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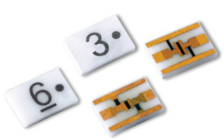

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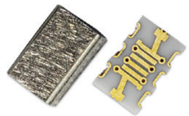

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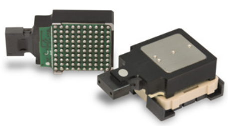

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Looking Back at IMS 2023

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REDUCING WIRELESS RF POLLUTION BY DESIGN AND TEST

Noisecom's programmable noise generator, equipped with a broadband noise source and noise-path attenuator, is a platform that can evaluate a receiver's "road-worthiness" in the face of RF pollution.

THE LOWEST-POWER ATOMIC CLOCK

At IMS, Microchip Technology tested and compared measurements between a miniature atomic clock and a chip-scale atomic clock using its 53100A phase-noise analyzer.

Find more IMS 2023 video coverage at www.mwrf.com/events/ims

Introduction

International Microwave Symposium 2023 in Review

DAVID MALINIAK, *Technology Editor, Microwaves & RF*

In the wake of 2023's edition of the International Microwave Symposium (San Diego, June 11-16), one pauses to take stock of what transpired, and to reflect on what it means for the design community as it moves forward. For one thing, the event's liveliness bodes extremely well for the rest of this year and beyond. A very busy exhibit hall and packed technical sessions indicates that the RF/microwave industry is alive, well, and primed for growth.

It's important to take a good look at the exhibits and absorb the fine points of technical presentations as discrete points of interest. Perhaps, though, it's more important still to try to piece together those discrete points into discernable trends. That's what I've attempted to do in the opening trends article of this eBook.

Some of the articles herein are contributions from the editors of our sister publication, *Military + Aerospace Electronics*, and while not necessarily IMS-related, they do provide insights into further trends of interest to the mil/aero design community. As such, they certainly reflect a great deal of what was on display and under discussion in San Diego.

Within this eBook, you'll find a selection of the most impressive product launches at IMS as well as links to some of the many videos we captured of interesting demonstrations. All told, we hope it provides you with at least a glimpse of the broad palette that IMS brings each year.

credit: Dreamstime

CHAPTER 1:

What IMS 2023 Told Us About Technology Trends

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

IMS's exhibits, product launches, and technical sessions combine to provide a glimpse into the future.

Annual industry gatherings like the International Microwave Symposium (IMS) are worthwhile in numerous ways. Of course, it's great to get out of the house/office and see the people you interact with remotely throughout the year. But more importantly, an event like IMS presents a snapshot of where the industry finds itself, and a glimpse of where it might be headed.

Clues to technology trends are found in many places. Certainly, wandering the exhibit floor and speaking to industry movers and shakers is paramount in discerning patterns shaping technology. Examining product launches can tell you something about where we are now vs. then. And don't forget the technical sessions—they're put together by people in the know who want to lay groundwork for what's on the horizon and beyond. Let's look at a few emerging trends evident at this year's IMS:

Rising Frequencies and Bandwidths

Recent spectrum auctions by the U.S. Federal Communications Commission (FCC) emphasize that the mmWave bands are a priority for the future of 5G. Auctions in the 24-, 28-, 37-, 39-, and 47-GHz bands have released almost 5 GHz of mmWave 5G spectrum to market colonization. More spectrum is to be made available in the 26- and 42-GHz bands, and the FCC is looking into the 70-, 80-, and 90-GHz bands as well.

Designing for these mmWave bands brings a multitude of challenges, not least of which are the inherent issues surrounding wave propagation. mmWave signals simply don't travel very far, which necessitates an increasingly dense thicket of base stations to enable mobile connectivity.

These challenges foster the trend toward various means of shaping and directing electromagnetic (EM) waves to improve propagation and increase relative signal strength

1. An example of the latest in beamforming ICs is Anokiwave's AWMF-0236, a quad-channel, dual-polarization device that covers 37 to 43.5 GHz.

in the desired direction(s) and frequencies. Beamforming technologies have been with us for some time and are gaining in importance. An example of the latest in beamforming ICs is Anokiwave's AWMF-0236, a quad-channel, dual-polarization device that covers 37 to 43.5 GHz (**Fig. 1**).

But another class of technologies, explored in a Workshop at IMS, is that of engineered surfaces and materials. Researchers from Corning, the Jet Propulsion Laboratory, Georgia Tech, and the University of Waterloo presented on various aspects of exploiting the physical properties of metasurfaces, tunable materials, and more. All offer great potential in 5G/6G applications.

RF Front-End Innovation

Coupled with the accelerating move toward mmWave bands and greater bandwidths is the need for innovation to support data-intensive applications. A good deal of this innovation is happening at the receiver front end, which continues to evolve to accommodate faster data conversion and processing capabilities in support of intelligent edge devices.

