

## SPECIAL REPORT

# INNOVATIONS FROM SEMICONDUCTORS TO DIGITAL TWINS DRIVE 5G

By

Rick Nelson, Interim Chief Editor

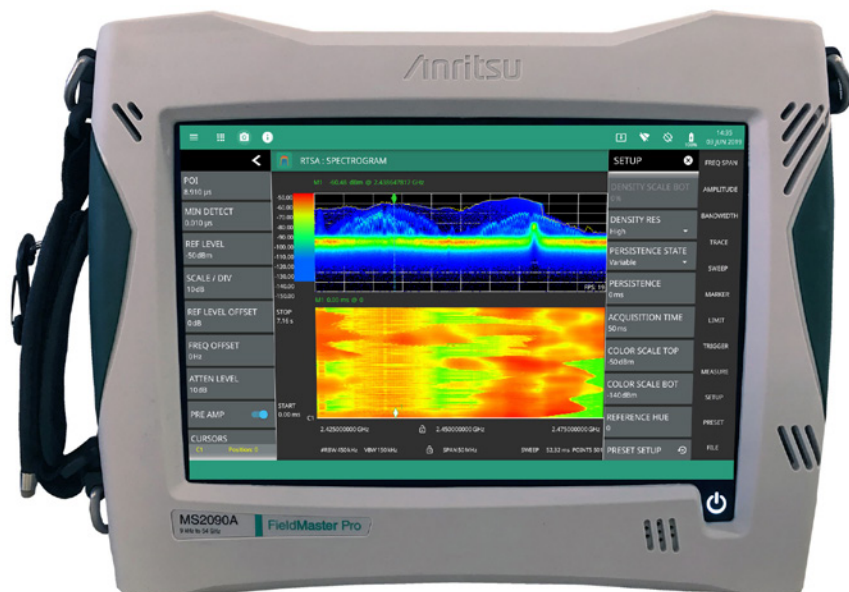
► 5G research spans the gamut from algorithm development to carrier-acceptance test and has implications for products ranging from integrated circuits to test-and-measurement equipment, manufacturing test, and modeling and simulation. New products targeting 5G appear frequently. As this article was going to press, for example, Anritsu was announcing real-time spectrum analysis (RTSA) tools for its Field Master Pro MS2090A handheld spectrum analyzer, which can serve aerospace/defense, satellite, radar, and 5G and mobile-backhaul applications.

We asked 5G industry participants to describe their approaches to the technology, the challenges facing their customers, and solutions they offer. Read on to find what they have to say. They also commented on topics such as compliance, cooperative efforts with other organizations, and techniques such as OTA test. You'll find discussion of those topics in a subsequent article.

## Key focus areas

On what 5G technology areas are you focusing?

**Roger Nichols, 5G program manager, Keysight Technologies Inc.:** The exciting and sometimes overwhelming part about 5G for Keysight is that we are involved in the entire development process—from computer-aided electronic-design tools to early design-validation test, conformance and carrier-acceptance test,



▲ Anritsu Field Master Pro MS2090A handheld spectrum analyzer.

manufacturing test, and system optimization. We are also now in a position to provide design, measurement, and optimization aids for the entire stack—from the physical layer up to the application layer. With 5G in the early phases of commercialization, we are involved in everything from continued research in RF technology (channel sounding for IIoT, FEMs, antenna testing and validation, power-amplifier efficiency), air-interface testing (protocol-stack development, design validation, conformance, and acceptance testing of devices and base stations, core and RAN—including fronthaul—network testing, and drive-testing). An example of the breadth of what we cover comes

from our UEE team who is now focused on a SW stack implementation that covers the entire physical layer, supporting multiple interfaces that span from radio/RF to O-RAN with a unified approach.

