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EDITOR'S NOTE

Oscilloscope features and specs evolve to match engineers' environment

An *EE-Evaluation Engineering* article from December 2018 describes how the definition of "mainstream oscilloscope" is in flux, with "high-end" features becoming "mainstream" or even appearing in entry-level scopes. It's not surprising that last year's high-performance specs become this year's mainstream performance specs—such as frequencies reaching 16 GHz, as described in our report beginning on p. 6 of this issue. But other features, too, are becoming prevalent in the mainstream category.

"Examples include jitter, eye diagrams, and FFT, which are now 'standard,'" according to Steve Sandler, founder and CEO of Picotest. "Some oscilloscopes now offer time-correlated spectrum analysis, including time-independent center-frequency, span, and resolution-bandwidth controls. The introduction of frequency-response-analyzer (FRA) features for the oscilloscope started with Johnnie Hancock at Keysight almost a decade ago. In the past year, almost every oscilloscope company has added the ability to perform Bode-plot stability measurements and power-supply rejection-ratio measurements."

Michael Rizzo, general manager at RIGOL USA, concurs and provides an example. "With the introduction of our new MSO8000 Series oscilloscope, we have brought advanced jitter analysis and real-time eye capability to the mainstream market," he said. "Customers in the space are demanding greater performance and more advanced analysis capabilities."

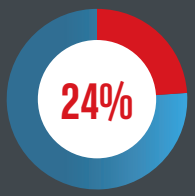
In some cases, features can migrate upwards from lower end scopes. "We introduced frequency-response/Bode plotting with our budget SDS1000X-E platform about a year ago and just recently introduced it on our SDS5000X, which is our flagship oscilloscope line," said Jason Chonko, applications marketing manager at SIGLENT Technologies North America. "This cross-platform functionality keeps development costs low and provides really useful functionality for customers across the budget spectrum."

When asked if she has observed the trend of high-end features moving into the mainstream, Kaitlyn Franz, test product manager at Digilent, responded, "In a way, yes. The 'power creep' of oscilloscopes is natural—people will always want bigger and better specs, but is that always the best option?" Commenting on one of her company's pocket-sized USB scopes, she said, "Of course there are applications that require very high bandwidth, etc., but what the Analog Discovery 2 lacks in high-end specs, it makes up for with versatility, being mindful of resources and user experience (one of its main selling points is the software—WaveForms SDK—that is constantly updated based on user feedback)."

User experience is, of course, a key concern, and one way to provide an enhanced UI is through a large screen. "In the past year, 4K UHD displays became much more affordable," said Trevor Smith, business development manager at Pico Technology. "They are being widely adopted for use with our PC-based oscilloscopes, which gives users more clarity when viewing, analyzing, and measuring complex waveforms." The good news for users of USB scopes is that they needn't buy a new instrument to take advantage of improved display and PC technology.

Also evolving is the way in which instruments such as oscilloscopes are being used. Franz identified a trend away from traditional offices toward distributed teams where a centralized lab space is not available or at least not readily accessible. In such an environment, affordability can be increasingly important. "More and more companies are starting to become distributed in both their soft skills teams, but also in engineering," she said. "With a distributed team, you can't necessarily have an entire bench for each different office or each at home office. So, it's really helpful for the engineers to have something on their desk that they can reach for to solve problems without having to go find a lab that has all of that equipment." EE

BY THE NUMBERS



Nano-Imprint-lithography equipment market CAGR between 2018 and 2024

146 MILLION

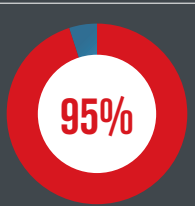
Nano-Imprint-lithography equipment market in 2024

Source: Yole Développement

40 BILLION

Estimated global commercial drone market by 2024

Source: Financial Times

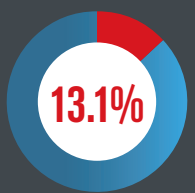


Year-over-year increase in global unit volumes for wearable technology market in Q3 of 2019

Source: IDC

36.6 BILLION

Worldwide sales of semiconductors in October 2019



Year-over-year decrease in semiconductor sales in October 2019

Source: SIA

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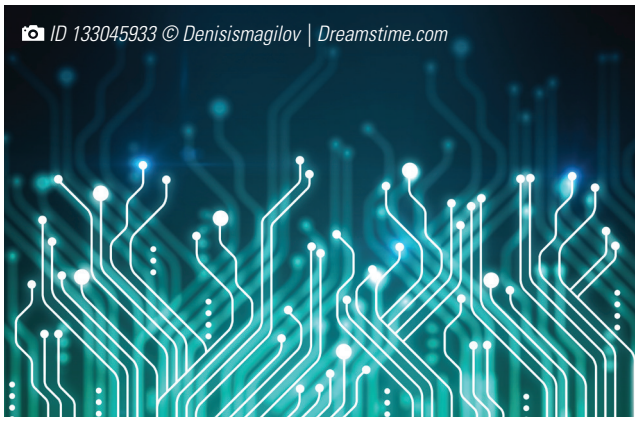
Tieto, STMicroelectronics collaborate on software

Tieto, a software and services company and a member of the ST Partner Program, and STMicroelectronics have announced collaborative efforts to develop Central Control Unit (CCU) software to run on STMicroelectronics' Telemaco3P platform.

Electrification and connectivity requirements of vehicles are pushing greater processing power and uncompromised cybersecurity. In turn, automakers' demands for Central Control Units meeting connectivity, data privacy, security, and over-the-air update needs have led ST to develop the Telemaco family of automotive, multiprocessor SoCs and its associated Telemaco3P Modular Telematics Platform (MTP), which provides an open development environment for prototyping advanced smart-driving applications. The secure and safe Telemaco3P automotive SoC embeds an isolated Hardware Security Module for state-of-the-art security.

Tieto's software R&D services division and ST are developing vehicle CCU software and next-generation telematics solutions based on the Telemaco3P platform. Tieto aids customers with system integration as well as design and development of a wide range of secure smart-driving applications. These applications will support high-throughput wireless connectivity, over-the-air firmware upgrades, and car-to-car communication solutions.

INDUSTRY REPORT



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SEMI: Semiconductor equipment sales set for rebound

Global semiconductor manufacturing equipment sales will drop 10.5% to $57.6 billion in 2019 from 2018's historic peak of $64.4 billion but stage a 2020 recovery and set a new high in 2021, SEMI reported recently in its Year-End Total Equipment Forecast.

Released at SEMICON Japan 2019, the forecast shows equipment sales registering a 5.5% increase to $60.8 billion in 2020 and continued expansion into 2021, with record revenues of $66.8 billion as leading device manufactures invest in sub-10-nm equipment, especially for foundry and logic.

The SEMI year-end forecast shows sales of wafer fab equipment—consisting of wafer processing, fab facility, and mask/reticle equipment—falling 9% in 2019 to $49.9 billion. The assembly and packaging equipment segment is on track to decline 26.1% to $2.9 billion in 2019, while semiconductor test equipment is forecast to drop 14.0% to $4.8 billion this year.

Taiwan will dethrone Korea as the largest equipment market and lead the world with 53.3% growth this year, followed by North America with a 33.6% uptick. China will maintain the second spot for the second consecutive year, and Korea will fall to third after throttling back capital expenditures. All regions tracked except Taiwan and North America will contract this year.

SEMI expects the 2020 equipment market recovery to be fueled by advanced logic and foundry, new projects in China, and, to a lesser extent, memory. In Europe, equipment sales will surge 45.9% to $3.3 billion. Taiwan is forecast to remain the top equipment market next year on the strength of $15.4 billion in sales, with China second at $14.9 billion and Korea third at $10.3 billion.

Wearable technology market surging

The wearable technology market's growth is accelerating, partly due to Apple's expansion of its product portfolio. Market researcher International Data Corp.'s estimates for Q3 2019 show global unit volumes soaring to 84.5 million units.

IDC stated in a press release that hearables—ear-worn wearables—represent about half of the market, with wrist-worn items such as smartwatches being the next-largest category. According to IDC, the global market for wearables shipping is likely to end 2019 with an increase of 71.4% from 2018.

Marvin Test Solutions completes SmartCan deliveries to Israeli Air Force

Marvin Test Solutions, Inc. (MTS) announced that it has successfully completed deliveries of all MTS-3060A SmartCan Universal O-Level Armament Test Sets to the Israeli Air Force (IAF). The rugged flightline hand-held MTS-3060A SmartCan can test all Alternate Mission Equipment (AME) and Aircraft Armament Equipment (AAE) including pylons, launchers, bomb racks, and pods. Addressing an armament test gap that exists across legacy 4th- and 5th-generation aircraft equipped with smart weapon technology (MIL-STD-1760), the MTS-3060A enables support for any aircraft and any smart or legacy armament system.

"The IAF has selected the SmartCan from Marvin Test Solutions as a universal flightline armament test set for F-16 and F-15 because of its robust test capabilities," said Major Dror Hadar from the Israeli

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Air Force. "With the SmartCan, IAF can replace several obsolete test sets with a single test solution that is smaller, easier to use, and still provides more test capabilities than all the obsolete test sets it replaces."

Incorporating advanced measurement capabilities to support new and Smart munitions and armament, the MTS-3060A has the capacity to grow as new and more complex weapon systems are added to the inventory. The SmartCan is currently deployed in over 12 countries on multiple aircraft and utilized by the U.S. Air Force Test Pilot School as a Smart weapons simulator for JDAM and AMRAAM.

Electronics manufacturers report slowing growth

According to responses to IPC's 2019 Pulse of the Electronics Industry survey, growth of the electronics industry is slowing, though the industry's outlook is still generally positive, IPC reports.

More than 80 companies responded to the survey, and reported global third-quarter sales growth that averaged 3.0%, the lowest level since IPC began its quarterly survey in 2017.

Q4 2019's composite score for the direction of the business environment fell to its lowest level since 2017, barely on a positive note. Present scores for Europe and the Americas turned negative this quarter. Although sales, orders, and profit margins were positive, labor, material costs, recruiting inventory, and order backlogs moved in a negative direction.

The industry's expected direction in the next six months remained generally optimistic, with all business indicators looking positive. Among the industry segments, PCB fabricators are the most optimistic about the next six months.

Overall, however, the six-month-outlook score continued to weaken compared to the first three quarters of this year. This indicates that the industry expects its health to remain generally good through the first quarter of 2020 despite some slowing.

The respondents' outlook for the next 12 months remains positive but is down substantially from previous quarters. While a majority of respondents in all segments described the 12-month business outlook as very or somewhat positive, only PCB fabricators were unanimous in reporting a positive outlook. The composite scores on the business outlook for the next 12 months are positive in all regions except Asia, where the score declined to neutral (0 on the index). The uncertainty of trade relations between the U.S. And China is a contributing factor to the lackluster 12-month outlook for respondents in Asia.

A ranking of opportunities that will drive the industry's future business growth showed that the Internet of Things (IoT) and smart systems is seen as the number one driver, followed closely by growing markets and 5G/high-speed communications. Defense and aerospace topped the list of growing vertical markets cited by the respondents. Medical device and LED lighting markets were also cited.

Respondents also ranked a list of major concerns about conditions in the business environment in terms of their impact on future business growth. Economic uncertainty is the leading concern. Asked about conditions or trends that are significantly increasing their costs, respondents predominantly cited the tight labor market and trade conflicts.

Pulse of the Electronics Industry is a global survey-based data service from IPC that provides a quarterly report on the health of the industry and its outlook for the coming year. The quarterly report shows what factors are driving or limiting growth, and how the outlook differs in various regions and segments of the industry. The confidential surveys are open to all in management positions in the electronics industry. Survey participants receive the report on the quarter's results.

Sierra Wireless selects R&S ATS1800C test chamber for 5G NR FR2 testing

Rohde & Schwarz has announced that IoT solutions provider Sierra Wireless has selected the compact antenna test range (CATR)-based R&S ATS1800C for mmWave frequencies (FR2) testing.

The transportable solution from Rohde & Schwarz features a state-of-the-art golden CATR reflector with rolled edges and a smooth surface to minimize scattering and to provide precise measurement results as required for operation at high frequencies. Test and measurement is moving from conducted testing to over-the-air (OTA) testing, especially in 5G NR due to the increased frequency range.

One challenge of OTA testing is to maintain a compact test chamber size while providing a large quiet zone (QZ), or useable measurement area, in a wide frequency range. Rohde & Schwarz developed the R&S ATS1800C to combine all this, meeting current and upcoming requirements for 5G NR OTA

testing. The R&S ATS1800C is a turnkey, high-end chamber with a small footprint of only 1.3 m2. Thanks to its movable design, it is highly flexible and transportable. The solution provides a large quiet zone of 30 cm, fulfilling 3GPP 5G NR conformance test requirements.

With its high shielding efficiency, the R&S ATS1800C is designed to provide a trouble-free environment for uninterrupted measurements of 5G antennas, modules and devices. A unique characteristic of the R&S ATS1800C is its gold CATR reflector, transforming the incoming spherical wave front to a plane wave. Manufacturing the reflector requires processes that are accurate in the micrometer range.

The R&S ATS1800C supports the testing of devices weighing up to 8 kg, which makes it well suited for testing a variety of active or passive DUTs. EE

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SPECIAL REPORT

INNOVATION DRIVES SCOPE OPTIONS

Performance, formfactor, and software choices adapt scopes to multiple applications

By Rick Nelson, Interim Chief Editor

Oscilloscopes span a range of performance and formfactor options, from a 110-GHz benchtop instrument to a pocket-sized USB model. High-end models target mmWave applications such as WiGig and 5G plus satellite communications and radar, while low-cost models aim to put a lab in the pocket of every engineer—or engineering student. In between, mainstream scopes address ADAS, power monitoring, IoT, embedded-systems design, EMC debug, and bus-decoding applications, among many others.

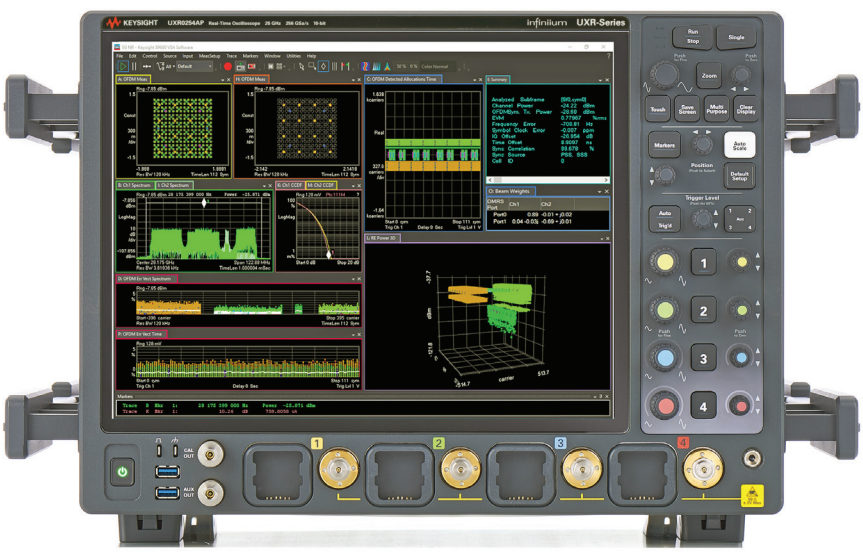
Targeting mmWave communications

Keysight Technologies has been focusing on the high end with new functionality for its UXR-Series oscilloscopes, which deliver fast, coherent analysis for wideband measurements up to 110 GHz to accelerate the development of next-generation mmWave communications applications.

Features include the ability to configure optional 5-GHz or 10-GHz analysis bandwidth windows within and above the UXR's natively licensed bandwidth; availability of more than 2 GHz of digital downconversion (DDC) analysis bandwidth that can be used in conjunction with available mmWave frequency extension options to extend DDC accelerated frequency ranges as high as 110 GHz; and hardware-accelerated DDC to decimate oscilloscope captures in real-time to enable deep captures exceeding several seconds of time and accelerating processing up to 100x faster than non-decimated measurements.

The company said the instrument also offers superior signal integrity with error vector magnitude (EVM) below 0.6% for 5G NR FR2 tests and 1% for 802.11ay technologies—consequently, EVM measurements can reflect the true DUT performance, without impairments caused by the noise of the measurement system. Finally, a bandwidth pricing model matches typical RF equipment, in which the price correlates with the analysis bandwidth needed—eliminating the need to purchase the full frequency range that the oscilloscope hardware supports.

▼ Keysight UXR-Series oscilloscope.



Performance to 16 GHz

Much recent innovation in the oscilloscope market has been at top frequencies from 2 to 16 GHz. Guido Schulze, product manager for oscilloscopes at Rohde & Schwarz in Munich, commented, "R&S RTP high-performance oscilloscopes combine high-class signal integrity with a fast acquisition rate of 750,000 waveforms/s. The high-precision digital trigger matches the acquisition-system bandwidth, with real-time de-embedding for triggering and acquisition. The new RTP13 and RTP16 models extend the maximum available bandwidth to 16 GHz."