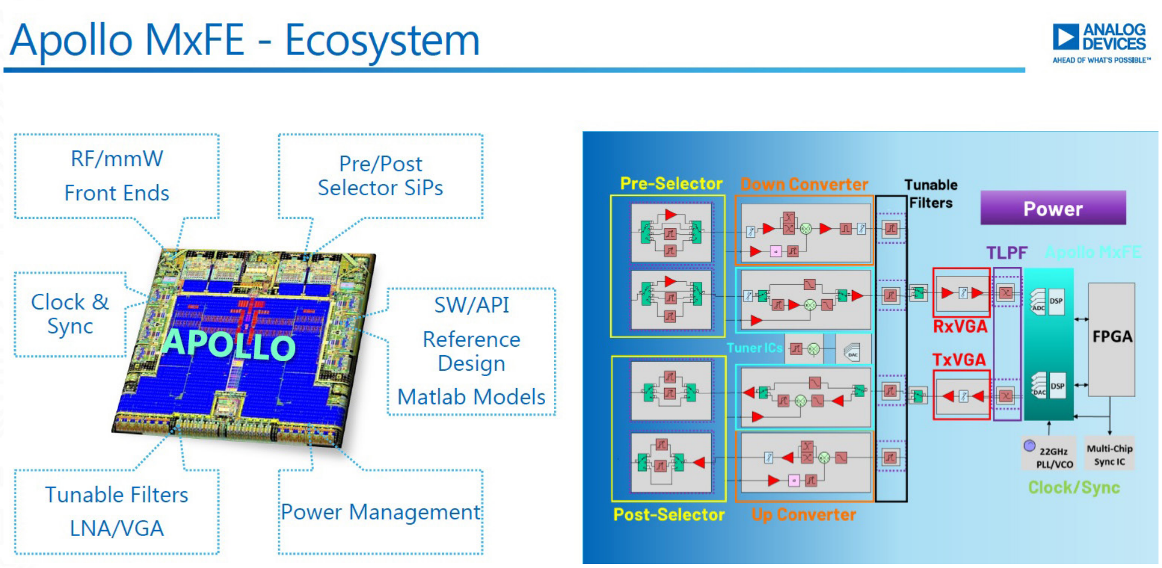
One of the more interesting, and forward-looking, launches at IMS was Analog Devices' Apollo MxFE mixed-signal front-end platform. The software-defined, direct RF-sampling platform is built for application versatility and rapid customization. Not only that, but the device is said to be the industry's first integrated radio capable of directly interfacing to the 6G bands from 7 to 15 GHz. A key to the device's flexibility is its dynamically configurable on-chip DSP, enabling rapid changes between narrowband and wideband profiles without disturbances to its JESD link.

An important facet of the Apollo MxFE platform, and one that portends a trend to watch, is the extensive ecosystem that ADI has built around it (**Fig. 2**). For platforms like the Apollo MxFE to succeed—and more will follow—is that they require a robust set of surrounding components. ADI has at the ready a PLL/VCO synthesizer, a complete power solution, a 10-channel precision synchronizer, and more.

Modularization = SWaP Gains

The flexibility and broad applicability of ADI's new front-end platform recalls other

2. ADI's Apollo MxFE sports a surrounding ecosystem that enables the device's broad applicability to phased arrays, surveillance uses, 6G communications, test, and more.



3. The trend toward modular RF system design continues with the launch of Spectrum Control's SCi Blocks. Shown is a SOSA-aligned OpenVPX module with an RF "stick" atop the module.

innovations seen at IMS centered on modularity and open architectures. In 2013, the U.S. Department of Defense began mandating the adoption of Open Systems Architecture concepts for defense-related hardware and software. In the ensuing decade, a great deal of development has manifested along these lines.

Modular, highly integrated subsystems are shrinking development cycles and minimizing risk, with communications capabilities being more easily added to overall system designs than ever before.

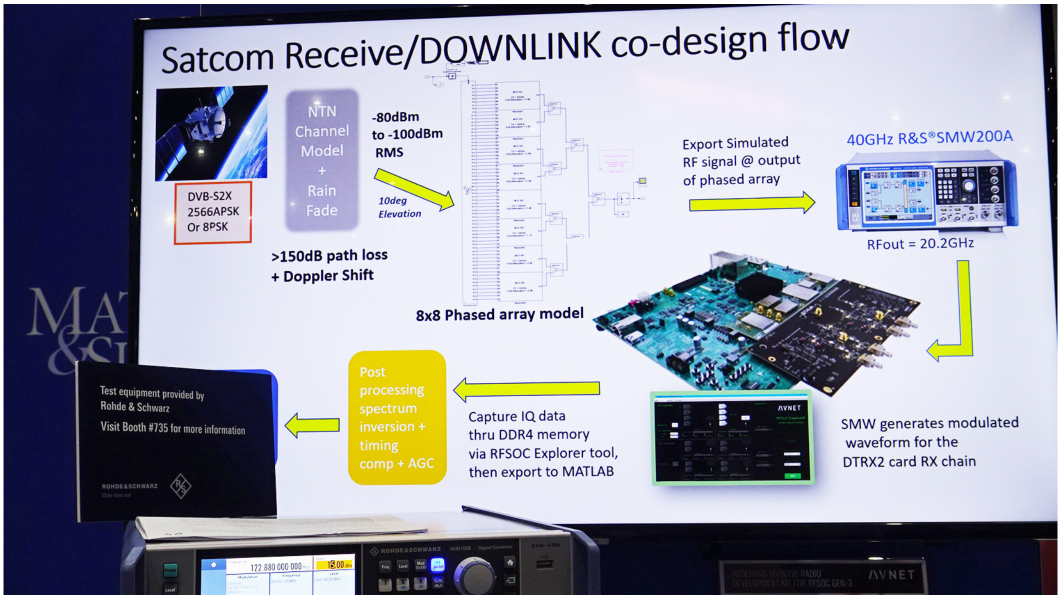
The trend toward modularization in military/aerospace system design is well exemplified by another IMS launch—Spectrum Control's SCi Blocks ("sky blocks"), a family of digitally enabled, plug-and-play RF functional elements that point the way toward the future of modular systems. The products come in three tiers—RF systems-in-package (RF SiPs), RF "sticks," and Sensor Open Systems Architecture (SOSA)-aligned OpenVPX modules (**Fig. 3**).