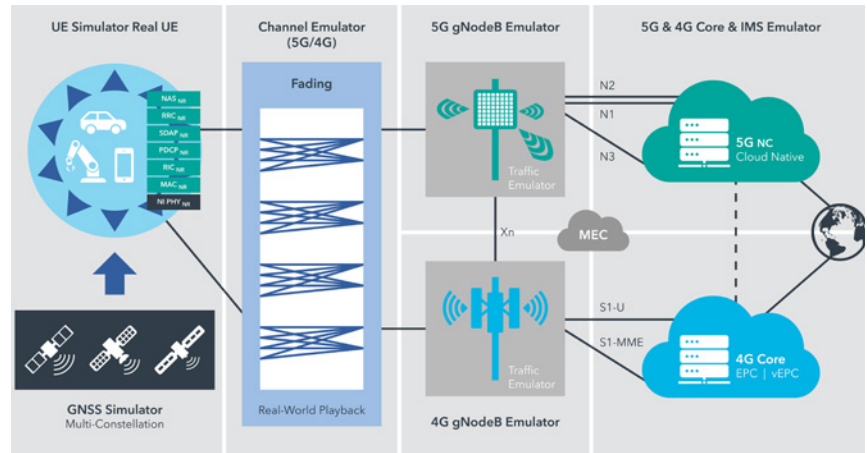
**Alejandro Buritica, senior marketing manager, Semiconductor Solutions, National Instruments:** NI's wireless research team has been focusing on releasing fully 5G NR standards-compliant test UE that can be used to validate 5G designs for hardware going into production and can also be used as a starting point for research in 5G verticals. NI also recognizes the importance of having accurate channel information and continues

to offer a channel-sounding solution for mmWave and sub-THz frequencies.

**Brian Walker, senior RF design engineer, Copper Mountain Technologies:** We focus on the precision measurement of the S-parameters which characterize the media over which 5G signals propagate. This is important for understanding RF phase and amplitude in a MIMO antenna array or the loss and gain through an RF front-end.

**Jon Semancik, director of marketing, Marvin Test Solutions:** Marvin Test Solutions is focusing on production test equipment for beamforming applications in the 28- to 44-GHz range. The recently released TS-960e-5G turnkey test system supports up to 24 ports for true multi-site test capabilities, and it includes DC, parametric, and RF test capabilities. The system integrates laboratory-grade RF performance directly to the mmWave DUT for multisite production test or device characterization of mmWave devices. In addition, MTS offers a full suite of digital and parametric testing and SPI/I<sup>2</sup>C interface support to functionally control and monitor the device under test. The ATEasy test executive and integrated test environment (IDE) is utilized for all test sequencing, control, timing, and documentation. ATEasy also incorporates advanced cybersecurity features, such as data and driver encryption and multilevel access control.

**Stephen Douglas, head of 5G practice, Spirent:** Spirent's 5G focus is in solutions around network emulation, Dev to Ops automation, and active assurance to provide a safe pathway across the new 5G lifecycle, helping our customers manage the complexity and challenges as they look to develop, launch, and operationalize 5G. In network emulation we have a portfolio of solutions which emulate all major parts of the 5G network including the New Radio base stations (gNBs), channel models (sub-6-GHz and mmWave), 5G New Core (Service Based Architecture), UE and traffic emulation (eMBB, uRRLC, mMTC including NB-IoT and CAT-M, 4G, Wi-Fi 6.0, security), and impairment emulation



▲ Spirent 5G network digital twin.

(latency, packet loss). Combined, these emulators create a digital twin, which emulates the 5G networks, traffic, and services.

Twins (emulators) can be used to test the performance of a real network or emulate network functions and services which are physically unavailable, complex, or costly to configure, providing a simple, repeatable, and predictable way to test and prototype, reducing the complexity and economics of testing and validating 5G. The twins are being used today by OEMs to validate 5G UEs, by NEMs to validate 5G network equipment such as new gNBs and the 5G Core, by CSPs to prototype new capabilities such as network slicing, and by universities to research future use cases in the automotive and Industry 4.0 space.

In Dev to Ops automation we have a portfolio of automated-test solutions which streamline continuous deployment processes such as 5G cell-site turn-ups, validating and activating new 5G Core networks and functions, or evaluating perceived user experience of the new 5G services including data, video, and voice.

In active assurance, we have solutions which continuously (24/7) actively test the operational network and services using synthetic traffic generation via software-defined test agents for a proactive way to monitor and assess performance, quickly isolate issues, continuously validate network and service continuity (for example, after change-management events), and assess security effectiveness for critical risks such as data breaches.