Asked about unique features, Schulze cited signal-integrity debugging in real time. "Unique features include real-time de-embedding, real-time differential math functions for two input signals, serial pattern trigger with clock data recovery of embedded clocks in real time up to 16 Gb/s, and mask and histogram test supported in hardware for fastest data-eye analysis," he said.

Schulze also cited what he called the first real-time scope-based time-domain reflection (TDR) and transmission (TDT) analysis systems on a digital oscilloscope. "This enables debugging of signal traces without dedicated test equipment such as vector network analyzers," he said.

Trevor Smith, business development manager at Pico Technology Ltd., commented, "We introduced the 9400 Series 5- and 16-GHz Sampler Extended Real

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▲ Rohde & Schwarz RTP oscilloscope.

Time oscilloscopes (SXRTO) that combine the benefits of real-time sampling, equivalent-time sampling, and high analog bandwidth. We also delivered some important new capabilities for our existing range of PicoScopes, including a decoder/analyzer solution for BroadR-Reach Automotive Ethernet."

According to Smith, "The 9400 Series SXRTOs have four input channels up to 16 GHz with market-leading timing resolution for accurately measuring and visualizing high-speed analog and data signals. Real-time sampling to 500 MS/s and equivalent time sampling (ETS) to 2.5 TS/s make the products ideal for capturing pulse and step transitions down to 22 ps and clocks and data eyes to 8 Gb/s. Most high-bandwidth applications involve repetitive signals or clock-related data streams that can be readily analyzed by equivalent-time sampling. The SXRTOs quickly build ETS persistence displays with statistics. They have a built-in full-bandwidth trigger on every channel."

"Our UltraVision II architecture built upon our Phoenix chipset has allowed us to bring three new series of scopes to market," commented Michael Rizzo, general manager, RIGOL USA. "All of the scopes share a common UI and HW architecture but are differentiated based on performance capability and analysis tools. The MSO5000 (70 MHz to 350 MHz), the 7000 Series (100 MHz to 500 MHz), and the MSO8000 (600 MHz to 2 GHz) provide a seamless portfolio from basic visualization tasks to advanced serial analysis. The Phoenix chipset allows us to deliver unmatched sample rate, memory depth, and instrument capability across the 70-MHz to 2-GHz market."

Other recently introduced scopes include the Teledyne LeCroy WaveRunner 8000HD High Definition Oscilloscopes (HDO), which are 8-channel, 12-bit-resolution, 2-GHz instruments. WaveRunner 8000HD leverages the company's HD4096 High Definition technology and a 15.6-in. touchscreen, high channel counts, and 5 Gpts of acquisition memory for critical applications such as high-power/3-phase power conversion, automotive electronics, power integrity and power sequencing, and embedded control systems.[1]

MHz-range value

Jason Chonko, applications marketing manager at SIGLENT Technologies North America, described the company's SDS2000X-E Series as a higher bandwidth budget scope featuring two analog inputs, 2-GS/s sample rate, and up to 350-MHz bandwidths. "The SDS5000X is our flagship scope with up to four analog inputs, 5-GS/s sample rate, and up to 1-GHz bandwidths," he said.

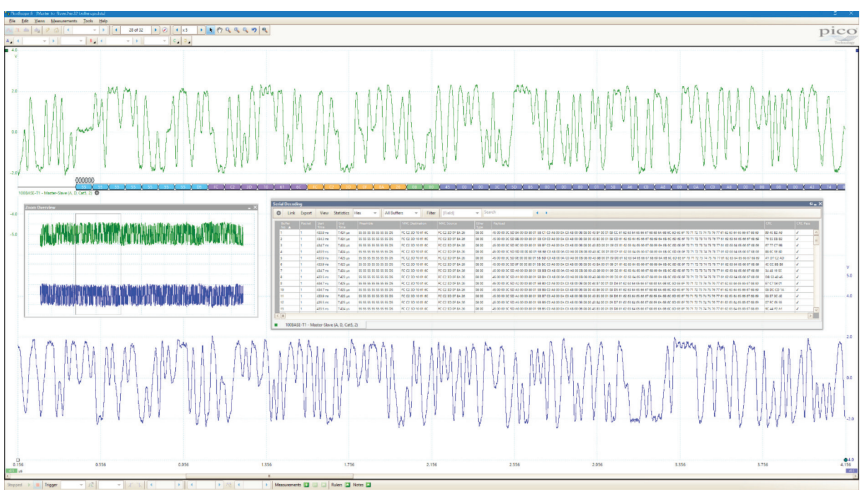
Chonko cited other features, such as web control and intuitive user interfaces plus the inclusion of free frequency-analysis/Bode functionality and a measurement engine that provides statistical trending and histograms on many measurement types. "Coupled with deep memory, you can now see far more detail than ever before with a single trigger event," he said.

James McGregor, global head of test, tools, and production supplies at Newark, said the company recently launched a new private-label collection, Multicomp Pro, stocking more than 60,000 components, tools, and instruments. The first of two of Multicomp Pro's newest oscilloscopes available at Newark is the MP720013 MSO/MDO 100-MHz oscilloscope, which has two analog and 16 digital channels with an external trigger and logic analyzer. It has a maximum real-time sample rate of 1 GS/s per channel and a record length of 2 Mpts per channel. "The 100-MHz logic analyzer has a sample rate of 20 S/s to 1 GS/s per channel and a record length of 4 Mpts per channel, enabling users to safely and confidently debug embedded systems," McGregor said.

The second is the MP72024 100-MHz digital storage oscilloscope, which has two analog channels with an external trigger. It has a maximum real-time sample rate of 1 GS/s per channel, a record length of 20 Mpts per channel, and a 55,000-waveform/s refresh rate. "This scope also has a 12-bit high-resolution ADC, fully restoring the waveform detail with 16 times the vertical resolution of traditional 8-bit ADCs, enabling users to capture the signals of interest while minimizing the effects of unwanted noise," McGregor said.

When asked about new products, Kaitlyn Franz, test product manager at Digilent, said, "We're sticking with our Discovery family. To date, we have the

▼ Pico Technology BroadR-Reach decoder screenshot.



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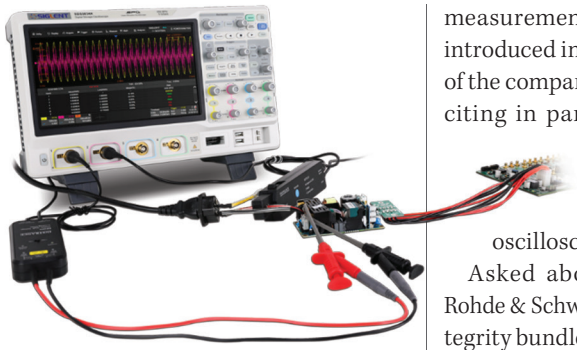


▲ SIGLENT SDS5000X oscilloscope in power-analysis application.

Analog Discovery 1 and 2, the Digital Discovery, and most recently, the Analog Discovery Studio, which has been adapted to be breadboardable."

The Discovery family's "...versatility and flexibility are second to none," she continued. "With the Analog Discovery 2, you're getting 12 benchtop instruments packed into a single 3-in. x 3-in. tool, including an oscilloscope, logic analyzer, spectrum analyzer, waveform generator, and more. With the Analog Discovery Studio, you also get a convenient, replaceable, and breadboardable interface."

Added functionality

Steve Sandler, founder and CEO of Picotest, said, "We have introduced many new measurement functions for oscilloscopes. Tektronix 5/6 Series oscilloscopes now have the ability to perform the 2-port shunt-through PDN impedance measurements, component impedance measurement, TDR measurements, noise-density measurements, VNA and FRA measurements to 8 GHz, DC-biased inductor measurements, DC/DC negative-resistance measurements, and clock power-supply modulation-ratio measurements (PSMR). These were all introduced in 2019." He added that many of the company's capabilities are unique, citing in particular that the Picotest NISM closed-loop stability assessment will soon be available for the 5/6 Series oscilloscopes.

Asked about software, Schulze at Rohde & Schwarz cited a special signal-integrity bundle to provide customers with unique functions for an attractive price. He also cited complete test solutions for debugging and compliance testing of serial protocols. "These include special software, fixtures, and probes for industrial, embedded, and automotive buses such as USB, SPI, DDR, and Automotive as well as industrial Ethernet." Finally, he mentioned special spectrum-analysis software, frequency zone triggering, and signal analysis capabilities.

Smith commented that PicoScope 6 PC software is regularly updated and offered free to customers, as new capabilities and functionality are developed. As an example, he said the company last year added decoders for Manchester/DALI as well as a BroadR-Reach solution. "BroadR-Reach is a full-duplex protocol operating on a single unshielded twisted pair (UTP), so users need a tool to separate the traffic in each direction," he said. "The PicoScope BroadR-Reach decoder/analyzer includes an innovative nonintrusive software-directional-coupler math-channel function that utilizes two probing points a known distance apart and a velocity-of-propagation algorithm to separate the transmitted data waveforms in each direction."

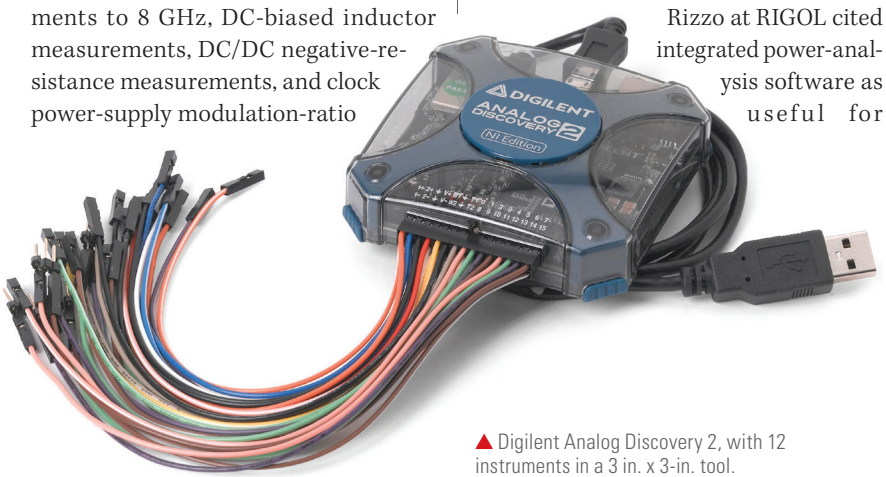
Rizzo at RIGOL cited integrated power-analysis software as useful for customers implementing switch-mode supplies. In addition, "Our Jitter and Real-time Eye application is a powerful tool for those characterizing serial communications," he continued. "Protocol Analysis allows complete embedded debug, and a web-browser interface allows for simple remote instrument monitoring and control.

SIGLENT also supports power analysis. Chonko said, "The Power Analysis option for the SDS5000X Series provides multiple measurements that are critical for power-supply designers trying to get the most out of their products.

According to Franz at Digilent, "WaveForms is our powerful multi-instrument software application. It seamlessly connects to our USB portable oscilloscope, logic analyzer, and function generator products such as both versions of the Analog Discovery, the Digital Discovery, and the Electronics Explorer board, with full Windows, Mac OS X, and Linux support. This software, coupled with the hardware instrumentation, brings a powerful suite of instruments to enable analog and digital design on your personal computer. Designed with a clean, easy-to-use graphical interface for each instrument, WaveForms makes it easy to acquire, visualize, store, analyze, produce, and reuse analog and digital signals. And the best part? It's free."

Applications

With respect to applications, Keysight cited RF technologies that have pushed frequencies above 100 GHz with bandwidth needs reaching tens of GHz, including technologies such as 802.11ay (WiGig), 802.11ad (gigabit wireless), satellite communications, radar, and 5G. "Keysight recognized the growing need for a cost-effective oscilloscope that supported today's emerging mmWave-technology wide-bandwidth measurement requirements," said Brad Doerr, vice president and general manager of digital and photonics R&D for Keysight's Communications Solutions Group, in a press release. "Keysight's UXR is the first oscilloscope on the market to address mmWave technologies and advanced applications such multiple input, multiple output (MIMO) with up to four



▲ Digilent Analog Discovery 2, with 12 instruments in a 3 in. x 3-in. tool.

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channels for the price of a 25-GHz scope."

Chonko at SIGLENT said, "We've been seeing an increase in embedded designers and software engineers using oscilloscopes for system verification. These are not typically hardware designers, and so oscilloscope ease-of-use is critical to their success."

According to Schulze at Rohde & Schwarz, "Nowadays designers combine multiple functional cores in one design. Our oscilloscopes cover all requirements for time-correlated analysis supported by the oscilloscope bandwidth—high-speed digital interface, serial buses, RF interface, and low-speed controls." He added, "Oscilloscopes for automotive and IoT development projects are often used as a standard tool for a variety of applications, so that they need to be complete including EMC debug, power measurements, and bus decoding."

He continued, "In the field of power electronics, vertical resolution, a low noise floor, and a deep memory are basic requirements for accurate measurement results. In addition, there is an increasing trend for the oscilloscope to take over more and more measurement capabilities from other dedicated devices. For example, Rohde & Schwarz instruments can use the Frequency Response Analysis function to measure the control-loop response or the power-supply rejection ratio of converter designs, saving the additional costs of a dedicated frequency response analyzer."

Smith said PicoScopes are used in a range of applications and in many different industries. "Development of ADAS and automated-vehicle technologies have featured quite often in the past 12 months," he said. "We saw some examples of PicoScopes used to capture real-world signals that are used to accelerate development of collision-avoidance algorithms."

According to Franz at Digilent, "In addition to learning/academic applications, we find that our use cases are far and wide. Most engineers use the Analog Discovery 2 as a quick test or monitor so they won't need to spend much time—power monitoring, embedded systems design, medical, etc."

According to Rizzo at RIGOL, embedded IoT is an area that brings many applications (such as automotive, communications, power management, military/aerospace, and medical) together with similar debug challenges involving power management, sensor communication, serial data, signal integrity, and RF integration. "Engineers may not be expert in all of these areas but require simple, reliable, and flexible test tools to identify issues, characterize performance, and validate designs," he concluded. EE

REFERENCE

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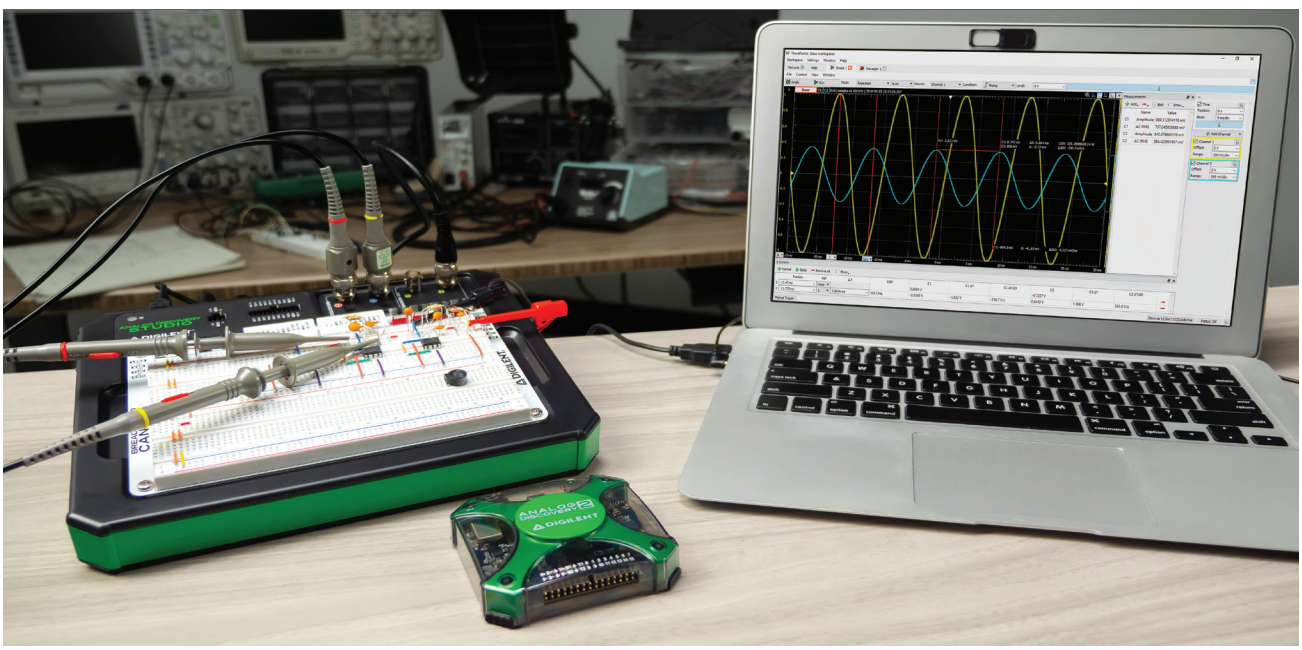

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Marvin Test Solutions TS-323 aerospace and satellite test system.