Model-Based Systems Design

While not a new concept, model-based design (MBD) is a trend that's been gathering momentum of late. MBD offers an approach to design work that's well-suited to the growing complexity of RF/mWave/mmWave communications systems. It spans both hardware and software design, encompassing requirements specification, system architecture modeling, design implementation, simulation, automatic code creation, and all the way to verification and validation.

Various IMS exhibitors are involved in aspects of MBD. One of the foremost enablers is MathWorks, whose MATLAB and Simulink tools figure into 5G design; AI for wireless; and digital, RF, and antenna design, among other areas. One of the important aspects of MathWorks' products is that they work together with other enabling products/technologies to facilitate MBD.

MathWorks staged several demos at IMS to show how its tools combine with other



4. Model-based design was demonstrated at IMS by MathWorks and Otava in the form of a satcom receive/downlink co-design flow.

vendors' products to allow for RF/microwave-related design work. For example, the company demoed how Otava's DTRX2 dual-transceiver mmWave radio card can team with MathWorks tools to target satellite-communications development to RFSoCs, using the Otava product to conduct over-the-air testing (**Fig. 4**).

Quantum on the Rise

Yet another buzzword heard often at IMS 2023 is "quantum computing." The emerging quantum-computing industry depends heavily on microwave technologies, and the links between the two disciplines are still being forged. Yet, makers of components such as RF connectors are discovering ways to adapt (literally and figuratively) to the new alliance between quantum physics and microwave engineering.

For example, Connectronics used IMS to debut a wide array of RF connectors and adapters designed for quantum-computing applications. Such applications require components to offer non-magnetic and cryogenic attributes.

On that front, Connectronics can modify its products with base-material and plating-finish combinations that minimize the connectors' magnetic signature. In this way, the connectors create minimal interference with the applied magnetic fields intrinsic to quantum computing.

References:

Related articles on our website:

Go Modular with RF to Shrink System Densities

Software-Defined Front End Empowers Next-Gen Wireless Solutions

Otava Shows Off Microwave/mmWave ICs and SoCs

mmWave ICs Enable Active Antennas in 5G and Satcom Applications

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CHAPTER 2:

IMS 2023 in the rearview mirror

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

This article is part of our IMS 2023 coverage. It's also in the TechXchange: It's About Time.

At a reinvigorated International Microwave Symposium, the industry flexes its muscle and points to a bright future.

For a few years now, the International Microwave Symposium (IMS), like virtually all in-person industry events, had been in the doldrums. Despite its reputation as "the flagship event dedicated to all things microwave," attendees and vendors alike were hedging their bets and hanging back, either scaling down their participation or just not showing up at all. The lingering effects of the COVID-19 pandemic, combined with our broad societal acceptance of working remotely and teleconferencing, served to throw a blanket over IMS.

Well, with IMS 2023 having recently concluded at the San Diego Convention Center, I can say without hesitation that those doldrums have passed. In fact, IMS 2023 was a blast! The exhibit floor, conference sessions, workshops, and social events were all extremely busy. As an editor whose days at IMS are full of non-stop meetings with industry experts, navigating the crowded aisles of the exhibit hall was challenging. Apologies to those who waited patiently for me to reach your booths.

Fortunately, all of the breathless running around was rewarded with a broad overview of the industry that you can get only at IMS. Here are some snapshots of highlights with links to our full coverage:

Analog Devices's Apollo MxFE front-end platform

Among the most impressive IMS launches was ADI's software-defined, direct RF-sampling, wideband, mixed-signal front-end platform. With Apollo MxFE, ADI has in its sights the future of phased-array radar, signals intelligence, industrial IoT, advanced test and measurement, mil/aero, and more. We're talking about the industry's first integrated radio that covers the 6G bands from 7 to 15 GHz with instantaneous bandwidths up to 10 GHz.

Tektronix's SignalVu-PC vector-signal-analysis software

Oscilloscopes have long since cemented their places on RF/mmWave designers' testbenches, but they continue to add functionality by way of new application-specific software. To that end, Tektronix now offers multichannel vector-signal-analysis capabilities in its 5 and 6 MSO Series platforms. The software endows the oscilloscopes with the functionality of a vector signal analyzer, pulse analyzer, WiGig or WLAN tester, and spectrum analyzer—all coupled with the advanced triggers of a digital scope.