**Andreas Roessler, technology manager, Rohde & Schwarz USA:** From our perspective, the research community has already moved on or is at least in a transition phase. While 5G is being commercialized, 6G research is taking off. Topics are manifold and among others they include the reach towards sub-THz and THz frequencies, with even wider bandwidths than currently possible in 5G. Potential applications target chip-to-chip, board-to-board, or rack-to-rack communication. However, these ultrahigh frequencies and bandwidths add another dimension to wireless communication: active sensing. From that perspective, 6G research may pave the way further to the holographic society—"your" digital twin—and Rohde & Schwarz is actively contributing to this research with our test-and-measurement tools and software solutions.

**Karim Hamed, GM, Microwave Communications Group, Analog Devices:** We are engaged across the entire scope of 5G phenomenon including enabling the equipment testing the network, as a core component integrated into the first 5G radios launched, and providing key technology for many of the 5G applications coming in the future. In the sub-6-GHz space with wider bandwidths and more stringent performance requirements, we continue to believe that the delivery of wideband DPD and GaN power amp (PA) charge-trap correction is essential. As for mmW, our investments are centered around delivering ever higher linear output power while meeting the customer EVM specs with a more highly integrated beamformer front-end.

**Ken Karnofsky, senior strategist, MathWorks:** As the wireless industry moves towards 5G, design concepts are becoming more complex. 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. We are focusing on working with companies to equip their wireless engineering teams with the knowledge surrounding a complete 5G workflow—connecting algorithm design, system simulation, OTA testing, prototyping, and implementation. This mitigates design challenges and saves design teams development and verification time.

## Key features

What key features are customers asking for in 5G solutions?

**Buritica, National Instruments:** The ability to test new device types such as IF-to-RF and RF-to-RF beamformers with simplified switching setups and calibrated signal paths. These features enable fast and accurate characterization, validation, and production test of the Tx and Rx amplifiers and phase shifters.

The industry is also working hard on producing fast and reliable solutions for OTA testing of mmWave devices. Engineers continue to request higher bandwidth test coverage, expecting 5G channel bandwidths, especially in the mmWave frequency bands, to keep growing to 800 MHz and beyond.

**Walker, Copper Mountain Technologies:** Customers are likely to need additional analysis software to help them process the complicated measurements they are making. Fulfilling those needs will be challenging.

**Semancik, Marvin Test Solutions:** 5G test systems must be able to measure and analyze several parameters not required in lower frequency applications. For example, gain, intermodulation, S-parameters, and noise figure are common. Test times and throughput tend to

be critical for most manufacturers of 5G devices. Achieving the lowest possible test times will be a major productivity push moving forward.

**Nichols, Keysight Technologies:** Now that 5G networks are beginning to go commercial, we see an increase in demand for solutions that test integrated radio and network systems. Network emulation and UE emulation systems lead this demand given the need for device, gNB, and network scaling. The features include mmWave coverage, massive MIMO testing, design-validation capabilities for regression testing of the device or base-station software updates, conformance and preformance testing, and end-to-end validation.

**Adnan Khan, senior business development manager, wireless products, Anritsu:** Key features of interest are calibration of antenna arrays as beamforming becomes an integral part of FR2 testing. Antenna and RFFE designers want to ensure that antenna array elements are properly calibrated relative to phase measurements. Another feature in strong demand is Dynamic Spectrum Sharing (DSS), which provides the ability for LTE and 5G NR to share spectrum in the same geographical area. This feature allows operators to immediately use 5G NR on LTE bands without having to wait for the FCC to carve out 5G NR spectrum from LTE bands, which could be a lengthy process.

**Douglas, Spirent:** 5G Core emulation—Customers want to develop and move quickly to the new 5G Core and need solutions to help efficiently validate the new architecture, its disaggregated capabilities, and new features like slicing.

5G device testing (location accuracy)—Moving beyond basic certification testing and carrier acceptance, testing focus is now on specific feature capabilities critical for emergency services and new industry use cases (e.g., automotive, smart factories). Location is a critical capability, and while 4G will dominate its implementation in the short term, there are numerous issues regarding multisignal interference which need to be resolved

in addition to the new sensor-fusion capabilities that will greatly improve location accuracy, especially indoors.

5G cloud and edge environment validation—The new 5G network is being designed with edge and cloud datacenters as key parts of the disaggregated architecture.

5G security continuous auditing—Live testing of security systems is necessary to proactively identify weaknesses to determine whether they are still fit for purpose.

5G user experience (data, video and voice)—This requires testing of perceived experience of end users using machine-learning-based algorithms that closely match what a viewer “sees.”