SPECIAL REPORT

FROM THE SIMULATION ENVIRONMENT TO THE FLIGHTLINE

Applications run the gamut from electronic warfare (EW) to in-flight entertainment

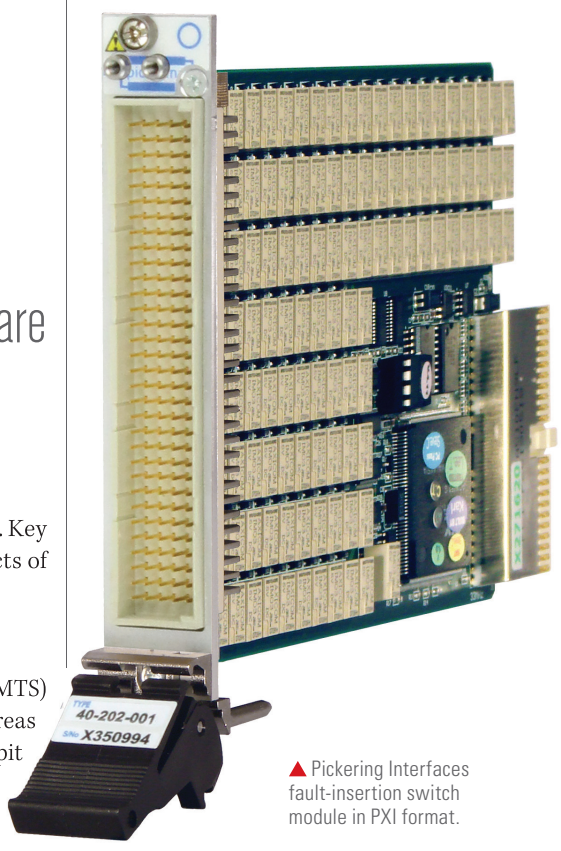
By Rick Nelson, Interim Chief Editor

Aerospace test applications run the gamut from electronic warfare (EW) to in-flight entertainment. Challenges extend from simulation, modeling, and data acquisition at the design and prototyping phases to manufacturing test and finally on to depot and flightline test. Equipment able to serve aerospace test applications extends from handheld instruments to complete systems comprising hardware and software. Key companies serve one or more aspects of aerospace test.

Vertical integration

For example, Marvin Test Solutions (MTS) serves most aerospace application areas including satellites, avionics, cockpit displays, communications, radar, and ruggedized flightline armament test, according to Jon Semancik, marketing director at the company. "MTS is a vertically integrated aerospace test and measurement company," he said. "As an aerospace test and measurement company with a solution-centric focus, our portfolio of PXI hardware, test software, and complete automated test systems offers the performance, flexibility, innovation, and value demanded by our customers. From our standalone test executive and development software to our custom, turnkey systems, MTS' product portfolio offers superior capabilities and delivers faster results, while ultimately reducing maintenance and sustainment costs. By leveraging our design and development expertise, we are able to take challenging test requirements and deliver test solutions that are easy to use, simple to maintain, and enable our customers to achieve high levels of mission readiness."

MTS offers a range of PXI/PXIe instrumentation and switching products (GX Series) as well as GENASYS benchtop (TS700 Series), GENASYS semiconductor (TS900 Series), and GENASYS aerospace and satellite test systems (TS-321/TS-323).



Pickering Interfaces fault-insertion switch module in PXI format.

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According to Bob Stasonis, technical product specialist at Pickering Interfaces, "We do a little bit of everything. We have worked on functional test applications for many different avionics FRUs (field replaceable units) including FADEC (full authority digital electronic control) for jet engines, cockpit instrumentation, satellite testing, SDR (software defined radios), flightline systems test for the A-10, and even cable testing within an aircraft fuselage."

Stasonis added, "Our extensive range of switching and simulation products are designed to work in many markets, aerospace being one of them. From a historical perspective, FADEC testing was the application that got Pickering into the HILS (hardware in the loop simulation) market. Today, we have the broadest range of FI (fault insertion) switch modules in the PXI formfactor."

Stasonis continued, "As FRUs get more complex, higher-density matrix switching becomes more critical for managing more digital and analog I/O. Microwave switching up to 67 GHz will become the norm as even defense contractors are looking to 5G communication for secure data transmission and potentially robotic surgery near the battlefront!"[1] He added that testing DAQ systems with thermocouples, RTDs, and other input types calls for compact automated simulation such as Pickering offers.

COTS for HIL

Bill Eccles, principal electrical engineer, Alan Murphy, western US Sales manager, and Peter Blume, president, all at Bloomy Controls Inc., said, "Bloomy is the market leader in providing complex, open platform, commercial off-the-shelf (COTS) hardware in-the-loop (HIL) test systems for airborne controls such as electronic engine controls and full-authority digital engine controls (EECs and FADECs), flight control computers, collision-avoidance systems, environmental controls, and mission computer systems. We also provide high-channel-count, high-speed data acquisition and closed-loop controls testing for systems integration labs (SILs) as well as many line replaceable units (LRUs) including electrohydraulic actuators and

▲ Bloomy Controls FADEC and ECC test platform.

controls, cockpit controls, and control-surface actuators. In addition, we provide manufacturing automated testing equipment for many of the electronic assemblies that comprise these LRUs. And Bloomy's MIL-STD-1553B communications solutions have been deployed in over 200 systems worldwide."

Eccles, Murphy, and Blume said the company offers a range of closed-loop/hardware-in-the-loop (HIL) test platforms that are customer-configured for specific application spaces, including FADECs/EECs, flight-control systems, and environmental controls. "Each platform contains a basic complement of simulation types which may be customized for the customer's control system requirements," they said. "The Bloomy Simulation Reference System provides a launching point for other closed-loop/HIL applications. Customers' test engineers may use these platforms and systems to jump start their test development cycles, thereby shortening schedules, reducing costs, and freeing resources to focus on the differentiating technologies which make their products unique in the marketplace."

They continued, "Bloomy provides several industry-first modules and interconnection solutions for the National Instruments (NI) Switch, Load, and Signal Conditioning (SLSC) and compactRIO platforms, which our customers can use to speed test-system development using COTS components. These include an 8-channel high-precision thermocouple simulation module, an 8-channel VDT/resolver simulation module, an 8-channel load module, a ThroughPoint interface panel, and a MIL-STD-1553B avionics bus communications module."

Tactical communications

"At Astronics Test Systems (ATS), we participate in tactical communications and avionics testing in addition to modernization efforts as they pertain to interoperability of allied and coalition defense elements wherever they deploy," said David Vondran, senior product marketing manager at the company. "For example, Link-16 is a mandate to bring different generations of airborne platforms onto a common communications network. By doing so in a secure manner, aircraft, ships, and ground forces can exchange tactical information, in near-real time, even in contested and congested environments. This level of communication complexity requires a trusted test solution for manufacturing and maintenance activities, which is where ATS excels."

Recent ATS solutions include the new ATS-3100 VRS (VST-based Radio Solution) for tactical communications

▼ Astronics Test Systems ATS-3100 VRS (VST-based Radio Solution) for tactical communications test.

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test of airborne radios, the Freedom R8100 for Avionics Ramp Testing, and single-rack Link-16 solution that can serve both manufacturing and maintenance needs. "In this way, we optimize our operational scenario (that is, size, weight, and power) for the depot setting so maintenance can deploy closer to the military assets they serve," Vondran said. "Our engineer-to-engineer collaborative culture is key for developing a reliable and sustainable platform."

EW hardware and software

EW has been one focus of Keysight Technologies Inc., which recently announced new EW threat-simulation solutions, including software and hardware, that generate modern EW RF environments to enable engineers to efficiently test their EW systems. The new solutions include two commercial off-the-shelf (COTS) products: Simulation View software, which enables the development, integration, and test of sophisticated EW systems with real-time RF modeling and dynamic high-fidelity visualization, and UXG Agile Vector Adapters, now available in 20-GHz, 40-GHz, and 44-GHz versions, which combine fast frequency, phase-and-amplitude, and time-delay switching speeds with real-time pulse descriptor word (PDW) streaming. (PDW is the data used for creating radar signals.)

Keysight's products, and the support of open interfaces and architecture, offer customers EW threat-simulation solutions ranging from benchtop testing to full-scale threat simulation. Scalability, coupled with the ability to reconfigure the system to utilize RF test assets effectively, delivers a modernized EW test and evaluation solution.

"Keysight understands that our customers need solutions that can maintain pace with the accelerating evolution of the EW threat environment," said Greg Patschke, general manager of Keysight's Information Warfare Group, in a press release. "We will continue to partner with our customers to create and deliver rapidly adaptable solutions that help them advance their labs to the next level of testing."

The open architecture of Keysight's EW threat simulation solutions enables customers to create scenarios with a variety of software tools, often utilizing a customer's existing threat databases. Customers can also choose the software tool that best fits their EW test needs for pre-scripted or dynamic real-time threat generation, or both.

Instruments and data acquisition

According to Jason Chonko, applications marketing manager at SIGLENT Technologies North America, the company's products can support aircraft electronic systems as well as basic circuit design and troubleshooting. "Our bench and handheld oscilloscopes are ideal for product development as well as on-board troubleshooting of electronic systems throughout the airframe," he said. "For communications, satellite, and radar applications, our growing list of RF products delivers high performance and capabilities. The SIGLENT spectrum analyzers, RF sources, arbitrary generators, and vector network analyzers provide deep insight into component and system-level performance. Testing and monitoring transmitters, receivers, as well as troubleshooting and characterization of components, adapters, and cabling are

▲ SIGLENT SVA1032X analyzer.

part of our list of strengths. The new 3.2-GHz VNA-equipped SVA1032X analyzers are easy to transport and can be used throughout the aircraft for *in-situ* testing of receivers as well as RF components."

According to David J. Rodgers, senior program manager for SAN, Ethernet, and Fibre Channel technologies at Teledyne LeCroy, "Our products will be used for evaluation and verification of wired, fibre-interconnect communications, focused on, but not limited to, ensuring fly-by-wire messaging is accurate, timely, and complete." Specific products include the SierraNet M168 Fibre Channel and Ethernet test platform, which includes data capture, analysis, and manipulation routines. "SierraNet enables test/validation engineers to observe and modify the physical interface and associated data frames used in mission-critical avionics and communications systems," Rodgers said.

Pacific Power Source specializes in programmable power test solutions for power-related military and aerospace test

◀ Keysight UXG Agile Vector Adapter (top) and UXG Agile Signal Generator (bottom).

▶ Pacific Power Source 6,000-VA 3-phase AC power source.

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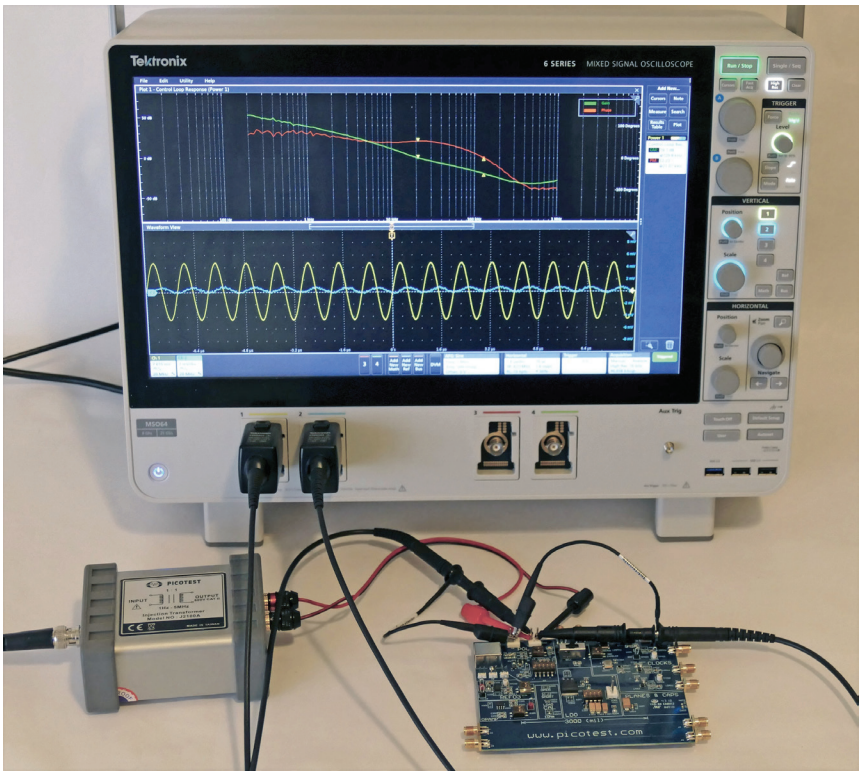
applications, according to Herman vanEijkelenburg, director of marketing at the company. "MIL/aero power systems are typically powered with voltages of 115 VLN for single-phase and 200 VLL for 3-phase AC power at 400 Hz and 28 VDC for DC power. These power sources are used in research, design, production test, and maintenance of avionics and weapons subsystems. Pacific Power Source is about to launch (February 2020) a complete new line of ultramodern, linear-technology-based programmable power sources with a color touchscreen user interface aimed at MIL/areo ATE power test applications."

Picotest focuses on power integrity, including low-power distribution network testing and PDN impedance testing, according to Charles Hymowitz, the company's VP of marketing and sales. "This applies to every application area," he said, adding that the company also addresses cable, connector, and PCB coupon testing.

Specific products include vector network analyzers, such as the 1-Hz to 50-MHz OMICRON LAB Bode 100 VNA; probes and impedance-testing accessories, such as 1-port and 2-port PDN probes, ground-loop breakers, active splitters, and PDN cables; power-supply testing accessories for step load testing, Bode-plot stability testing, and PSRR/PSMR testing; new oscilloscope support for impedance, Bode, and PSRR testing; and a "pocket" TDR for cable, connector, and PCB coupon testing

"We are focused on supporting power-integrity testing," Hymowitz emphasized. "We are the only company with power-integrity test accessories that support VNAs and oscilloscopes from all instrument companies. Power-integrity problems cross applications, disciplines, and customer bases. Since voltage levels are falling, power integrity is becoming a bigger and bigger problem for *everyone*."

Diversified Technical Systems (DTS) focuses on flight test, modification testing, compatibility, and rotor structural integrity, according to Huy Nguyen, aerospace and defense sales manager at



▲ Picotest test setup with Tektronix 6 Series oscilloscope.

the company. "SLICE6 AIR is the smallest COTS onboard rugged data-acquisition unit available," he said. The miniature SLICE6 AIR allows test engineers to embed the data recorder in locations that were previously inaccessible. SLICE6 AIR can be used standalone, networked for high channel-count tests, or easily integrated into existing Ethernet-based flight test instrumentation."

CTT supplies customers worldwide with power amplifiers (including GaN narrow-band power amplifiers), frequency converters, frequency multipliers, transmitters, transceivers, and receivers from 10 MHz to 100 GHz. "Amplifiers can be supplied in connectorized assemblies or rack-mount configurations," a company marketing representative said. "Setting CTT apart from other manufacturers is our unique spectrum of Custom Engineered Options (CEOs) that can be readily integrated within most package formats." Typical options include DC/DC converters, AC/DC converters, TTL control, samplers, couplers and detectors, heat exchangers (conduction, convection, forced air or liquid), and waveguide inputs/outputs.

▲ DTS SLICE6 AIR COTS onboard rugged data-acquisition unit.

"Since 1981, CTT has been designing and delivering microwave amplifiers and assemblies for use in test and measurement areas including EW, electronic countermeasures (ECM), electronic support measures (ESM), and radar systems including surface-aperture radar (SAR)," said the representative. "The products find use in missiles, jammers, UAVs, seekers,

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▲ CTT GaN narrow-band power amplifier.

decoys, data links, simulators, and commercial communications systems."

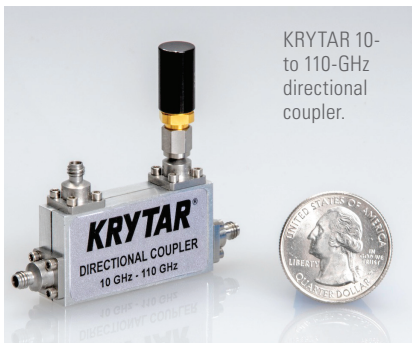
In related news, Anritsu recently added real-time spectrum-analysis (RTSA) tools for its Field Master Pro MS2090A handheld spectrum analyzer, which can measure the amplitude of a single spectrum event as short as 2 µs and detect a single event as minimal as 5 ns. Its ability to more accurately detect intermittent interfering signals provides distinct advantages in a number of aerospace/defense, satellite-system, and radar applications, the company said.[2] The Field Master Pro MS2090A RTSA provides a continuous stream of FFT measurements over a 110-MHz analysis bandwidth, which enables a 2.055-µs probability of intercept (POI).