Microchip Technology's chip-scale atomic clock

Timing is everything in life, and even more so in digital circuits. Microchip came to IMS with an interesting demo of its SA65 chip-scale atomic clock, which the company says is the world's lowest-power chip in its class (<120 mW). The device delivers short-term stability (Allan Deviation) of 3.0×10^{-10} at $\tau = 1$ s from −40 to +80°C. The SA65 has all you need to quantify oscillators.

Those are just a handful of interesting launches and demos we saw at IMS 2023. There's lots more where that came from in our online issue with full IMS 2023 coverage, with more being added as I write. If you couldn't get to San Diego, I hope our efforts provide you with at least a flavor of what the show was like.

Read more articles from our IMS 2023 coverage and in the TechXchange: It's About Time.

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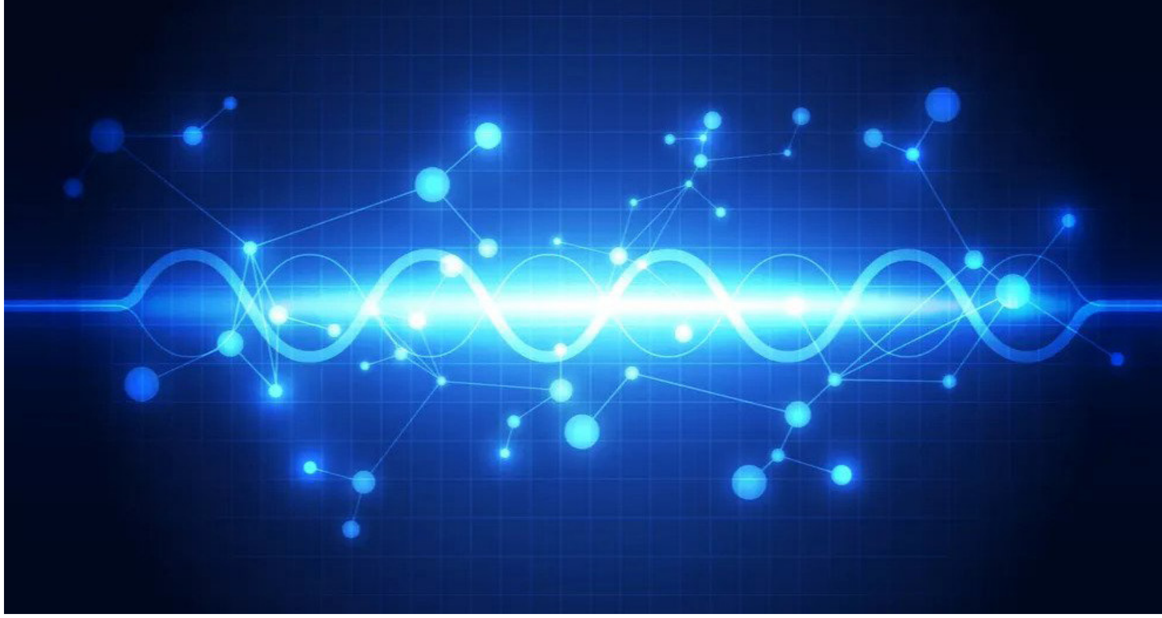

CHAPTER 3:

Wanted: Tiny Efficient Military RF and Microwave Transmitters and Receivers for Sensors and Communications

JOHN KELLER, Editor-In-Chief, *Military Aerospace Electronics*

These RF and microwave components should exceed today's state of the art, and overcome long-established design limitations of the so-called Chu Limit.

ARLINGTON, Va. – U.S. military researchers are asking industry to develop small RF receivers, transmitters, and antennas for space-constrained RF and microwave applications in sensors and communications.

Officials of the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va., issued a broad agency announcement on Friday (HR001123S0041) for the Macaroni project to develop tiny RF receivers and transmitters. Details of the project are secret.

These RF and microwave components not only should exceed today's state of the art, but also should seek to overcome long-established design limitations of the so-called Chu Limit that constrains the bandwidth of data that can be sent and received from small antennas.

Measurement and control of the electromagnetic spectrum is a key research area the U.S. Department of Defense (DOD), researchers point out. Spectrum dominance requires quick and efficient control of electromagnetic radiation from DC to the X-ray regime.

Related: Wanted: enabling technologies in atomic vapors for electric field sensing in electronic warfare (EW)

The primary challenge of the Macaroni project involves receivers and transmitters that are much smaller in size than the wavelength of the sent and received electromagnetic radiation.

In classical antenna theory, the sensitivity-bandwidth product is fundamentally limited by the shape and size of the antenna. This performance degrades significantly as the antenna size becomes much smaller than the electromagnetic wavelength of operation.

Yet size-, weight-, and power- (SWaP)-constrained applications are driving efforts to move beyond traditional constraints, and develop efficient, electrically small antennas still presents a challenge.

Recent advances in quantum sensors, materials science, electromagnetic shielding, laser technology, resonators, cryogenic systems, and vacuum components have pushed the state of the art in sensing technologies. As these enabling technologies improve, a wider variety of protocols and methodologies become possible and previous notions of the performance limits require validation, researchers say.