5G Energy Efficiency—This involves continuously evaluating energy efficiency of network equipment and networks in relation to optimizing for performance, quality, and service.

**Roessler, Rohde & Schwarz:** We see the need for DSS. This feature enables 5G NR-LTE coexistence as both technologies use the same frequency bands. The majority of network operators worldwide are actively utilizing FR1 spectrum. The frequency bands and channels are occupied and used by LTE—thus not available to roll out a 5G coverage layer using lower frequency bands. DSS enables this by implementing several features that allow NR and LTE to use the same spectrum without creating interference. This functionality requires in-depth testing.

**Dr. George Hurtarte, wireless product marketing strategist, Teradyne:** The following are some of the key test features that customers are asking for to test 5G NR devices:

- Capability of testing millimeter-wave devices in the frequency range of 6 to 44 GHz. They need to test both the RF and IF frequency ranges of new millimeter-wave transceiver and modem devices.
- An easy ATE upgrade path from traditional sub-6-GHz to millimeter-wave testing. This is a key challenge as manufacturers have a large installed base of sub-6-GHz ATE and desire to redeploy such installed base with millimeter-wave testing capability.

▼ Keysight Technologies VXG microwave signal generators.



- OTA test techniques for module-level devices. Unlike sub-6-GHz products that can be tested with contacted probes, millimeter-wave module devices require over-the-air testing techniques.
- Higher port-count instrumentation for testing high-density millimeter-wave phased-array antenna elements. At millimeter-wave frequencies, phased antenna arrays with up to 32 to 64 antenna elements are possible, as compared to less than eight antennas for sub-6-GHz devices.
- Fast time-to-market and high-performance test solutions for characterization of new 5G NR device requirements. As the new 5G standards evolve from Release 15 to Release 16 and future releases, manufacturers need a test platform that can efficiently test new devices at the highest performance and quality levels for both characterization and fast product ramp-up.
- Easy-to-use test instruments for testing millimeter wave devices. Test engineers and technicians who are experts in millimeter-wave technology are very scarce in the marketplace, and they need to run very fast in the learning curve.

Finally, customers are looking for low cost of test for mass production as high-volume 5G smartphone applications ramp up in volume into the 2022 timeframe.

**Hamed, Analog Devices:** Our customers need circuit- and system-level enabling technologies that have a direct impact on weight, range, and power consumption

while meeting ever tougher performance requirements. Wideband, power-efficient implementation of DPD algorithms spanning multiple deployment scenarios and a complete system facilitating system-level optimization and calibration allow OEMs to focus on end-product performance rather than optimizing a multi-vendor line-up at a component level. We expect system-level solutions tightly coupled with an enabling software layer and algorithm expertise to be in high demand in the coming years.

**Karnofsky, MathWorks:** Today's wireless standards are so complex that engineering teams designing next-gen communications systems are struggling to keep up. The proliferation of Bluetooth, Wi-Fi, WLAN, LTE, and other communications protocols are further stretching design teams across RF, antenna, analog, digital, software, and systems engineering. Designers from these varied and highly-specialized engineering fields typically lack a single, sharable modeling platform, and they've had to resort to disparate,

incompatible simulation and test tools that undermine collaboration.

So, how are companies looking to mitigate this challenge? Customers are looking for a unified workflow that enables designers to efficiently simulate, test, verify, and validate their designs as early as possible—which is more prevalently required to meet shrinking deadlines and tight budgets.

## Products and solutions

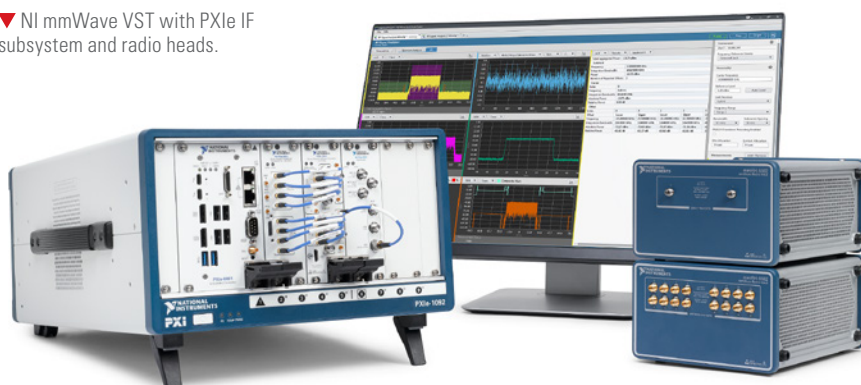
What products/solutions/capabilities have you introduced recently in the area of 5G?