In addition, Rohde & Schwarz recently expanded the available frequency options for its analog R&S SMA100B RF and microwave signal generator, offering now a contiguous frequency range from 8 kHz up to 72 GHz. "The instrument provides the purest output signals while maintaining the highest output power level, far outpacing the competitive solutions," said Simon Ache, director of signal generation product management at Rohde & Schwarz, as quoted in a recent report on signal generators.[3] "It is capable of handling the most demanding component, module, and system T&M tasks in the RF semiconductor, wireless communications, and aerospace and defense industries."

Highland Technology recently introduced a new member of its aerospace simulation suite—the P348 midfrequency sinewave dual-channel quadrature modulator instrument with C-coupled baseband I and Q inputs. It is suitable for a range of transducer simulation applications that make use of eddy-current, inductive, and capacitive sensors. It is also suitable for classic RF modulation tasks. The carrier frequency can range from 500 kHz to 20 MHz.[4]

From components to I/O boards

"KRYTAR specializes in the design and manufacture of ultra-broadband mmWave, microwave, and RF components and test equipment for both commercial and military applications,"



KRYTAR 10- to 110-GHz directional coupler.

according to a representative from the company's marketing department. "KRYTAR products offer solutions for many applications including EW, commercial wireless, SATCOM, radar, signal monitoring and measurement, antenna beamforming, and EMC testing environments." The KRYTAR product line includes directional couplers, directional detectors, 3-dB hybrids, matched-line directional dividers (MLDD), power dividers/combiners, detectors, terminations, coaxial adapters, and a power meter. The products cover the DC to 110.0-GHz frequency range.

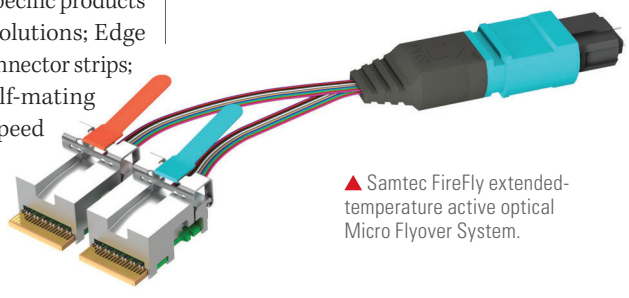
Samtec focuses on radar, including long-range discrimination radar (LRDR) and phased-array radar; communications (Manpack radio); and navigation, according to Brian Niehoff, technical marketing engineer at the company. Specific products include modified COTS solutions; Edge Rate rugged, high-speed connector strips; Razor Beam fine-pitch self-mating connectors; Q-Strip high-speed mezzanine connectors; high-speed cable assemblies; and the FireFly Micro Flyover System.

Russell Nieves, vice president of sales at Acromag, said his company focuses on radar, avionics, and flightline test systems, offering embedded computer technologies, including user-configurable FPGA I/O modules. "We design and manufacture a diverse portfolio of COTS products that customers can use right from the start," he said. "They are made in the USA (Michigan), and we have been doing this for over 60 years." Nieves continued. "We see customers continually wanting to upgrade speed and capacity for things like data acquisition and video imaging. We try to develop new products in a timely fashion to meet these requirements."

Model-based design

MathWorks provides computing environments for engineers to analyze, simulate, implement, and verify their complex logic designs such as radar schedulers, flight-control algorithms, or SDR transceivers, according to Albert Ramirez Perez, aerospace industry marketing manager at the company. "Model-based design is used by engineers to identify the optimal detailed design," he said. "Using desktop simulation, failures can be identified earlier in the process, avoiding costly project delays and increased workloads."

Ramirez Perez continued, "Engineers use MATLAB and Simulink families because the tools provide a wide range of the most-commonly used algorithms and techniques for designing complex logic using numerical computations, not only by executing individual test cases, but, more importantly, allowing them to build a set of test cases that covers the required specification. Model-based design allows engineers to focus most of their efforts on maturing and optimizing the specifications, minimizing the requirements and design errors and maximizing the test



▲ Samtec FireFly extended-temperature active optical Micro Flyover System.

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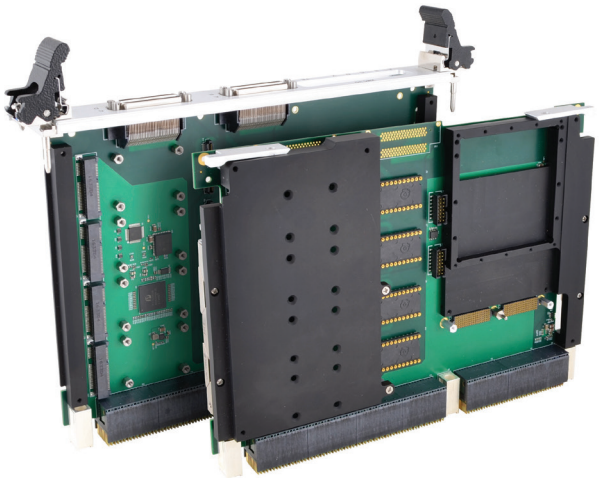

◀ Acromag VPX4520 carrier card.

coverage in a common desktop environment, so later phases can be streamlined. Finally, engineers are able to automate the implementation, easily use formal methods for verification, and perform functional testing where the full set of evidences are automated."

MathWorks offers textual and graphical desktop design environments that engineers use in traditional V-cycle and agile development, Ramirez Perez said. "On top of the base platforms MATLAB for math and programming and Simulink for simulation and model-based design, a set of toolboxes for specific technologies is available providing predefined algorithms. Engineers can find analysis, design, and optimization products in the main industries such automotive, aerospace, or semiconductors with algorithms relating to areas including artificial intelligence, 5G, automated driving, and radar and phased array, among others. Model-based design horizontal products cover engineering needs in most of the V-cycle phases: systems, software, testing, and integration."

He added that the just-released System Composer for systems engineering and architecture complements mature products for requirements validation and coverage, software automatic code generation (C, C++, HDL, PLC, or CUDA), formal methods and static analysis, and model-in-the-loop, software-in-the-loop, and hardware-in-the-loop functional verification for requirement-based testing.

"For complex environments and projects, MathWorks offers training and consulting services to guide teams to apply best practices in development workflows," he said.

MIL vs. commercial

Many of the products described in this article are suitable for both military and commercial aerospace test. According to Semancik at MTS, "There are many similarities between military and commercial aerospace customers—for example, the need for the manufacturer to implement and maintain quality-management systems such as AS9100D and AS5553.

Semancik continued, "Test result(s) traceability is also important; therefore, developing test systems with common user interfaces and report generation capabilities resonates with both customer groups."

"The requirements of military and commercial aerospace customers are very similar, with the overriding trend toward increasing the use of commercial, off-the-shelf (COTS) testing equipment in order to reduce cost and lead times," said Eccles, Murphy, and Blume at Bloomy Controls.

According to Nieves at Acromag, "Communications standards are very similar, but extensive certification requirements are higher in the MIL/aero market."

"All customers are looking for optimal solutions that address both their unique requirements and the constraints they are dealing with," according to KRYTAR marketing. "For military applications, products are designed and constructed to meet MIL-SPEC requirements."

Stasonis at Pickering commented, "Our military and commercial aerospace customers share the common traits of demanding specifications, reliability, and product availability for a long time."

However, Stasonis continued, "If there is a difference between them, it is probably the military's need for secrecy. In some cases, we are not allowed to know what we will be testing. The commercial industry is much more open with us. Military presents a whole different dimension of test—for example, the military is looking at electronic warfare and different communication protocols for security and secrecy. Whereas, commercial applications may be more concerned with seatback entertainment and taking credit card info at 35,000 feet. So, it can be different levels of complexity."

Eccles, Murphy, and Blume also cited a divergence between military and commercial customers. "One obvious difference is security; however, most of our aerospace customers have commercial as well as military contracts, and therefore Bloomy is ITAR-registered and has many security procedures in place. Also, military-aerospace applications are increasingly using FAA certification processes where previously they did not—even for mission-related systems. There is also a greater variety of military airborne systems than commercial systems in service, and military systems tend to be reconfigured for different mission profiles, with new sensor hardware, weapons systems, and software requiring integration. Thus, a military aerospace platform tends to have a greater requirement for test/validation throughout its lifecycle."

vanEijkelenburg at Pacific Power sited power-rating differences. "While functional requirements are often similar between the two, military aerospace customers generally need 115/200-VAC, 400-Hz, or 28-VDC power testing while commercial customers are moving toward higher voltages for both AC and DC power systems as well as higher frequencies up to 800 Hz," he said. "This is to support ever-increasing power demands of large commercial airliners like the Airbus A380 and Boeing 787 Dreamliner. Higher AC and DC voltage reduces current levels, allowing power switchgear and cabling to be reduced in both size and weight, which is important for on-board equipment."

Ramirez Perez at MathWorks also commented on differences. "The first difference is the severity of the process and the standards that programs need to comply with, which is due to the impact of a potential failure in the system measured," he said. "Engineers need to design their systems

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considering worst-case scenarios. A failure in commercial aerospace can lead to injures or casualties to the civilian population whereas a failure in a military application is directly related to the capability to accomplish a mission with mainly tactical or economic impacts for the operator."

Ramirez Perez continued, "Secondly, commercial aviation has been driven by COTS environments, which reduce the cost by using enough reliable, well proved components. COTS systems ease the verification and integration at the final platforms but constrains the flexibility of engineers to achieve new designs. On the other side, military developments have given a higher priority to customizations, security, and isolation through specific implementations, which offers more freedom to engineers on their designs, but increases the complexity of the testing and verification solutions."

MIL/aero OEMs are all looking for shorter time to market and easy-to-use solutions," said Niehoff of Samtec. "That is where Samtec is filling the need with COTS items."

Synergy

"In general, there is a modernization trend driven by the need for more data (not just voice)," commented Vondran at Astronics Test Systems. "The physical layer of the communication link is evolving to meet this need with SDR architectures. This evolution will continue to keep pace with the complexity inherent in these communication applications. If true, we predict the synergy between military and commercial aerospace will become more the norm (than the exception). Our position as a trusted supplier will continue to fuel these modernization efforts."

"Both commercial and military/aerospace customers require tools that are precise and adhere to the specifications for which the instrument(s) are designed," said Rodgers at Teledyne LeCroy. "A key difference in military applications is the nature of the systems communications and components therein; there are more 'mission-critical' concerns and functions in a military airframe."

"Numerous components in all microwave systems have continuously evolved and are now being optimized for specific applications," according to CTT marketing. "Both military and commercial configurations can benefit from improvements in increased sensitivity, reduced size and weight, higher efficiency, reduced cost, and increased system power efficiency. Improvements in these areas can spring from either the system designer or from breakthroughs at the component level."

Aerospace test trends

Several trends point to the future of aerospace test. "Aerospace programs are leveraging the cost and technology benefits of the commercial marketplace," said Rodgers at Teledyne LeCroy. "This trend assists the aerospace market in providing an increase in product-development options at reduced costs to deploy. However, the aerospace industry, by nature of the products and services they supply and support, needs to ensure the general market products and designs can withstand the scrutiny and rigors of the level necessary to be used in aerospace applications. Test and measurement tools and practices must be maintained at the highest level possible in support of the aerospace requirements."

Eccles, Murphy, and Blume commented, "The SIL is becoming exponentially more important to Bloomy's aerospace customers as the complexity of their control systems increases. We expect that the wide variety of sub-tier suppliers of controls and their test systems will require commonality and interoperability of these test systems. It is likely that the coming months and years will, by necessity, see standards emerge for standardizing the command and control of these test systems as well as for sharing data among them."

"Along with emerging technologies like 5G, artificial intelligence (AI), and quantum computing, there will be an increase in the number of connected devices enabling an entirely new paradigm of connectivity and capability—which means that customers will require higher-performance and frequency with lower latency and wider bands," according to KRYTAR marketing.

"Customers want to be able to stream real-time and record," commented Nguyen at DTS. "SLICE6 Air supports both real-time streaming that's viewable in industry-standard and nonproprietary data formats, as well as dual onboard recording to 16-GB nonvolatile memory."

CTT marketing sees a range of applications—narrowband, wideband, or ultra-wideband (microwave and mmWave)—operating in pulsed or CW mode, for new multifunctioned systems that effectively conserve weight, space, and power consumption.

"COTS buy-in is becoming more and more accepted," said Niehoff at Samtec. "Samtec's SET capabilities strengthen customer confidence in using a COTS product in their application."

"The advances in AI and machine learning will likely mean more HILS applications to test for all possible circumstances, whether it is hardware, firmware, or software testing," said Stasonis at Pickering. "We are also seeing a drive for smaller test systems in order to more easily bring support to the battlefront."

"In general, the trends in the aerospace industry are slow in adoption (compared to something trendy like 5G)," according to Vondran at Astronics Test Systems, "Even so, the transparent, collaborative, and methodical process towards modernization seems to be moving toward a faster cadence. This agility combined with trusted relationships is what will accelerate the future of aerospace test into reality."

Many of the spokespersons quoted in this article have elaborated on the points raised here and have weighed in on additional challenges and trends in aerospace test. A future article will provide more on the topic. EE

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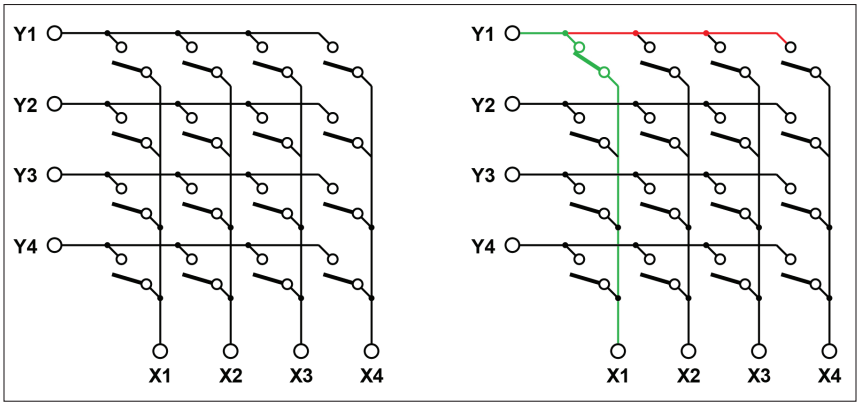
WHAT'S ALL THIS TALK ABOUT DENSITY?

When it comes to switching in functional test, density is key. In this article, let's examine some of the reasons why.

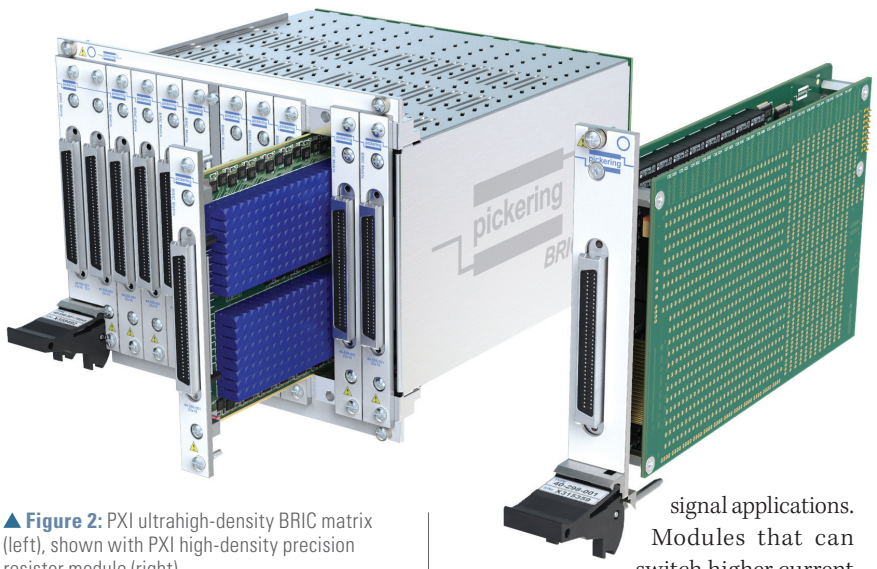
By Bob Stasonis

In the world of test, smaller is better, provided the system can test my particular devices under test (DUTs). There are many reasons to look at smaller footprints in test—manufacturing floor space, shorter cable lengths, and portability come to mind.

In the world of signal switching and test, the word is not necessarily smaller, but denser. Switching density is always a subject for debate as to how much switching is necessary, particularly in modular test systems because of the fixed physical size of modular devices. In this short article, we will take a brief look at some of the advantages of high-density switching and some sample applications that benefit from it. For brevity's sake, this article will focus on crosspoint matrices. The purpose of a crosspoint matrix is to allow any number of multiple signal inputs to be connected to any number of signal outputs—basically any test resource to any test point on one or more DUTs. A 1-wire crosspoint matrix uses an array of SPST relays to close an X to Y path. In **Figure 1**, with path Y1 to X1 closed (green path, right image), a stub appears (red) on the line which limits the matrix bandwidth.