Related: Department of Homeland Security surveys industry for bistatic radar to detect and track unmanned aircraft

For transmitters, new insights in active antenna technology, control schemes, methods of impedance matching, and strategies for volume filling also present new opportunities. Recent efforts in piezoelectrics, magnetoelectrics, high-index materials, and multiferroic materials may be leveraged to improve the efficiency trade space for small antennas.

DARPA researchers are interested in any transmit and receive technologies that can achieve performance beyond the Chu limit that can incorporate electric and magnetic technologies -- especially in solutions that minimize the antenna size relative to the operating wavelength.

DARPA would like proposals that involve teaming arrangements within and among organizations with relevant expertise, research facilities, and capabilities in electrically small receivers and transmitters. Researchers say they believe proposals from multi-disciplinary teams will be necessary to achieve the Macaroni goals.

Disciplines spanning physics, electrical engineering, mechanical engineering, materials science, computer modeling, and systems engineering are expected.

Related: DARPA moves forward with two companies on second-phase project for secure radio communications technologies

The Macaroni program is a 45-month three-phase program, starting next February, with an 18-month first phase, an 18-month second phase, and a nine-month third phase. The project emphasizes two technical areas: receivers and transmitters.

Receiver work will focus on receive sensitivity, link closure, and systems integration. Transmitter work will focus on transmitter strength, demonstrating a transmitter system, and system ruggedization.

Companies interested should request the classified addendum to the Macaroni project for additional technical details by filling out a request form, online at https://sam.gov/api/prod/opps/v3/opportunities/resources/files/620b30e4acc44e7a87f6a34f260b7e4e/download?&token=, and emailing it to HR001123S0041@darpa.mil.

Those interested in bidding should upload abstracts no later than 10 July 2023, and full proposals no later than 13 Sept. 2023 to the DARPA BAA website at https://baa.darpa.mil. Email questions or concerns to DARPA's Jonathan Hoffman at HR001123S0041@darpa.mil. More information is online at https://sam.gov/opp/07e3eda5a19f4462be14e613d4712ad9/view.

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Air Force Research Laboratory-Kirtland demonstrated a tactical high power microwave operational responder (THOR), with an aggressive agenda to reach warfighters soon.

CHAPTER 4:

An Upward Trajectory for Directed-Energy Weapons

JIM ROMEO, editorial contributor

Directed-energy weapons are electromagnetic systems that convert chemical or electrical energy to radiated energy.

Directed-energy weapons are electromagnetic systems that convert chemical or electrical energy to radiated energy. They are focused on target and on physical damage that degrades, neutralizes, defeats, or destroys an adversarial capability. Directed-energy weapons include systems that use high-energy lasers that emit photons, and high-power microwaves that release high-power radio frequency waves.

High-power microwave weapons create beams of electromagnetic energy over a broad spectrum of radio and microwave frequencies intended to couple and interact with electronics located at a target and then causing damage or temporary disruption.

“There’s no direct definition for what’s the difference between a high-power microwave directed-energy weapon and a radar, but we’ve tempted to basically have a dividing point of that,” says John Tatum in a webinar, sponsored by the Defense Systems Information Analysis Center in 2019 [https://dsiac.org/webinars/high-power-radio-frequency-microwave-directed-energy-weapon-effects/]. “ If a source has a peak effective radiated power of greater than 100 megawatts or radiated energy of greater than one joule per second, it typically will fall into the area of high-power microwave sources.”

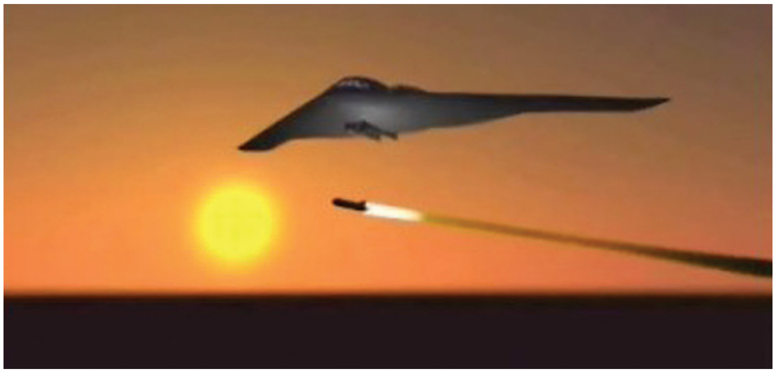
As Tatum explains, the range of frequencies of these radiation sources can vary significantly on the electromagnetic spectrum of high frequency to very high frequency to ultra-high frequency to microwaves to millimeter waves.

“The most important thing to remember about high-power microwave and directed-energy weapons is that they can attack targets with and without intentional antennas and receivers,” Tatum explains. “That’s unlike traditional electronic warfare jammers. They also can produce persistent effects that last much longer than the time the team is on the target. As a result, they can produce temporary electronic upset or significant energy damage. As a result of this, we have an unconventional electronic attack. “

Ongoing development

Prototype development for directed-energy weaponS has been ongoing in the U.S. Air Force, Army, and Navy. The Office of the Secretary of Defense (OSD) continues to seek program money to expand and continue development of these weapons systems.