**Buritica, National Instruments:** We recently launched a new addition to our portfolio of PXIe Vector Signal Transceivers in the form of the mmWave VST. This instrument has a modular architecture composed of a PXIe IF subsystem to which users connect external mmWave radio heads. This way, users can generate and analyze lab-grade, high-bandwidth signals in the IF range from 5 to 21 GHz and in the mmWave range from 24 to 44 GHz.

For RF-to-RF device testing, the mmWave VST can place the radio heads with high-power, bidirectional ports very close to the RF connectors on the outside of the anechoic chamber. Engineers can also take advantage of the VST's IF ports to interface IF-to-RF DUTs.

This mmWave VST also adds calibrated, multiport mmWave measurement capabilities to NI's Semiconductor Test System (STS). Additionally, we continue to collaborate with industry leaders like Tokyo Electron to bring direct-dock

▼ NI mmWave VST with PXIe IF subsystem and radio heads.



wafer-probing solutions to the STS, leading to fast wafer-level test of new 5G RFICs.

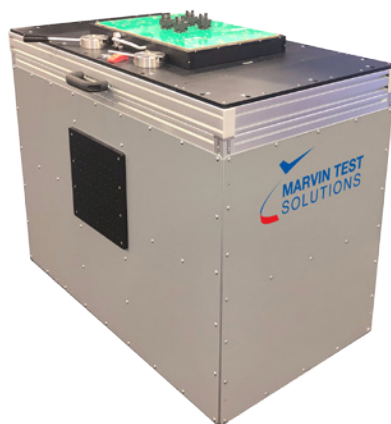
**Walker, Copper Mountain Technologies:**

We released an 18- to 54-GHz frequency-extender module (FET1854) last year, which was primarily targeted at 5G applications. The 1.85-mm coaxial interface simplifies the connections to devices which need to be tested.

**Semancik, Marvin Test Solutions:**

MTS recently introduced a mmWave/5G production test system capable of 50-GHz signal delivery to the UUT. The TS-960e-5G mmWave test system delivers proven performance up to 50 GHz. The system integrates laboratory-grade RF performance directly to the mmWave DUT for multisite production test or device characterization. In addition, MTS offers a full suite of digital and parametric testing and SPI/I<sup>2</sup>C interface support to functionally control and monitor the device under test. For production test applications requiring integration with an automated handler, the TS-960e-5G is available with an inTEST manipulator, which provides precise positioning of the test head and the flexibility to interface to automated probes and device handlers. The TS-960e-5G's device interface board (DIB)/receiver interface is designed to be

▼ Marvin Test Solutions TS-960e-5G mmWave test system.



compatible with virtually any device handler. The TS-960e-5G can be configured with up to 256 dynamic digital channels. The base TS-960e-5G platform uses the GX5295—a 3U PXI, 32-channel, 100-MHz digital I/O card with per-channel parametric measurement units (PMUs). A wide range of digital and analog instrument options can easily be incorporated into the TS-960e-5G, offering users a compact test system that can support both functional and DC parametric test capabilities. The system is also available with digital vector conversion tools that support ASCII, WGL, STIL, VCD, eVCD, and ATP vector formats.

**Nichols, Keysight Technologies:**

It is a long list. We continue to evolve our fundamental RF source/analysis measurement capabilities with software updates for the updated standards. We also recently introduced a scalable PXI microwave signal generator, used to generate complex waveforms that are required for emerging 5G, aerospace, and defense wideband applications. We also introduced the first

integrated dual channel 44-GHz vector signal generator with 2-GHz bandwidth. We have launched multiple network emulation solutions for UE test, and these continue to evolve at a rapid pace to keep up with the standards and use models of the expanding 5G customer base. We have introduced extensions to our existing EPC test product to support 5G NSA and a new solution for 5G SA.