▲ **Figure 1:** Crosspoint matrix, with green showing path Y1 to X1 closed and red showing a stub, which limits bandwidth.



▲ **Figure 2:** PXI ultrahigh-density BRIC matrix (left), shown with PXI high-density precision resistor module (right).

Advantages of density

Loosely defined, switching density is the number of relays that can fit into a unit of measure such as a test-system 19-in. rack unit or a modular instrumentation platform slot. For example, in the PXI modular format, 544 relays can be accommodated in a single-slot matrix module. However, using an architecture such as Pickering's BRIC, higher slot densities can be achieved, with up to 768 relays per slot (**Figure 2**). To achieve the high densities, the relays must be physically small, with a 0.5-A maximum limit, usable for many small-signal applications. Modules that can switch higher current signals will require physically larger relays, and the resulting density per PXI slot will go down. But the critical point here is that thanks to the advancement in relay technology, switching density has dramatically improved in the past 10 years. This means

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that switching systems are smaller, assisting the test engineer in keeping the overall test systems smaller and reducing test-floor footprints, which can directly relate to the advantages I referred to earlier. If you are using a modular formfactor such as PXI, greater switching density can mean that you don't have to purchase that additional modular chassis for instrumentation because switching took up too many slots.

Putting more relays on a switch module results in shorter paths on the PCB, and as paths get shorter, the usable bandwidth increases. Furthermore, more relays on a module mean less external wiring is needed. For example, to construct a 16x32 matrix using a 16x16 module as a building block, two modules are required along with 16 external wires. But as switching density has increased, 16x32 modules are available, eliminating the need for external wiring. Reducing wiring length is especially crucial in RF applications where long signal paths result in attenuation/loss of power.

It is important to note that higher density designs typically require that signal-carrying traces on the PCB be placed closer together; this accommodates the increase in relay count, which can increase channel-channel crosstalk.

Now let's see a few applications that benefit from a high-density switching system.

Semiconductor test

For years, IC chips have been getting more complex, and consequently, so have the test systems that verify the operation of these chips. That complexity comes at a cost—several million dollars per tester is not out of the question. As a result, chip manufacturers are always looking for ways to lower their cost of test. True, there is still a need for those multimillion-dollar systems for complete chip and wafer validation, but most of these devices can be tested in simpler ways once good manufacturing quality has been achieved.

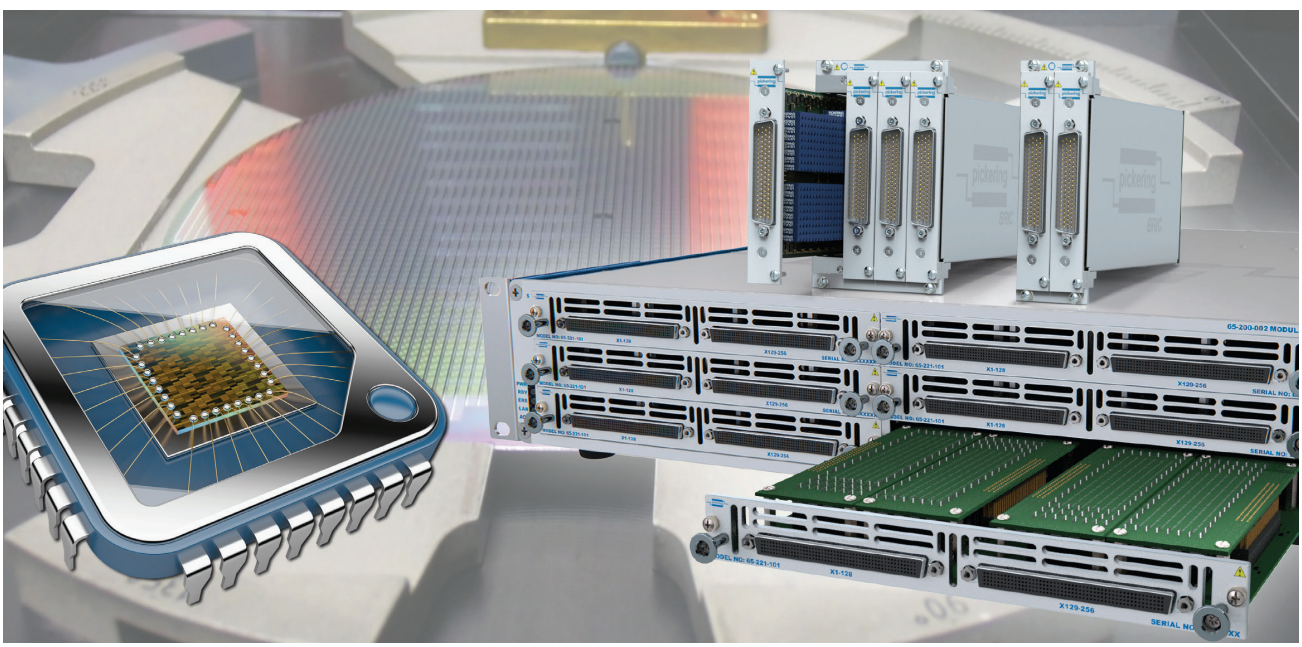
It turns out that many analog tests can be set up using a very large matrix (**Figure 3**), a pulse generator, and one or more SMUs (source/measure units). Now, I emphasize a large matrix because of the sheer number of test points on a wafer or pins on a device—1,000 connections at any one time is typical today.

The testing we are talking about here is aimed at characterization and validation of wafers and chips/dies in product development and NPI (new product introduction). Here are some of the tests used:

- Wafer-level test can test for shorts/opens and capacitance.
- I_{DDQ} testing is a method for testing CMOS integrated circuits for the presence of manufacturing faults. It relies on measuring the supply current (I_{DD}) in the quiescent state (when the circuit is not switching, and inputs are held at static values). The current consumed in this state is commonly called I_{DDQ} for I_{DD} (quiescent) and hence the name.
- For chip-level as well as wafer testing, there is I-V testing for transient charge trapping. One version of this test is called SPCT (Single Charge Pulse Trapping). SPCT uses a pulse generator to do fast I-V curves to either avoid charge trapping or measure charge trapping as a function of a device's switching frequency. With some modeling work, SPCT can distinguish the initial charge-trapping centers from those created later by voltage stresses.

One important thing to note is that in many of these tests, a large number of test points must be connected to ground to provide a stable test environment. So, it is essential that the matrix you select should be able to close a large number of the matrix's relays simultaneously. The number of relays will depend on the product you are testing.

▼ **Figure 3:** Ultrahigh-density switching matrices for semiconductor test.



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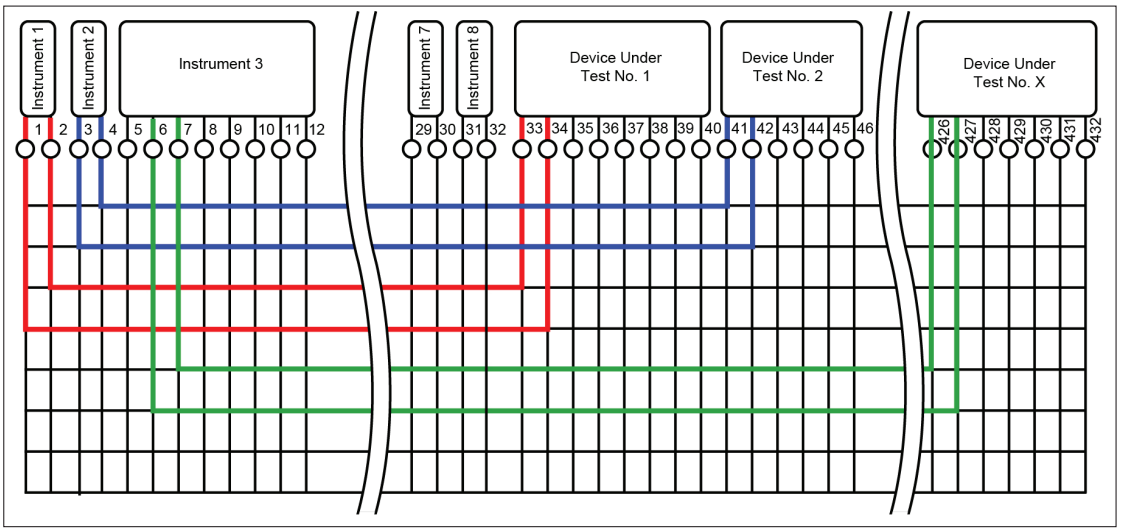


◀ Figure 4: Several DUTs connected to the X-axis of a crosspoint matrix.

▼ Figure 5: DUT connections via three different cable types. *(Courtesy of Virginia Panel Corp.)*

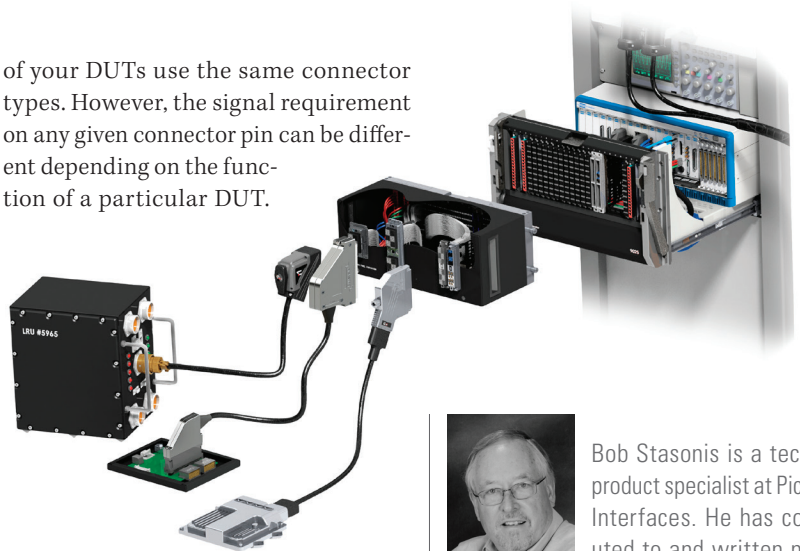
Board test with multi-up fixtures

With the IoT and the trend to increasingly miniaturize electronic devices, PCBs are also decreasing in size. Now it is often not practical to individually manufacture—much less test—a 1-in.-square PCB. Hence, such PCBs are assembled in a panel, also called an array. These PCBs are usually tested as a group as well. Once testing is complete, the panel is broken up and the good PCBs are sent on to the next stage of the system assembly. Failed PCBs are either scrapped or sent to rework.

In this case, a large matrix is ideal to share resources between each DUT. In **Figure 4**, you see several DUTs connected to the X-axis of a crosspoint matrix. A number of instruments are also connected to the X-axis. The colored lines show a number of simultaneous instrument connections. The number of connections is limited by the number of Y-axis lines available. Once measurements are made, the matrix can reroute the instruments to other DUTs and repeat the measurement made earlier.

Board test with multiple test programs

If you are in a repair-depot environment, or a company that has a high-mix, low-volume manufacturing strategy, chances are your test system needs to be very versatile to address multiple DUT types on the same system. For functional test, chances are that many of your DUTs use the same connector types. However, the signal requirement on any given connector pin can be different depending on the function of a particular DUT.



(See **Figure 5**. Note the three different cable connectors for DUT connections.)

This type of situation is where a crosspoint matrix can make your test system much more flexible as it can connect every test resource to any DUT test point, rerouting resources programmatically.

Conclusion

There are many test strategies that depend on the type of test to be performed, volume and mix of DUTs, and your budget. Clearly, no one test system can do it all, at least not economically. But if you have testing needs similar to what has been described here, a crosspoint matrix may be an important part of your test plans. EE

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ON A ROLL: NEW MANUFACTURING PROCESSES INSPIRED BY FLEX

By Meny Gantz

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Flexible printed circuits (FPCs) are making a profound impact on electronic design, ushering in smaller, lighter, and increasingly functional devices that would otherwise be difficult, if not impossible, to build. Now, the market demand for highly innovative circuits has roll-to-roll (R2R) manufacturing emerging as a truly effective means for printing FPCs in high volumes, with minimum handling damage, with high yield, and at high speeds.

The benefits of FPCs are enormous: they can be folded, bent, bonded in place, or free-flexing in many different configurations and in extremely high densities. Designers across a wide range of applications from commercial printers, implantable medical devices, and digital cameras to smart phones, automotive electronics, and beyond, embrace flex circuits for systems requiring reliable connectivity between moving parts, for designing products with smaller form factors and light weight, and for optimizing their packaging. As R2R manufacturing gains in popularity and its capabilities are refined, the ability to improve the yield of FPCs is a reality.

Industries driving innovation

For the last decade, smartphone development has been driving flex circuit innovation to meet demands for ultrahigh functionality and connectivity speed in a light and thin design. FPCs, with their lightweight, thin profile and ability to support fine-line features, and flexibility to be bent and folded, are natural must-have alternatives to replace bulky, rigid PCBs, connectors, and cables.

Inside today's smartphones, there are often 20 or more strong, thin flex circuits. These innovative FPCs range from relatively simple circuits to sophisticated folded flex circuits, all within exceptionally small enclosures. These FPCs may be simple, connecting the mainboard to the microphone or battery, or more complex, enabling the delivery of huge data volumes of high-resolution RGB multimedia from the processor to the color OLED display, driving a 13-megapixel display.

Beyond smartphones, FPCs are rapidly finding their way into automotive electronics. Inside smart and autonomous vehicles, flex circuits are replacing the legacy cables connecting hundreds of electronic devices spanning the car's computer, motor and brake controls, radars, cameras, mobile antennas, internet connectivity, and widescreen dashboard display. Manufacturers need connections that are lighter, less expensive to manufacture, and more reliable, and FPCs are frequently the answer. FPC manufacturers are even creating longer, thinner flex PCB high-density flat cables—as long as two meters—to replace outdated cables and connectors.

Keeping production capability ahead of new device designs

With high demand from smartphone manufacturers and automakers, and the introduction of 5G, which will necessitate new materials and better transmission, designers are pushing flex circuits to their technological limits. Simultaneously, innovative new designs are pressuring flex circuit suppliers to accelerate production processes and lower costs.

Demands for even higher density capabilities in flex circuits require thinner layers and finer conductive lines. The inherent physical fragility of flex circuits—thin materials are prone to wrinkling and stretching—pose some key manufacturing challenges that can negatively affect yield and potentially impact a design's viability.

These challenges are being addressed by flex-supporting technologies that enable large-scale flex PCB production while

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ensuring high yield and quality output. More flex circuit suppliers are adopting these advanced flex manufacturing processing techniques to enhance manufacturing efficiency and improve yield while maintaining cost and market competitiveness. That's where R2R manufacturing is making significant inroads.

The move to roll-to-roll manufacturing

R2R manufacturing can handle highly sophisticated flex PCB designs and offers inherent advantages by eliminating damage and increasing the volume production of flex PCBs. Whereas sheet-to-sheet processes are hindered by multistep batch-handling procedures and small substrate sizes, R2R processing enables the high-speed, continuous processing of a long flexible web, producing tens of thousands of small FPCs in one long continuous production web. R2R can accommodate single- and double-sided flex circuits, as well as the processing of the inner layers of a multilayer flex circuit.

R2R is cost-effective because it eliminates the high potential handling-damage risk of working with super-fine sheet substrates in manual or with automatic flex sheet handling mode, resulting in higher quality and higher yields. It's estimated that 20 to 30% of flex circuits are produced with R2R processing today, and the majority are flex circuits targeted for smartphones. Manufacturers that work with advanced designs see the great benefits of moving to R2R direct imaging (DI) for two main reasons. Firstly, the move from traditional exposure R2R to DI R2R is estimated to improve yield by 10 to 15%, thus making DI R2R an enabling process and critical to high-volume, high-yield manufacturing. Secondly, the yield improvement gained from moving from sheet-by-sheet manufacturing to R2R manufacturing is expected to be between 2 and 4 percent.