CHAMP uses high-peak power microwaves lasting less than half the time it takes to blink - too brief to harm human beings but more than enough to disable or destroy electronic circuitry.



The Air Force Research Laboratory Directed-Energy Directorate at Kirtland Air Force Base, N.M., has been working on two non-lethal high-power electromagnetic weapons — the Active Denial System (ADS) and the Counter-electronics High Powered Microwave Advanced Missile Project (CHAMP).

ADS is a low average power microwave system designed to penetrate the skin to a depth of 1/64 of an inch — about the thickness of three sheets of paper. It has been compared to feeling the blast of heat that comes from opening a hot oven; extensive testing has shown it to have no damaging effect on human skin or organs. Used against ground forces or armed mobs, it would force them to disburse and retreat.

CHAMP uses high-peak-power microwaves lasting less than half the time it takes to blink — too brief to harm human beings but more than enough to disable or destroy electronic circuitry. A CHAMP system mounted in a UAV could fly over an enemy-held city and surgically destroy enemy command, control and communications systems — even hitting one building, skipping the next, then hitting a second — without damaging any critical civilian systems or harming anyone in the target area. Damage to enemy capabilities would be at least as great as a direct strike with a bomb, but with no structural or collateral damage.

Air Force Research Laboratory-Kirtland demonstrated a mobile tactical high-power microwave operational responder (THOR), with an aggressive agenda to reach warfighters soon. The intent of THOR is to be up and running in three hours by two people. It's designed to take down several enemy unmanned aerial vehicles (UAVs) simultaneously with rotational antenna control to provide 360-degree coverage, with the firing mechanism and overall systems control, coming from a laptop computer.

Since 2019 the Army Space and Missile Defense Command at Redstone Arsenal, Ala., set out to develop four 50-kilowatt Multi-Mission High Energy Laser (MMhigh-energy laser) Stryker-mounted weapons. Those would be 10 times more powerful than an artillery system soldier have been testing in Germany since 2018. Part of the Army's Maneuver-Short Range Air Defense (M-SHORAD), MMhigh-energy laser would protect mobile Brigade Combat Teams from unmanned aerial systems, rotary-wing aircraft and rockets, artillery and mortar (RAM).

Vehicle-mounted laser weapons

The Army is also developing a 100-kilowatt-class High Energy Tactical Vehicle Demonstrator (high-energy laser-TVD) prototype laser system for Medium Tactical Vehicles. The Army's work will serve as a research component for other directed energy weapons across the military services.

Navy leaders have launched prototypes for some of its Navy Laser Family of Systems (NLFoS) weapon systems which include Solid State Laser-Technology Maturation (SSL-TM) system for amphibious ships and the Optical Dazzling Interdictor-Navy (ODIN) for destroyers. High Energy Laser and Integrated Optical-dazzler and Surveillance (high-energy laserIOS) system, a 60-kilowatt weapon developed by Lockheed Martin, was test launched on an Arleigh Burke-class destroyer (USS Preble DDG 88) in August of 2022.

Aboard the guided missile destroyer USS Preble (DDG 88), this high-energy laser uses an integrated optical dazzler and surveillance unit (high-energy laserIOS). It is a 60-plus kilowatt laser and is designated Increment 1 of the Surface Navy Laser Weapon System (SNLWS) program. [https://www.militaryaerospace.com/sensors/article/14289209/shipboard-electronics-unmanned-hypersonic]

Lockheed Martin referred to the high-energy laserIOS as an "endless magazine that never runs out of bullets." It's able to destroy surface and airborne threats and dazzle or blind optical sensors aboard hostile ships and aircraft, and optical seekers of anti-ship missiles.

Directed-energy weapons include systems that use high energy lasers (HEL) that emit photons, and high-power microwaves (HPM) that release radio frequency waves.

According to a September 13, 2022, report [https://crsreports.congress.gov/product/pdf/R/R46925] "Department of Defense Directed Energy Weapons: Background and Issues for Congress," prepared by the Congressional Research Service summarized budget allocations, the OSD is prepared to allocate generous program funding outlays to develop these weapons systems. The report states:

"In FY2023, OSD requested $16 million for High Energy Laser Research Initiatives, including basic research and educational grants, and $49 million for High Energy Laser Development, which funds applied research. 19 OSD additionally requested $111 million in FY2023 for High Energy Laser Advanced Development, which is focused on 'scaling the output power of DE systems to reach operationally effective power levels applicable to broad mission areas across the DOD."

Also in the report, OSD also requested $11 million in FY2023 to continue ongoing assessments of directed energy weapons, including assessments of the weapons' effects, effectiveness, and limitations. In addition, DARPA's Waveform Agile Radiofrequency Directed Energy (WARDEN) program seeks to "extend the range and lethality of high-power microwave weapons ... [for] counter-unmanned aerial systems, vehicle and vessel disruption, electronic strike, and guided missile defense."

Strategic focus on directed-energy weapons

"One of the most crucial strategic needs in today's cutting-edge RF and microwave weaponry is test, design, and measurement." says John S Hansen, aerospace & defense strategic planning for Keysight Technologies in Santa Rosa, Calif. Keysight's core focus is design, test and measurement of electric and electronic systems. Keysight's instrumentation and modeling software tools are used in the development and calibration of such high energy systems, but not the operation.

