8—Heath’s first personal computer. We also received the admonition “And don’t come back for any other computer products until this one is on the market and selling at or above forecast.”

5. The Heathkit H-8 was an 8-bit microcomputer kit based on the Intel 8080A.

We introduced the H-8 *(Fig. 5)* along with the H-9 ASCII CRT Terminal, the H-10, Paper Tape Reader-Punch, the H-11 16-bit computer (based on the DEC LSI-11), and a substantial collection of accessories. In the course of development, the personal-computer market was growing rapidly, so getting approval to develop additions to the H-8 was nowhere as hard as the H-8 pitch.

First appearing in the August/Fall 1977 Heathkit catalog, computers were given 10 of the 104 pages—a major display for an entirely new product line. For comparison, ham had 11 pages, audio had 15, and test had 21. The “President’s Letter” *(see next page)* showed management was still nervous—would personal computers really sell? And yet, personal computers became Heath’s largest selling product line by year’s end.

What happened to the Heath computer business?

In one word: success. In a few short years, personal computers evolved from the domain of the "techie" or early innovator, to the early adopter, and then to general use. As with many products, once a particular product was no longer confined to the early innovator market, product volumes became large enough to drive costs of assembled product down.

Also, interest in assembling the product from a kit became the domain of a very few. Relative to many other products, the personal computer went through this evolution very quickly. The immediate and intense interest in personal computers quickly drew interest away from kit building as the users were fascinated with what could be done with the computer itself. Early in the life of Heath computers, fully assembled as well as kit computers were offered under the name Heath Data Systems. Shortly, Heath was acquired by Zenith, who changed the name to Zenith Data Systems.

You mentioned one time that Heath was responsible for a number of "Firsts." What were they?

There are too many to list here, but the back page of the Heath 1966 general catalog lists some 42 Heath "firsts" as of that time. Many of these were the product of Heath employees thinking about how to make construction of a Heathkit successful.

"Firsts" included:

- A TV with on screen digital Channel and Time display: *Elementary Electronics,* May-June, 1974 –"The fact is, today's Heathkit GR-2000 is the color TV the rest of the industry will be making tomorrow…there is no other TV available at any price which incorporates what Heath has built into their latest color TV."
- A kit microwave oven.
- A kit single-board, 100-W SSB transceiver, priced at $100
- The first frequency counter using 74LS TTL.
- Over 60 retail stores devoted to displaying and selling kit electronic products.
- Mid-'70s catalogs featuring over 400 products in kit form.

Why is it you can still buy some original Heath products online, at hamfests, etc.?

There are two reasons: Volume—over the course of 40+ years Heath produced literally tens of millions of products; and downsizing. Many of the people who built those kits are now in or reaching the stage of life where they're paring back.

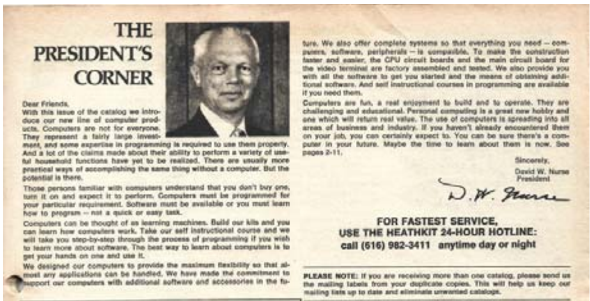
Can you summarize how all of this information offers lessons on how to make a successful electronic business?

Probably the single greatest lesson is focus on customer service. Heath lived by "We will not let you fail." Even before this slogan was formally introduced, it was the company mantra.

Certainly, a secondary driver of success was the employee interest in the products. We all used them at home, vied for the opportunity to build a kit whenever possible, and, as noted earlier, many, many Heathkit product concepts came from the employee base vs. a formal product planning process. Unique products added to that success.

Where can I find more information on Heathkit?

The web is an excellent place to start. Just searching on Heathkit will keep you going for a long time!


THE PRESIDENT'S CORNER

Dear Friends,
With this issue of the catalog we introduce our new line of computer products. Computers are not for everyone. They represent a fairly large investment, and some expertise in programming is required to use them properly. And a lot of the claims made about their ability to perform a variety of useful household functions have yet to be realized. There are usually more practical ways of accomplishing the same thing without a computer. But the potential is there.

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Computers are fun, a real enjoyment to build and to operate. They are challenging and educational. Personal computing is a great new hobby and one which will return real value. The use of computers is spreading into all areas of business and industry. If you haven't already encountered them on your job, you can certainly expect to. You can be sure there's a computer in your future. Maybe the time to learn about them is now. See pages 2-11.

Sincerely,
David W. Nurse
President

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Chuck Penson (Ham Call WA7ZZE) has written three excellent books describing virtually all of the products in three major product lines: amateur radio, test equipment, and audio.

Terry Perdue (K8TP), an 18-year veteran of the Heath Ham Engineering Department, produced a very interesting collection of Heath pictures, articles, and documents, including an audio file of an interview with Heath's first Director of Engineering—employee #19.

Erich E. Brueschke, KC9ACE and Michael Mack wrote an informative article for the Antique Wireless Association titled "The History of the Heath Companies and Heathkits: 1909 to 2019." It first appeared in the *AWA Review.*

Lou Frenzel chimes in.

Thanks, Chas. Great overview. My recollection is virtually the same as yours. Heath was a fun place to work for hobbyists like hams and audiophiles, and as you're fond of saying, "It was like working in a candy factory."

We both became hams in our high school days, you K1KJY (now W8IAI) and me W5TOM (now W5LEF) and both had early Heath product build experiences. Working at Heath was also a major educational experience because the company had good execs and great business procedures. We learned that a continuous steam of exciting and unique new products, superior documentation, and world-class customer service can make most companies successful. Thanks again for sharing your experience with *Electronic Design* readers.

Chas responds.

Lou, I have really enjoyed this discussion. It has been an opportunity to review one of the most enjoyable parts of my career. It occurs to me many former Heath technical people are regular *ED* readers. I am sure some of them can elaborate on Heath's history and some may have corrections to comments from my 30-plus-year-old memories. I'd love to hear them and other memories. ed

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