Advancements in roll-to-roll

The R2R manufacturing market is quickly advancing, with new capabilities for direct imaging, UV laser drilling, and automated optical inspection (AOI). These advances dramatically boost yields and make it more affordable for manufacturers to invest in the R2R manufacturing process:

- **Direct imaging**—DI helps decrease overall cost of ownership while maintaining quality at high speeds. It provides greater flexibility on a wide range of flex materials and applications. Direct imaging, a staple in sheet-to-sheet flex PCB manufacturing, is now available for R2R processing and offers high depth-of-focus (DoF), enabling better defect detection. In addition, DI enables the ability to image and register, compensating for flex distortions.
- **Flex laser drilling**—Advanced UV laser drilling systems can be employed to drill small vias through a wide range of materials of varying thinness and strength, including polyimide, LCP, coppers, and others, with limited or no residue or damage to the bottom of the via, no undercut, and with advanced registration accuracy.
- **Flex AOI**—With the transparency of polyimide-based material comes significant inspection challenges. New AOI tools have been developed with triple-vision imaging capabilities, enabling the FPC to be scanned to ensure improved detection with fewer false overcalls from the bottom pattern layers. Until now, AOI has typically involved manually handling panel sheets during the inspection and verification stages. The manual method often results in handling damage for the delicate and thin FPC sheets, creating a substantial increase in scrap. Recently developed advanced AOI technologies enable remote classification, which eliminates the need to review the entire roll online or move up and down the roll to find specific panels. This not only saves a great deal of time as the verification process occurs simultaneously but also ensures higher throughput and yield as it does away with further manual handling with all its implications.

The various attributes of R2R help manufacturers increase their precision and quality, while improving their production throughput and yield and ultimately improving profits. Both direct imaging and UV laser drilling, when used with R2R manufacturing equipment, reduce the handling and risk of damaging the delicate flex PCBs.

Other recent advancements in R2R include increasing the width of the flex materials it can process by up to 520 mm, a welcome development for manufacturers and designers that opens up a number of design improvements. So while direct imaging with R2R is very fast, with a 260-mm roll printing at 20 mm/s X 260 mm, the output is approximately 19 m^2 per hour. That output doubles with the wider 520 mm roll—in the same timeframe.

And one of the more exciting developments in R2R manufacturing is the ability to change rolls more quickly on the manufacturing floor, streamlining the changeover and increasing overall production.

Conclusion

Flexible printed circuits are invaluable for a wide range of applications, but producing these ultrathin, flexible, and fragile interconnects comes with many challenges. Extra care must be taken throughout the production process to ensure that the technology benefits that these circuits enable aren't compromised by low yield rates and manufacturing inefficiencies that ultimately drive up the cost of end devices.

Leveraging highly efficient R2R processing with advanced AOI, direct imaging, and UV laser drilling capabilities is providing designers with many more options for creating cutting-edge electronics in the smallest form factors, and even in shapes yet to be imagined. EE

Meny Gantz is the VP of marketing in Orbotech's Printed Circuit Board (PCB) division, where he is responsible for guiding the division's overall marketing and go-to-market product strategies and product roadmaps. Meny joined Orbotech in 2000 and has served in a number of product management and marketing positions within the PCB division, both at the company's HQ in Israel and in Asia Pacific. Meny is a graduate of MIT's Artificial Intelligence: Implications for Business Strategy executive program and has an executive MBA from Tel Aviv University.

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MEETING 5G CHALLENGES FROM CODE GENERATION TO SPECTRUM CONGESTION

By **Rick Nelson,** Interim Chief Editor

5G research spans the gamut from algorithm development to carrier-acceptance test, as explained in a special report in our December issue.[1] In that article, industry experts including Ken Karnofsky, senior strategist, MathWorks, commented on trends in 5G technology and the challenges 5G presents. In a follow-up phone conversation, Karnofsky elaborated on topics including automatic code generation, helping engineering teams obtain the necessary skills and tools to meet 5G challenges, math-based visualization of propagation characteristics, scatterers in multipath environments, and issues related to spectrum congestion and coexistence.

Rick Nelson: **In our December special report on 5G, you commented, "Currently, the entire signal chain, from RF to baseband, can be implemented in a single programmable device or module. However, most engineering teams do not have incumbent engineers with the expertise to design and integrate these devices into a complete system." Are these devices FPGAs?**

Ken Karnofsky: It depends on whether the design is for a base station or mobile phone. Ultimately in many cases, once devices get into full production, they will become ASICs. In the early stage of base-station design there is a significant FPGA component. For handsets and mobile devices FPGAs can be used in emulators or prototyping systems, but of course the ultimate final product is going to be an ASIC in that case.

RN: **So, you can develop an algorithm in MATLAB and translate that to one of the FPGA design tools?**

KK: Yes, that is certainly one aspect of what we offer. The system architect will be working with a floating-point algorithm where they are not really concerned about the constraints of the physical device, but they want to understand the behavior and they might also simulate algorithms in the context of an end-to-end signal chain that could include RF impairments or aspects of the antenna characteristics, which are becoming more important with MIMO systems in 5G. Then often a couple of things can happen. For developing prototype systems there's definitely growing interest in automatically creating those prototype systems from the models, which would involve converting the abstract floating-point model to something that represents the fixed-point hardware. Some of the architecture could be implemented in hardware, and the last stage is generating the code for the implementation.

As the state-of-the-art for more production-system ASICs or FPGAs, we are seeing that automatic code generation is being adopted by some companies—it's more of a leading-edge type of process for particular IP blocks or algorithms within the system. But by and large the overall system is often hand-coded in VHDL or Verilog. I am not aware of anyone who is automating the implementation of an entire baseband modem—that's a tall order and is somewhere in our future—but for specific algorithms, we are definitely seeing more automatic code generation.

RN: **What are the advantages of hand coding?**

KK: There are established workflows, such as verification workflows, and existing tools and skill sets. Adopting a different methodology is something of a challenge and is not done lightly, even when there are compelling advantages for doing so. But also, there are aspects of the chip design that really have to do more with memory management and other types of components that to date have not really been a MathWorks focus. We are starting to introduce capabilities for modeling those parts of the systems, but automating the implementation is still in the future.

RN: **You have mentioned that engineering teams may lack needed expertise for 5G. How does MathWorks help with this—with training or by building more capabilities into the tools?**

KK: Some of both. One aspect we are seeing as 5G comes online is that there is a real need and demand for educating the engineering workforce, which may be familiar with LTE or other aspects of communication, but which is new to 5G. And some aspects of 5G in terms of the flexibility of the standard add a lot of complexity. And there are some new concepts that are of strong interest every time we engage with the customer. We've produced a short video series that we call "5G Explained"—it's a series of about 10 videos on various aspects of the 5G physical layer. And when we look at where people go on our website for information on wireless topics, the series has climbed into the top five pages—so there is clearly an interest in that topic, and we see it when we present that material at specific customer sites. Usually, we get a full room of people who are interested in 5G as well.

So that is one aspect. The other aspect is more about system modeling where the baseband meets the RF and antenna system. So that would involve beamforming architectures, using more digital algorithms like digital predistortion to compensate for impairments or nonlinearities in the power amplifiers, and the large bandwidths that are necessary to get the 5G data rates. These factors are really causing a rethinking and rearchitecting

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compared with the way things were done in LTE or previous types of systems. So, to design those algorithms, it's preferable to have a model of the other components so that you can evaluate the architectural tradeoffs. For example, in the beamforming space people are looking at all-digital architectures vs. hybrid digital and analog architectures, and there are both efficiency and cost reasons to take different approaches. Fully doing that type of cross-domain tradeoff isn't necessarily something which engineers have been trained on traditionally. The traditional tools available to them may be more circuit-oriented and tend to focus either on RF antenna propagation or DSP algorithms. How do you bring all those together? So that is one question we are answering, and one area we are certainly investing in is providing a modeling environment where you can put pieces together and get some insights earlier before you start building prototype hardware.

RN: **Is there a hardware-in-the-loop aspect to this, and if so, could you provide an example?**

KK: There is, to some extent. One example is a demonstration we put together in collaboration with National Instruments, where we have a model showing DPD together with a model of the power amplifier. The intent is not that we are delivering DPD IP. That is a very specialized task, and our customers want to create their own that's specific to their product. Our intent was to show a modeling approach, and in the demonstration, we took the DPD algorithm and instead of a model of the power amplifier we put the algorithm in the loop with some NI PXI test equipment and an actual hardware power amplifier. We pumped the test vectors through the test equipment, it drove the power amplifier, and we got the results back into MATLAB, where we could update the coefficients, etc. That's one HIL example. It provides the capability to validate the implementation vs. what was predicted in the model.

RN: **One expert quoted in my December report on 5G said there are two types of challenges with 5G: ones that have existed for previous cellular generations and ones that are completely new to 5G. Would you agree with that?**

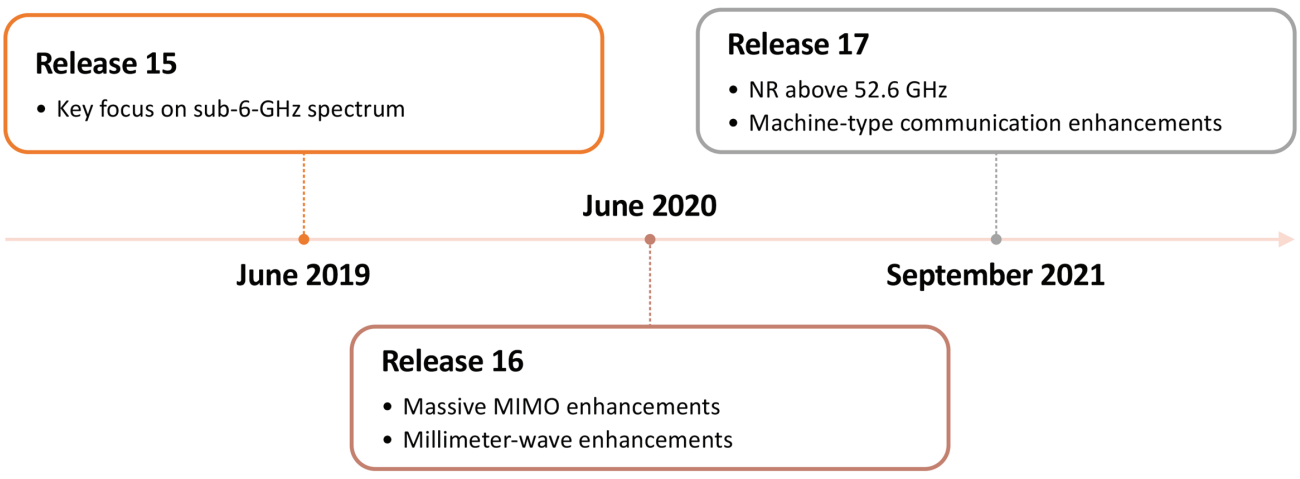
KK: Yes, certainly. There are several technical drivers for that. One, I already mentioned the large bandwidths that actually introduce challenges in terms of making the RF technology operate in a linear fashion. The second one is massive MIMO. It's not happening right now in the early stages of 5G because Release 15 is primarily below 6 GHz. *[Editor's note: see the nearby 3GPP 5G Release Timeline.]* As you get into millimeter wave, the massive MIMO architectures are something that really hasn't been seen before.

The third one is in the digital baseband physical layer. The frame structure of 5G is extremely flexible by intent, so you can reuse the same structure to achieve high throughput, high-capacity systems, or you can dial it down so you have low latency and lower data rates for IoT and those types of applications. So, they are anticipating all these different use cases that have different requirements, and the result was a very flexible but complex frame structure that's driving up the number of scenarios or test cases that you need to evaluate. That definitely is a challenge both in terms of understanding but also in terms of the amount of time it takes actually code and validate the design and test it.

RN: **Once 5G networks have been deployed, is there an ongoing role for MathWorks to play in evaluations of quality of experience or coverage?**

KK: Yes, I would say so. An early indication of that is that we have recently introduced capabilities for visualizing and analyzing coverage using math-based visualization of propagation characteristics. So, you're

3GPP 5G Release Timeline



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looking at coverage analysis, the strength of a link, and that type of thing. And then in millimeter wave, the types of channels use different technologies than are being used at lower frequencies.

It is not quality of experience *per se*, but channel modeling is an area that's really critical, and we see that the base-station providers and the carriers are equally interested in that and are trying to understand those propagation characteristics. What happens when you are in an urban area and your signal is bouncing off buildings or being absorbed by materials in ways you didn't have to worry about with lower frequencies? In LTE also there is an interest in that kind of scenario planning—where do I put my base stations, how does that affect coverage, what is the impact of terrain and buildings and those types of effects? So, we have introduced some capabilities in terms of the visualization and analysis, and I think we are certainly seeing an interest from customers that is motivating us to keep investing in that.

technology, or communication between vehicles, you want to be able to track mobility. If you were designing such a system you would want to know where the vehicles are, how fast they are going, what other sensor modes they are using to detect the presence of other vehicles or obstacles, and then how they are communicating with each other. And we see some interesting university research in this area. One university is doing this type of analysis from the perspective of fuel consumption. You can use vehicular communication networks to detect traffic patterns so you can brake more efficiently or accelerate more efficiently and basically optimize fuel consumption that way. I think it will have an impact on those designs just as vehicular communications is certainly a market for wireless technologies. It works both ways.

You also mentioned Industrial IoT. One customer just gave a talk at one of our MATLAB EXPO conferences that was about replacing Ethernet in factories with the new 802.11ax, sometimes called Wi-Fi 6. They are looking to see whether they can get low enough latency in a Wi-Fi system so that you can actually do industrial control using wireless technology as opposed to cables.

"What happens when you are in an urban area and your signal is bouncing off buildings or being absorbed by materials in ways you didn't have to worry about with lower frequencies?"

RN: **In our December issue, in addition to the 5G report, we had an interview with one of your colleagues, Philipp Wallner, industry manager for industrial automation and machinery at MathWorks, who discussed the Industrial IoT.[2] He described a New Zealand energy company that continually (every 30 minutes or so) uses Simulink models to optimize the grid load and make sure the grid will continue to operate (for the next 30 minutes). It seems there should be something analogous for a 5G network.**

KK: Exactly. Can you design a network that will actually support this traffic? There is an interesting emerging interaction between the world of automated driving and autonomous vehicles and the next generation of wireless infrastructure. If you think about the extent to which the industry adopts the 5G version of V2X

And they've done enough research to see that it is a promising proof of concept, and his talk was about how they are using MathWorks tools to do the modeling of the modifications they would need to make the standard able to achieve the required latency, and they are prototyping the proposed system on some programmable SDR type of hardware. It's not 5G, but 802.11ax is the Wi-Fi equivalent of 5G with many of the same issues relating to new antenna technologies influencing the design of the baseband and tradeoffs between throughput and latency. There are many of the same considerations—just in a Wi-Fi world, not a cellular world.

RN: **One industry expert said 5G is moving from the relative friendly trial phase to the much less friendly environments of commercial deployments. Would you agree with that?**

KK: Absolutely. I would say yes because there are large investment decisions and considerations regarding consumer acceptance and qualifications. The degree of testing that's required to achieve the quality of experience that the consumer wants is quite different from the testing you would do in a lab to determine whether one device can talk to another one successfully.

RN: **You have commented on the simulation of scatterers in multipath environments. Do you use real-world data for this?**

KK: We can bring in external sources where you can put terrain on the map so you have real data about elevation of mountains and other terrain aspects, and we recently introduced the ability to take open street-map data to put buildings on the map as well. We don't yet have the building properties, so you can't tell yet whether it's a glass building or a brick building, but you can tell that the building is there and how tall it is. Also, we introduced some ray-tracing technology—which is incorporated in channel models that are used to determine how something will reflect off a building surface and how that affects the reception. It answers the question, can you get a signal from point A to point B successfully in that type of environment?

RN: **What next, 6G?**

KK: Certainly, we try to stay in touch with the academics who are doing that type of work. And at the 2019 Brooklyn 5G Summit, the keynote discussed 6G.[3] So there is certainly research on 6G. But in the near term, there is still the 3GPP's Release 16, which is still 5G. What's more immediate in terms of what's next are the other use cases that were envisioned for 5G. So, we have mobile broadband that is starting to be deployed, but the low

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latency and massive IoT device use cases are really coming in Release 16, as is also more on the implementation of the millimeter-wave technologies. I think there are still a lot of decisions regarding Release 16, but it is wrapping up, so I think the main issues are pretty well understood. And there will be one more 5G release before the move into 6G.

One question involves practical considerations for the consumer of the technology who is thinking about an industrial setting or a sports arena or something like that. The question is whether to use 5G or the newer versions of Wi-Fi technology, which have some of the same goals as 5G. There both technical and business decisions that the consumers will have to make. There is discussion of private 5G networks on unlicensed bands, so do you go with a private 5G network or do you set up a next-generation Wi-Fi network? There is an emerging trend where evaluation of those alternatives is going to be an important consideration for the consumers of the technologies—each technology will end up finding its place, but it's not completely clear yet which one will win in which scenarios.

RN: **Other thoughts?**

KK: We talked about scatterer-rich environments, but there is also just spectrum congestion. There are situations where there are incumbents and new technologies in the available spectrum, so we are hearing a lot from our customers about coexistence and interference mitigation as other engineering challenges. If you are transmitting and receiving one particular type of signal, how do you make sure that is done in a robust way given that there are lots of other signals in the same frequency bands that you have to deal with?