"These types of higher energy weapon systems require a very tight matching of system elements to ensure maximum power is coupled to the antenna, which additionally requires

High Energy Laser and Integrated Optical-dazzler and Surveillance (HELIOS) system, a 60-kilowatt weapon developed by Lockheed Martin, was test launched on the destroyer USS Preble in August 2022.

rigorous calibration and maintenance processes. It is very important to design, test, and measure electric and electronic systems with the most advanced instrumentation and modeling software tools in the development and calibration stage of such energy systems. For example, Electronic Design Automation (EDA) software design tools can be applied or adapted to facilitate the modeling and development process of amplifiers and antennas including beam shape and steering. Test instruments can be used to investigate such things as the temporal characteristics of pulses or other waveform properties at a low power level," says John S Hansen, Aerospace & Defense Strategic Planning for Keysight Technologies.

James Marceau is a managing director with Alvarez & Marsal's private equity performance improvement group. He has been a trusted expert at the highest levels of the U.S. Department of Defense (DoD) and all branches of the military, Homeland Security and foreign governments where advises aerospace and defense (A&D) OEMs, prime contractors and others in the defense industrial base.

Marceau emphasizes that the development of electromagnetic and high-energy RF and microwave weapons is a significant field of research for the aerospace and defense industry, and militaries are showing substantial interest in this field globally.

"Directed-energy weapons have been deployed primarily as a force multiplier, able to damage physical targets with greater precision and accuracy, resulting in a competitive advantage over traditional weapons. Especially given the current heightened global threat landscape in Europe and Asia, militaries are seeking any potential advantages," he says. "There have also been increased efforts to develop Air Defense suppression systems that use airborne lasers to disrupt or disable an opponent's own defensive weapons."

Directed-energy weapons are electromagnetic systems that convert chemical or electrical energy to radiated energy. They are focused on target and on physical damage that degrades, neutralizes, defeats, or destroys an adversarial capability.

Defensive laser weapons

Marceau says that growth in this market is driven by investment from branches of the Air Force, other Defense agencies, and the private sector companies who are eager to test the strength and effectiveness of directed-energy weapons. “Examples of current and prior developments include High Energy Laser (high-

energy laser) weapons against Unmanned Aerial Vehicles (UAVs) and Infrared-based Passive Airborne Warning systems. In general, there is an emphasis on miniaturization and adaptability of Electronic Warfare (EW) systems so they can be more easily integrated into airborne platforms. Non-offensive applications of the electromagnetic, RF, and high-power microwave (high-power microwave) technology, such as Terrestrial Radios, have been in use for decades, while Situational Awareness capabilities involving Light Detection and Ranging (LIDAR) and Signals Intelligence (SIGINT) are constantly being developed.”

Dr. David Stoudt is a senior executive advisor at Booz Allen Hamilton in Maryland. Stoudt provides leadership and guidance on the science and business of advancing directed energy capabilities for American warfighters. He previously spent 32 years serving in the Department of Navy, 12 of them as the Navy’s first distinguished engineer for directed energy, an executive position and helped lead the establishment of world-class directed energy programs and facilities at the Naval Surface Warfare Center in Dahlgren, Virginia (NSWCDD).

“A key trend right now is the imperative to reduce size, weight, power, and cooling (SWaP-C) requirements in order to make these weapons viable for operational deployment,” says Stoudt. “There is an ongoing challenge of directed energy weapon systems being too heavy, too large, too under-powered, and too expensive for widespread deployment.

In the modern battlespace, we must balance the need for power with the need for mobility. Now, with the development of fiber lasers, electromagnetic and high-energy weapons can take a more meaningful role in the DOD arsenal. By using modular open-system architectures and optimizing SWaP-C, military and operational utility is enhanced to bring directed energy where it previously couldn’t be integrated into warfighting platforms.”

Stoudt emphasizes that direct energy systems are developed with a definite intent to play a role in defeating unmanned aerial systems. “The primary use case and key differentiator right now is using directed energy systems to defeat Unmanned Aerial Systems (UAS),” he says. “Epirus? next-generation family of Leonidas systems utilize solid-state software-defined high-power microwave to achieve significant counter-electronics effects against UAS targets. Leonidas utilizes software-defined Active Electronically Scanned Array (AESA) with AI-enabled power management schemes to drive dozens of solid-state repetitively pulsed GaN tunable narrowband power amplifiers. This allows for a rapidly tailorable narrowband waveform to enhance effectiveness. The SPEAR (Specialized Portable Electromagnetic Attack Radiator) system is an ultra-wideband, portable, compact, and high-power electromagnetic source that can also be used against individual and swarm drone threats. Due to its portable size, low weight, low power requirements, and efficiency, SPEAR provides Counter small Unmanned Aircraft System (C-sUAS) capabilities to ground vehicles, fixed platforms, and field troops. The SPEAR application contributes critical niche advantages to a layered defense approach, which is foundational to achieving overmatch and defeating threats. It’s important to note that directed energy is a uniquely versatile technology family, with several subsets that can be tailored to different applications.”