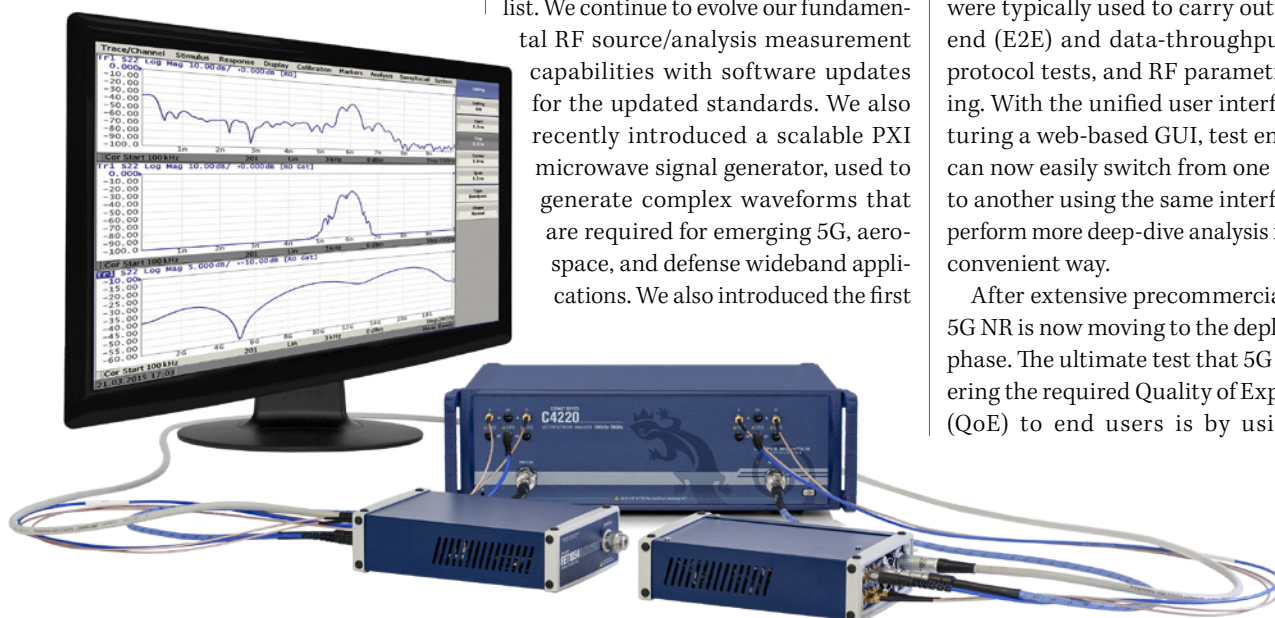
**Douglas, Spirent:**

Here are several: the 5G Core Network Emulator (Landslide); 5G Device Testing (8100 5G); 5G Cloud RAN/fronthaul/midhaul testing with 10G/25G/100G optical test ports and protocol emulation for eCPRI, NGFI, CPRI over ROE, and XTRAN/ORAN over eCPRI; 5G slicing packet network (SPN) testing, which provides soft slicing with SR/DiffServ/MPLS VPN/EVPN and hard slicing with FlexE; and 5G Test as a Service, providing multivendor NFVi and 5G Core (VNFs) benchmarking, baselining, and continuous validation.

**Roessler, Rohde & Schwarz:**

Rohde & Schwarz launched the R&S CMX500 mobile radio tester platform for 5G device testing at the beginning of this year. The unique capability of this powerful, new hardware platform is its unified graphical user interface approach. In the past, different software tools and applications were typically used to carry out end-to-end (E2E) and data-throughput tests, protocol tests, and RF parametric testing. With the unified user interface featuring a web-based GUI, test engineers can now easily switch from one domain to another using the same interface and perform more deep-dive analysis in a very convenient way.

After extensive precommercial trails, 5G NR is now moving to the deployment phase. The ultimate test that 5G is delivering the required Quality of Experience (QoE) to end users is by using test



▲ Copper Mountain Technologies vector network analyzer with FET1854 frequency-extender modules.

solutions running on and with real 5G devices in a live network. Operators wishing to test the quality and performance of 5G NR mobile networks using commercially available UEs—for example, the Samsung S10 5G—can do so now using the range of Rohde & Schwarz mobile-network-testing solutions for engineering, coverage, performance, application QoS, site acceptance, and benchmarking. These include the QualiPoc Android smartphone-based optimizer, the R&S TSME6 scanner, and R&S SmartAnalytics software. For infrastructure deployment, Rohde & Schwarz has recently released the 5G Site Testing Solution to enable efficient gNodeB site testing and troubleshooting.