RN: **Dynamic spectrum sharing (DSS) is one approach for getting 5G and LTE to coexist.**

KK: That's right. And we are seeing similar situations elsewhere. A couple of years ago there was the introduction of the Citizens Band Radio Service.[4] The FCC made available some spectrum that used to be and still is being used by Naval radars but is now available for LTE. So, if you happen to be in a port city where there are Navy ships and an LTE network that you want to use that spectrum for, some interesting spectrum-management problems arise. And that won't be the last example, I am sure. EE

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2. Nelson, Rick, "Models and simulation support digital twins and industrial IoT," *EE-Evaluation Engineering*, December 2019, p. 16.
3. "5G shares the stage with 6G at the sixth annual Brooklyn 5G Summit," NYU Tandon School of Engineering, Polytechnic Institute, May 7, 2019.
4. "Citizens Band Radio Service (CBRS)," FCC, April 13, 2017.

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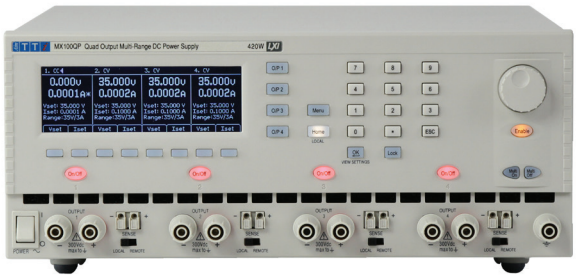
TECH FOCUS

POWER SOURCES



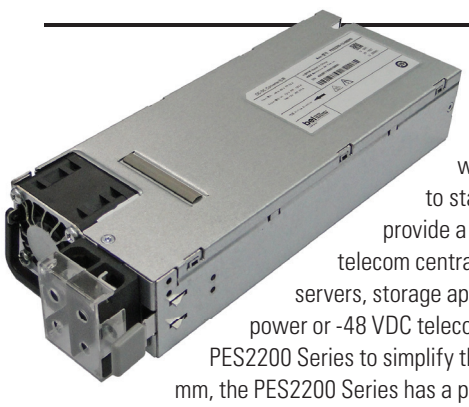
In the test of products ranging from communications ICs to automotive drivetrain and battery systems, power sources—from benchtop units to floorstanding cabinets—are critical tools. The global power supply market, valued at $24.31 billion in 2017, is expected to swell to $39.46 billion by 2025, according to a December 2019 report by Verified Market Research.

4U, 30-kW rack-mount programmable DC load

Elektro-Automatik has announced the EA-ELR 10000 30-kW programmable electronic load, which incorporates SiC power conversion devices. It combines its high-efficiency programmable DC load with an equally efficient inverter (regenerative) output stage, returning up to 95% of the energy used in the test back to the AC grid. A master-slave bus provides for parallel connection of multiple units to a maximum input power rating of 1,080 kW. The ELR 10000 provides a range of programmable functions to simulate complex testing such as electric vehicle traction motors, battery discharge testing, PV simulation per EN 50530, and MPP tracking. An FPGA-based function generator with a value table of up to 3,276 points enables creation and operation of load profiles that include sine wave, square wave, sawtooth, and ramp functions. The supply features DC simulated load input voltage ratings of 60 V to 2,000 V and current ratings from 40 A to 1,000 A. DC inputs and AC power (342 to 528 V, 3-phase, 50/60 Hz) are galvanically isolated, as are the built-in USB, Ethernet and analog control interfaces. **Elektro Automatik**

Compact 4-channel 210-W power supplies

Saelig Company Inc.'s AIM-TTi MX100Q Series power supplies are versatile 4-output laboratory power sources that use mixed-mode regulation to provide up to 210 W of power, shared by up to four outputs, in one compact case. Mixed-mode regulation combines switch-mode architecture with linear final stage regulation to give performance characteristics resembling a totally linear design but at reduced weight. Each output can provide 0 to 35 V at 0 to 3 A, with output combination abilities that extend output voltages up to 70 V and currents up to 6 A. The MX100Q Series provides fine precision output adjustment with a resolution of 1 mV and 0.1 mA. All relevant information is displayed on a large backlit graphic LCD, with control via soft keys, a numeric keypad, and a spin wheel. More than 50 output combinations are available. Features include 50 memorized settings for each output plus 50 further settings for all four outputs together. Multi-on and multi-off keys supplement the individual output on/off keys. **Saelig Company**



2,200-W power supply

Bel Power Solutions has announced the PES2200 Series 2,200-W high-density power supplies with full digital control. Variants for AC- and DC-input enable server, storage, and telecom OEMs to standardize on a power-entry module across their product range. PES2200 Series power supplies provide a main output of 12 VDC for powering intermediate bus architectures (IBA) in datacenter and telecom central office equipment. The convergence of IT and telecom infrastructures means that computing servers, storage appliances, routers, and networking switches may be installed in data centers with AC input power or -48 VDC telecom environments. Manufacturers of computing, network, and storage equipment can use the PES2200 Series to simplify the integration and servicing of their servers and appliances. Measuring 80 mm x 40 mm x 195 mm, the PES2200 Series has a power density of 59 W/in.^{3} and provides a 12-V output plus an always-on 12-V standby output at 3.5 A. Digital control, programming, and monitoring using the Power Management Bus protocol improves the ability of OEMs to control the power supply while increasing reliability and efficiency over a wide operating range.

Bel Power Solutions

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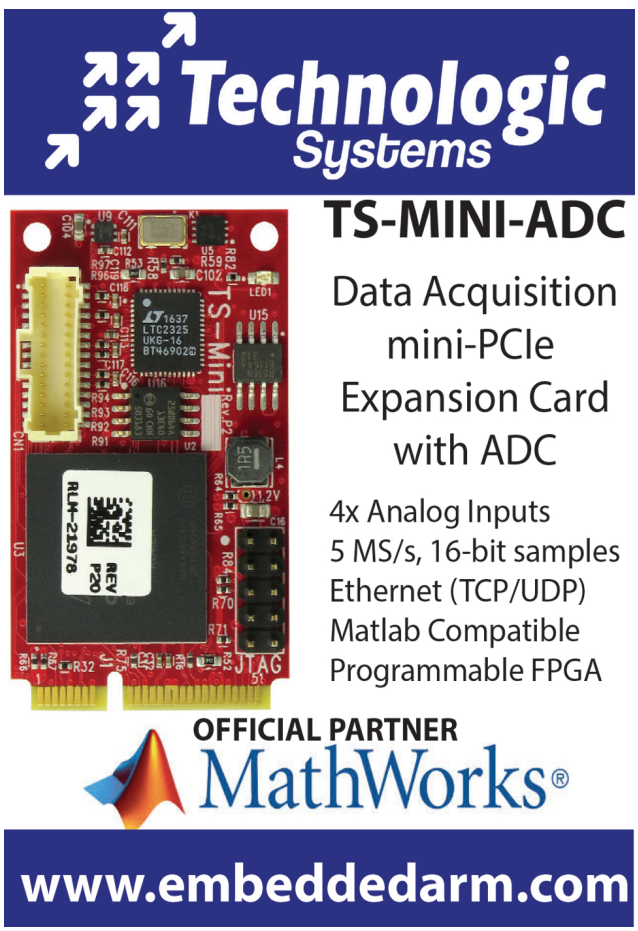
NGM200 power-supply series

Being part of the same power supply family, the R&S NGL200 and the new R&S NGM200 Series offer the same performance and specifications to supply stable outputs with a minimum of residual ripple and noise. Devices that switch from a few microamps in sleep mode to several amps in active mode benefit from the fast load recovery time of less than 30 µs. The 2-quadrant architecture provides both source and sink functions, to simulate the charging and discharging of batteries as well as to operate as an electronic load. In addition, the R&S NGM200 Series includes four new features: the FastLog function that captures spikes even in the µs range, additional measurement ranges that increase the read-back accuracy in the lower ranges, a battery-simulation option that supports the modelling of batteries to simulate real life conditions, and a built-in digital voltmeter that measures voltage values at any point in circuits of the device under test.

Rohde & Schwarz

3-phase 4,080W 24-V industrial power supply

The TDK-Lambda brand TPS4000-24 power supply extends the existing 3,000-W rated TPS series. Delivering up to 4,080-W output power (24 V at 170 A) in a 2U-high package, the TPS Series operates from a delta or wye 350- to 528-VAC 3-phase input. This industrial power supply is suitable for use in many applications including test and measurement equipment, semiconductor fabrication, additive manufacturing, printers, lasers, and RF power amplifiers. The high voltage, 3-phase input avoids the requirement for costly step-down transformers and assists phase load current balancing. The TPS4000-24 features isolated AC fail, DC good, and dropped phase signals, remote on/off, remote sense, and a 12-V 0.3-A standby supply. TDK Corp.



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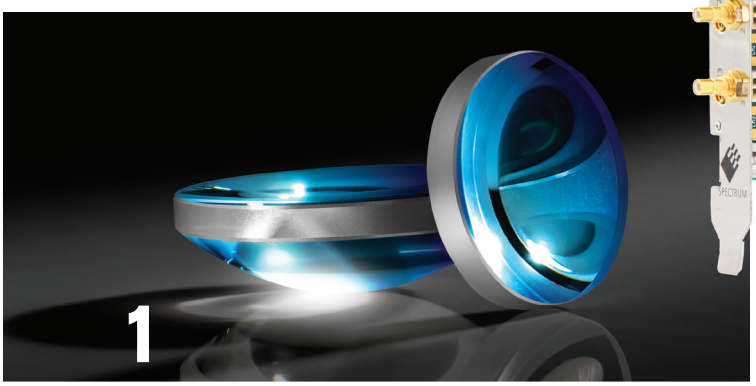

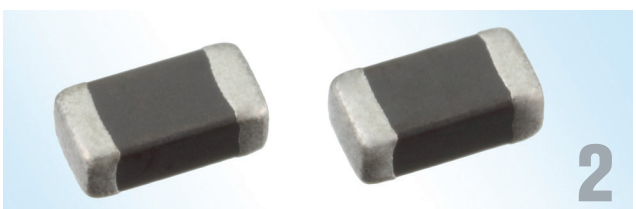

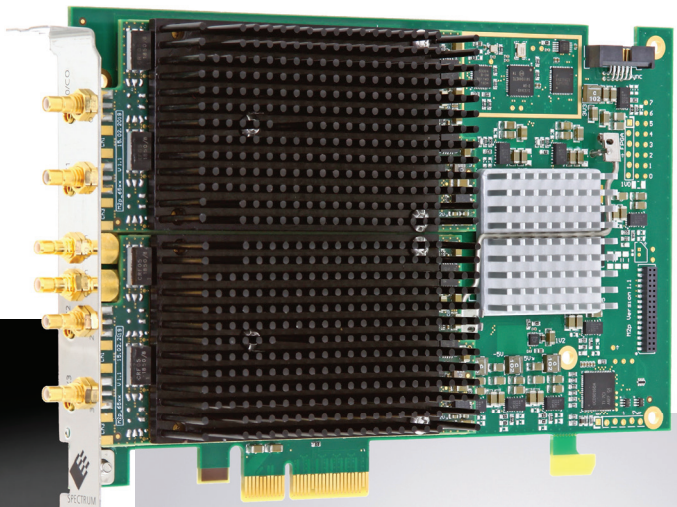

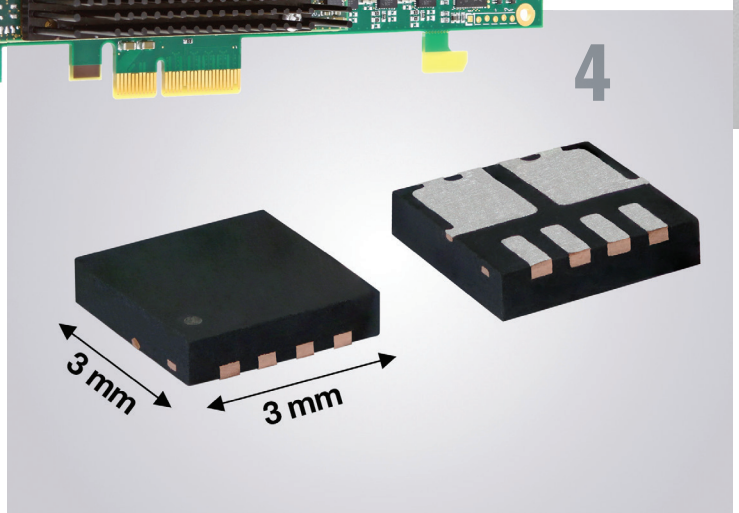

1. NIR and line-scan lenses

Two additions to the vendor's product offerings include new near-infrared (NIR) precision aspheric lenses (pictured) and TECHSPEC LS Series line-scan lenses. The NIR precision aspheric lenses are designed and optimized to eliminate spherical aberration. They are polished through a computer-numerical-controlled (CNC) process for high performance across the NIR spectrum. NIR precision aspheric lenses are also available with low numerical aperture designs to maintain beam shape or with high numerical aperture designs for applications that require light-gathering. The new TECHSPEC LS Series line-scan lenses are suitable for applications such as electronics and semiconductor wafer inspection.

Edmund Optics

2. EMC filters

Two new MAF1608GAD-L noise-suppression filters, designed for audio lines, have a footprint of 1.6 x 0.8 mm and an insertion height of 0.6 mm. They offer rated currents of 3.2 and 2.3 A, respectively, and low DC resistances of typically just 0.021 and 0.045 Ω. Their impedance at 900 MHz is 120 and 200 Ω, respectively. Their low DC resistance and rated current of more than 2 A make them suitable for smart speakers and external speakers for tablets that require power levels of 2 W or higher as well as for headphones and microphones.

TDK Corp.

3. AWGs

Six new arbitrary waveform generators (AWGs) have joined the M2p.65xx Series PCIe cards. The new AWGs boost the available output range to generate waveforms with amplitude swings up to ±12 V into 1 MΩ or ±6 V into 50 Ω. To achieve the higher output voltage ranges, the cards have been fitted with additional amplification and larger cooling plates. This makes the cards wider, so that they occupy two PCIe slots, but they are still just 168 mm in length and can fit into almost any PC, turning it into a flexible waveform generator.

Spectrum Instrumentation

4. Dual n-channel 60-V MOSFET

A new common-drain dual n-channel 60-V MOSFET in the compact, thermally enhanced PowerPAK 1212-8SCD package can increase power density and efficiency in battery-management systems, plug-in and wireless chargers, DC/DC converters, and power supplies. The SiSF20DN offers $R_{S\text{-}S(ON)}$ down to 10 mΩ typical at 10 V in a 3-mm by 3-mm footprint. The vendor reports this value is 89% lower than for its previous-generation devices. The result is reduced voltage drop across the power path and minimized power loss. The device uses an optimized package construction with two monolithically integrated TrenchFET Gen IV n-channel MOSFETs in a common-drain configuration.

Vishay Intertechnology Inc.

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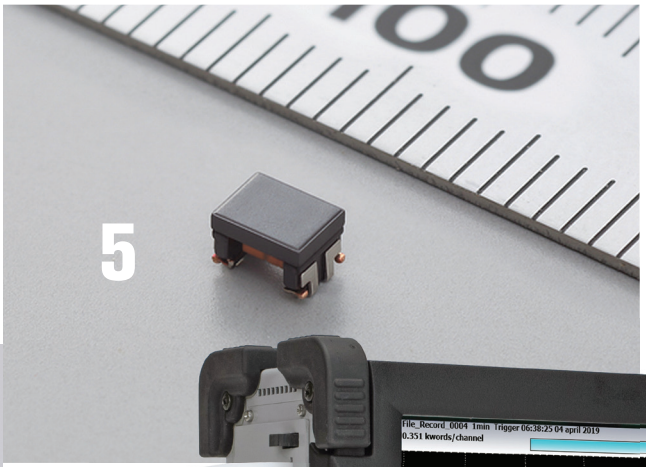

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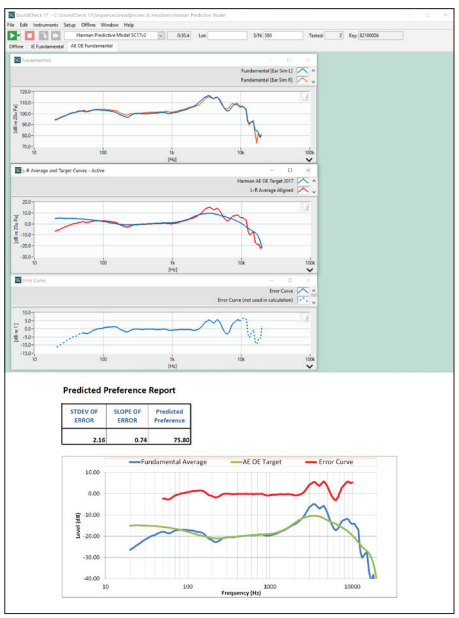

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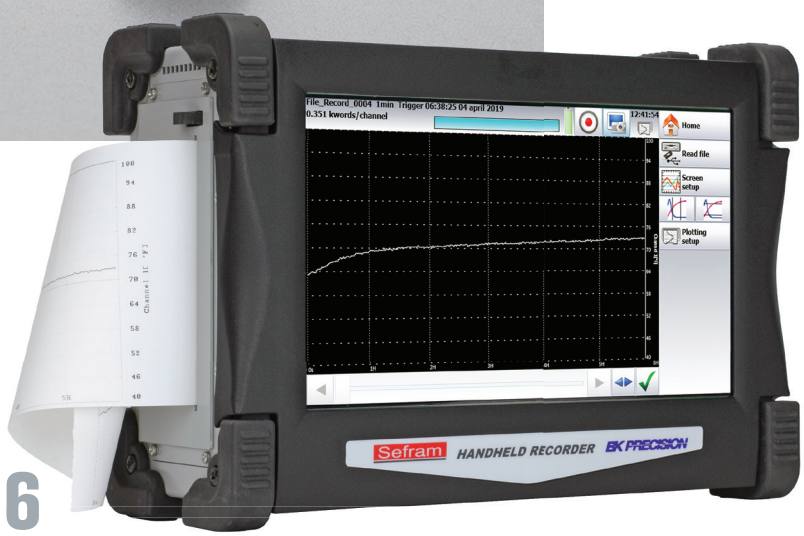

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5. Choke for Automotive Ethernet

The DLW32MH201YK2 common-mode choke coil (CMCC) for Automotive Ethernet (100BASE-T1) withstands temperatures ranging from -55 to +150°C, which compares favorably to the -40 to +125°C temperature range of conventional products, the vendor said. This improved performance has been achieved by employing metal termination that absorbs the stresses associated with temperature change as well as by optimizing the combination of the vendor's original materials and product design. Features include a 3.2-mm x 2.5-mm size, compliance to AEC-Q200 (a specification defined by the Automotive Electronics Council), and a rated voltage of 80 V.