**Hurtarte, Teradyne:** An UltraFLEX test solution for the 5G NR millimeter-wave market, the new UltraWave-MX44 instrument enables faster time to market and higher product yields for semiconductor devices used in emerging 5G mmWave applications. It extends the UltraWave24 capability up to 44 GHz to address the 5G NR standard while maintaining full DIB and docking compatibility. Industry-leading programming software and debug tools provide fast time to market. It supports characterization and production device testing for probe, package, over-the-air, and module applications. Patented active thermal control and NIST-traceable integrated calibration circuitry deliver superior instrument performance and tester-to-tester repeatability. It offers full test coverage for 5G multiantenna beamforming devices

In addition, the UltraWaveMX20 is an UltraFLEX test solution expanding test coverage to 20 GHz for 6-GHz-band Wi-Fi and cellular, ultrawideband, and 5G IF devices. The new UltraWave-MX20 D16 instrument enables faster time to market and higher product yields for semiconductor devices used in emerging applications operating up to 20 GHz. It extends the UltraWave24 capability up to 20 GHz. It maintains full DIB, docking, and program compatibility with current applications with no system reconfiguration and offers industry-leading programming software and debug tools for fast time to market. It



▲ Teradyne UltraFLEX semiconductor test system.

supports characterization and production device testing for probe, package, and module applications. Patented active thermal control and NIST-traceable integrated calibration circuitry delivers superior instrument performance and tester-to-tester repeatability.

**Hamed, Analog Devices:** In the sub-6-GHz space, we recently introduced an integrated high-power switch with a low noise amplifier (LNA) in multichip modules for TDD systems. The ADRF5545A/ADRF5547/ADRF5549 family covers cellular bands from 1.8 GHz to 5.3 GHz and is optimally designed for massive-MIMO antenna interfaces. Incorporating a high-power switch in silicon process and a high-performance low-noise amplifier in GaAs process, this new family of devices offers high RF power-handling capability together with high integration without any compromise.

In the mmW 5G space, we introduced our 24/26/28GHz-mmW 5G chipset composed of the 16-channel ADMV4821/ADMV4801 dual/single-polarization beamformer ICs, the ADMV1017 mmW up/down frequency converter (UDC), and the MxFE RF data-converter platform (AD9081 and AD9082). This chipset offers the highest available level of integration at infrastructure-grade level of performance while simultaneously addressing the n257, n258, and n261 bands in a single footprint for each function. The 24- to 30-GHz UDC + beamformer + MxFE form a 3GPP-compliant chipset with best-in-class equivalent isotropically radiated power (EIRP) while delivering

superior EVM when tested with stringent 5G NR waveforms covering 64/256QAM modulations.

**Karnofsky, MathWorks:** MathWorks has introduced 5G Toolbox for MATLAB, which provides standards-compliant waveforms and reference examples for modeling, simulation, and verification of the physical layer of 3GPP 5G NR communications systems.

## Investment protection

How are you helping customers protect their investment in 4G equipment as the move to 5G becomes more secure?

**Khan, Anritsu:** Anritsu is lowering the cost of entry into 5G by allowing our existing customers to repurpose their existing 4G assets towards 5G. For example, customers can use our radio communication analyzer MT8821C as an LTE anchor. This also gives customers the option of using a GUI they are familiar with for testing. Also, for conformance systems, Anritsu can use many 4G solutions in 5G applications.

**Nichols, Keysight Technologies:** In some cases, the equipment that was used in 4G is capable of 5G measurements with software updates and in some cases with no change. In others, the platforms must be completely rebuilt—mmWave with different frequencies, bandwidths, requisite data rates, and OTA test methodologies has driven a host of new platforms. You can imagine that it is in our best interests to make existing platforms work for new generations since platform development, for any company in any industry, represents significant investment—so we take these investments seriously for ourselves and our customers.

**Hamed, Analog Devices:** As much as 5G has stolen the limelight recently, 4G is not going away, and global penetration of 4G still has some room to grow. Our portfolio depth and generation-agnostic approach where applicable enable us to continue to support customers at various stages of network development and help OEMs tailor a solution for the specific end-user deployment scenario. 