Murata Manufacturing Co. Ltd.

6. Multifunction recorders

The DAS30/50/60 data recorders feature a sampling interval of 1 µs (1 MS/s), an input range of ±5 mV to ±500 V, and internal solid-state memory to 64 GB. With a CAT III isolation rating, these instruments are suited for a range of applications from sensor signal logging to electrical power analysis. A built-in power-analysis application measures and records voltage and current on both single and 3-phase networks. The results are displayed as a harmonics graph, Fresnal diagram, and oscilloscope waveform. An integrated thermal printer is optional for all three models.

B&K Precision

7. Expandable vision controller

Powered by an eighth-generation Intel Core processor, the 4Sight XV6 expandable vision controller is designed specifically to handle intensive vision applications on the factory floor, including warehouses, plants, and manufacturing or fabrication facilities. The latest addition to the 4Sight Series, the XV6 provides a reliable platform with expansion capabilities for video acquisition. The 4Sight XV6 can support intensive machine vision applications. 4Sight XV6 vision controllers offer desktop-level processing performance, with support for up to three displays, including VGA, DVI-D, HDMI, and DisplayPort. The 4Sight XV6 comes preinstalled with Microsoft Windows 10 IoT Enterprise 2019 (64-bit).

Matrox Imaging

8. Audio test sequence

A new SoundCheck test sequence predicts listener headphone preference based on statistical models developed by Sean Olive, Todd Welti, and Omid Khonsaripour of Harman International. The sequence measures a headphone in SoundCheck and saves the results to an Excel template. Within Excel, a predicted preference score on a scale of 0 to 100 is calculated based on the Harman Target Response Curve. The calculation involves subtracting the target curve from an average of the headphone left/right response to obtain an error curve and analyzing this curve to calculate the score.

Listen Inc.

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R&S RTP SCOPES AND MARVELL 88Q6113 MULTIPORT MULTIGIGABIT SWITCH MEET WIDEBAND TEST REQUIREMENTS

by EE Staff

Rohde & Schwarz and Marvell announced that they have successfully demonstrated compliance tests and debugging for high-speed digital interfaces on the 88Q6113 multigigabit automotive switch platform. Developments in advanced driver-assistance systems are creating a new approach to in-vehicle network architecture design, the companies said, adding that with today´s vehicles leveraging at least a hundred ECUs, the current network architecture has reached its limits. The automotive industry is now focusing on a domain or zonal controller architecture to simplify network design and maximize performance. A domain controller can potentially replace the functions of many ECUs providing capabilities for high-speed communications, sensor fusion, and decision-making, as well as providing support for high-speed interfaces for cameras, radar, and lidar.

The Marvell 88Q6113 is suitable for implementing a domain/zonal controller network architecture and is fully compliant with the IEEE 802.3 automotive standard, delivering high bandwidth with advanced routing and security. The 88Q6113 is an 11-port Ethernet switch that supports RGMII/MII/RMII, SGMII, XFI multi-speed SerDes (1/2.5/5/10 Gb/s), and PCIe Gen 3.0, making it suitable for integrating the full range of sensors required for advanced driver-assistance systems and autonomous driving.

Signal integrity is a key factor for ensuring error-free data communication with all these high-speed digital interfaces, the companies said. In particular, the introduction of PCIe Gen 3.0 into the automotive industry will bring new challenges to engineers not yet familiar with the technology.

▲ Rohde & Schwarz RTP oscilloscope

Rohde & Schwarz and Marvell reported that they were the first companies to execute successfully 1000BASE-T1 compliance tests, for the Marvell´s 88Q2112 Ethernet transceiver, using an R&S RTO oscilloscope. The latest improvements to the R&S RTP oscilloscope family include the 16-GHz acquisition bandwidth required to perform signal-integrity tests and debugging for SerDes, LVDS, PCIe Gen 3.0, MIPI, and more, as well as automotive Ethernet interfaces all present in Marvell´s 88Q6113 multigigabit automotive switch platform. The R&S RTP includes real-time de-embedding for signal-integrity analysis and has the highest acquisition rate on the market. In addition, the R&S RTP offers bus-measurement features supporting the high-precision latency measurements essential for debugging switches and networks, making this oscilloscope suitable for automotive network test.

Dr. Nik Dimitrakopoulos, automotive market segment manager at Rohde & Schwarz, commented, "With the introduction of domain and zone controllers in automotive networks, engineers will be faced with new challenges by the integration of fast serial interfaces like PCIe. Rohde & Schwarz is closely following the trends and test requirements in this industry. The addition to our portfolio of 16-GHz bandwidth for R&S RTP digital oscilloscopes can assist the automotive industry to overcome these challenges and fits perfectly in this market. We are very proud to assist Marvell in providing quality assurance for their products to their customers."

Tim Lau, senior director of product marketing, Automotive Business Unit at Marvell Semiconductor, added, "The Marvell 88Q6113 extends our multigigabit leadership, with interfaces delivering high bandwidth to connected controllers and sensors. We are proud to partner with Rohde & Schwarz to complete compliance testing and deliver reliable, high-quality solutions in this unique, emerging market." EE

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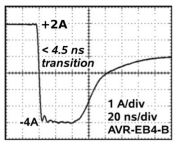

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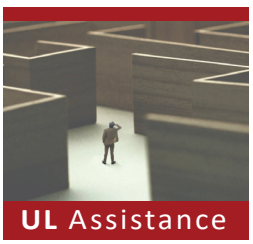

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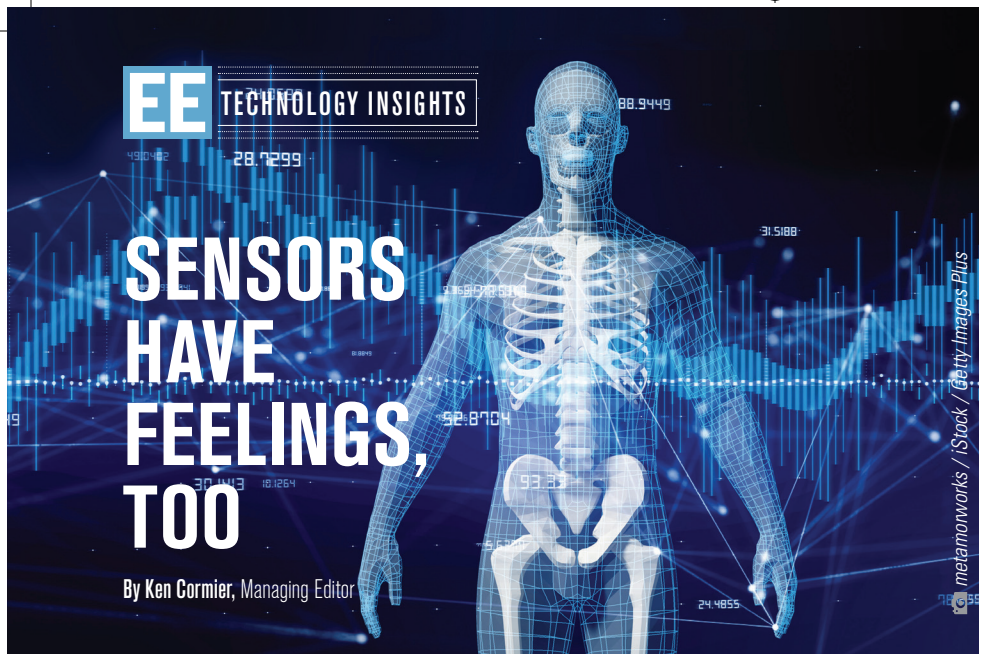

Sensors are allowing electromechanical devices to analyze and interact with environmental conditions, as they detect, touch, smell, and taste with quantifiable results. Here are some recent news items within the industry:

Sensor is gout watchdog

Researchers at the California Institute of Technology, led by Wei Gao, assistant professor of medical engineering, have created a highly sensitive wearable human sweat sensor that they say is able to detect low concentrations of metabolites and nutrients that herald a possible oncoming gout attack. Gout results from high levels of uric acid crystallizing in human joints, which causes inflammation and pain.

The sensor was engineered to measure respiratory rate, heart rate, and levels of uric acid and tyrosine in test subjects. Data accuracy was confirmed through blood tests.

The mass-producible, graphene-based sensors could be useful in closely monitoring cardiovascular disease, diabetes, or kidney disease, according to Gao.

"Such wearable sweat sensors have the potential to rapidly, continuously, and noninvasively capture changes in health at molecular levels," Gao says. "They could enable personalized monitoring, early diagnosis, and timely intervention."[1]

Robot sensor market expected to double by 2025

The robot sensor market, valued at $1.98 billion in 2018, is predicted to reach $4.16 billion by 2025, according to a report by Brandessence Market Research. The market's CAGR is expected to be 10.8% during the intervening time period. There are an estimated 1.8 million industrial robots in production globally, making up a market near $35 billion.[2]

Flexible graphene photodetectors for wearable fitness monitoring

New flexible and transparent wearables combine graphene and semiconducting quantum dots that are able to noninvasively scan health vitals, such as heart rate, arterial oxygen saturation, and respiratory rate, using heterogeneous integration of a flexible UV photodetector with a near-field communication, according to an article in *Science Advances*. The optical vital sign monitoring is done with conformable sensors which are transparent and flexible. Benefits include broadband wavelength sensitivity (300 to 2,000 nm) and high responsivity resulting from a built-in photoconductive gain, which "allows a design freedom that the nontransparent and bulky readout electronics can be placed away from the sensor, and therefore, transparency and form factor of the active sensing area can be preserved," according to the article.[3]

2020 Sensors Expo & Conference

If you want an up-close look at the latest innovations in sensors, mark the Sensors Expo & Conference on your 2020 calendar. The event, in its 35th year, will take place June 22-24 at the McEnery Convention Center in San Jose, CA. There are 350 sensor industry leaders planning to exhibit on the expo floor, and a comprehensive conference program will cover today's applications and future trends. Go to www.sensorsexpo.com for more information.

MEMS system market to expand to $122.83 billion by 2026

According to an October 2019 report by Allied Market Research, the global microelectromechanical system market size, valued at $48.74 billion in 2018, is predicted to reach $122.83 billion by 2026, with a CAGR of 11.30% during the intervening time period. The report further states, "Impending need of device miniaturization in various electronic devices such as smartphones, wearable devices, medical instruments, and other electronic devices fuel the growth of the MEMS market. The demand for these devices is on a continuous rise with the decline in average selling prices (ASPs) and increase in benefits of MEMS devices, such as low cost, less space consumption, and high accuracy."[4]

3D-printed biosensors

Researchers at Georgia Tech have created highly flexible biocompatible battery-free wireless sensors using "aerosol jet" 3D printing, which uses a mist of droplets that is blown onto a substrate through a small nozzle. Two layers of ink are deposited: one that dries to a polyimide insulator, and one of silver nanoparticles. "The beauty of our sensor is that it can be seamlessly integrated onto existing medical stents or flow diverters that clinicians are already using to treat aneurysms," said Georgia Tech researcher Woon-Hong Yeo. "We could use it to measure an incoming blood flow to the aneurysm sac to determine how well the aneurysm is healing, and to alert doctors if blood flow changes."[5] EE

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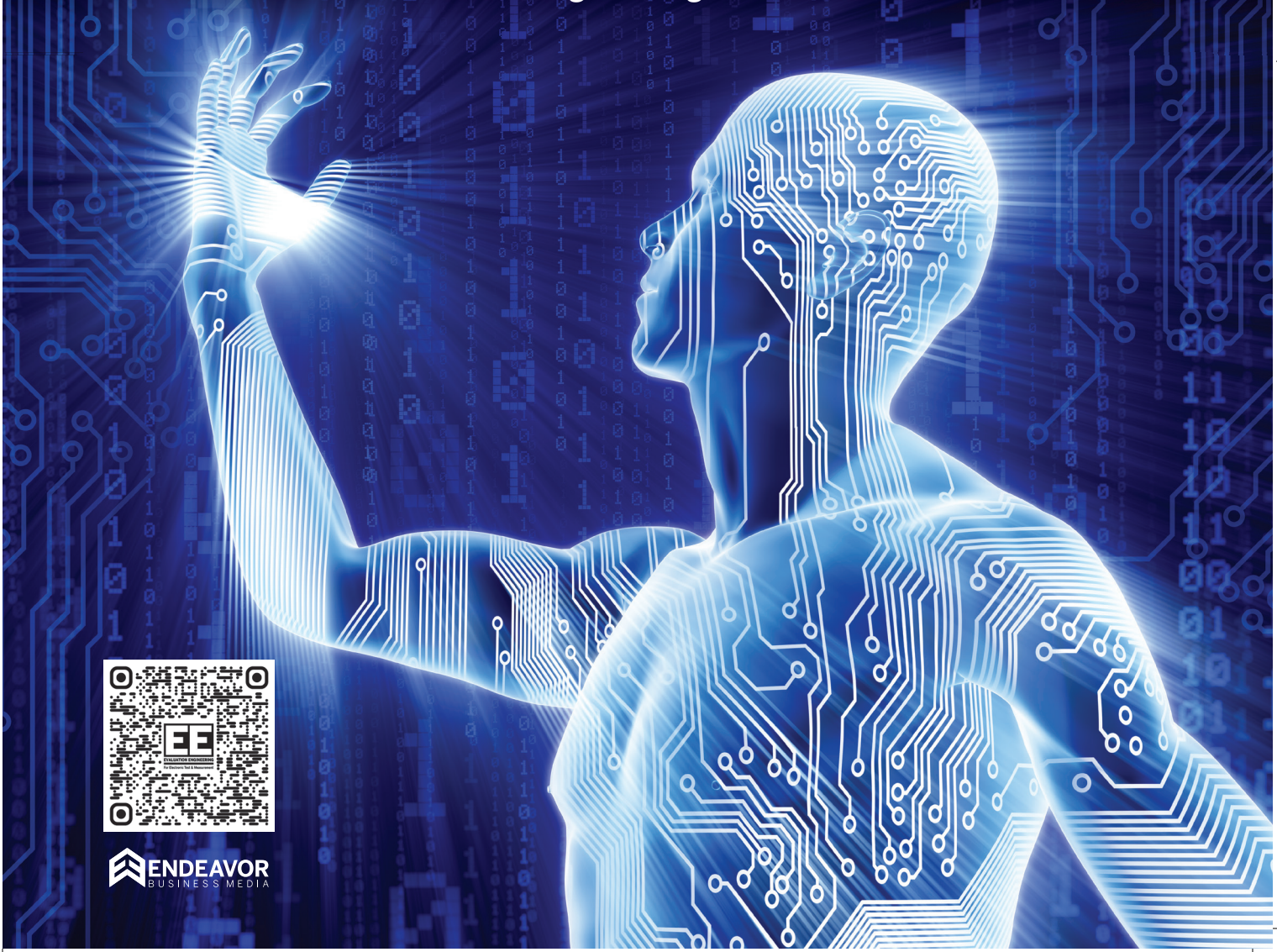

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