Electromagnetic weapons

Electromagnetic and high-energy RF and microwave weapons are crucial in how they both serve to improve warfare capabilities and new innovation. The use of electromagnetic pulses is a significant capability that stands to be a notable differentiation in this technology and the future of this class of weaponry.

"The ability to control and direct high-power microwave weapons is what makes them so effective and valuable to the development of warfare capabilities," note James Marceau. "Electromagnetic pulses (EPM) can disable electronics within a large radius, and when these energy bursts are concentrated, they can overwhelm all computers, networks, and sensors, without harming human life. In warfare situations where low-collateral-damage combat is required, such as densely populated urban areas, these weapons are highly effective. A largely ignored but important benefit of directed-energy weapons is the anticipated lower costs. By decreasing the need for ammunition-based weapon systems, costs related to maintenance, disarming, and disposing of ammunition can be reallocated. Leveraging this opportunity will only further increase innovation capabilities surrounding directed-energy weapons."

Epirus is developing solid-state, software-defined directed energy systems that enable unprecedented counter-electronics effects and power management solutions to optimize power efficiency in defense and commercial applications.

Dr. Stoudt points out that the number of potential applications for DE systems is growing every day, which is largely explained by the versatility of the technology behind the weaponry.

"This is due to the flexibility of the DE spectrum, but also the reality that kinetic solutions are either not sufficient or cost-effective to bring to bear against a wide range of threats and in a number of operational scenarios," explains Stoudt. "The convergence of the operational need to combat these threats with the rapidly increasing maturity of directed energy technology is greatly increasing the demand for fieldable weapon systems. The country that develops and fields this technology at scale first will have a distinct advantage over their adversaries."

There are numerous examples that illustrate the value of how directed energy weapons can have great utility.

Stoudt says that the ongoing Ukraine-Russia war is an example of the future of warfare in which urban combat among large civilian populations and the use of unmanned aerial vehicles is the norm.

"Whether you call them electromagnetic, high-power RF, or high-powered microwave (high-power microwave) weapons, they can be used to neutralize enemy capabilities and combatants nonlethally and, in many cases, avoid material damage or civilian casualties," explains Stoudt. "Beyond this, the systems offer a wide-range of benefits including deep magazine capacity, a more simplified resupply logistics strategy, low cost per shot, speed-of-light engagement, and extreme accuracy."

Non-lethal weapons

Stoudt adds that there are a number of examples of this type of weapon on the market, including the Epirus' family of Leonidas systems, and the SPEAR which utilizes high-power radio frequency to achieve counter-electronics effects against UAS targets.

"Additionally, THOR (Tactical High-Power Operational Responder) is a very high peak power counter-swarm electromagnetic weapon developed by the Air Force Research Laboratory that is used to disable aerial drones, especially drone swarms," says Stoudt. "Looking ahead, we will continue to see the development of high-power radio frequency systems that bring the newest technology to bear against the growing threat of unmanned aerial vehicles, as well as other adversary capabilities.

"Directed-energy weapons are likely going to reach sophistication and full maturity within the next ten years, so the development of electromagnetic and high-energy RF weapons is expected to continue," says James Marceau. "Increasing air threats, such as hypersonic missiles, create another need for directed-energy weapons as a potential deterrence method, and I expect this to be explored further in the coming years. Lastly, the Aerospace & Defense industry is not immune to rapid advancements in artificial intelligence (AI). We may see electromagnetic weaponry integrated with AI and autonomous systems to increase effectiveness. This could provide opportunities for new players to contribute their expertise outside of the traditional OEMs and mid-tier suppliers. However, directed-energy weapons still face several obstacles that will need to be investigated: high levels of power supply are needed, they must be durable and accurate in rough weather conditions, and High Energy Laser (high-energy laser) systems need cooling solutions to maintain constant temperatures."

Marceau says that his Aerospace, Defense, Aviation and Space team at Alvarez & Marsal regularly helps our corporate and private equity clients identify R&D and go-to-market opportunities and strategies for emerging technologies, such as directed-energy weapons. "This technology is critical for national security, and the evolving global threat landscape has increased demand and public and private investment in companies focusing in this area," he says. "As these capabilities mature and advance in technology readiness level (TRL) and into production, manufacturers of these weapons and suppliers will likely need to navigate high demand signals, supply chain disruption and raw material availability, inflation cost increases, operational issues during scale-up, and competition for top technical talent."

The future of directed-energy technology

The importance and visibility of directed energy weapons is at the forefront of how many of the services are approaching further development of directed energy technology.

The U.S. Navy, for example, is reorganizing its key warfare center that develops many related programs and prototypes of this weapons category. Recently, Naval Surface Warfare Center Dahlgren Division (NSWCDD) reorganized part of their workforce to include the Integrated Engagement Systems Department, leadership looked at the two different directed energy weapons categories of high-energy laser and high-power microwave (high-power microwave) weapon systems. These areas historically maintained in a single division. They have reorganized and split them into respective divisions, recognizing the need for continued growth and development in both areas that have similar technical roots. They acknowledge that the impetus behind the warfare centers reorganization is in response to a growing demand from the operational community for novel DE weapon systems resulted in a corresponding growth in NSWCDD's technical capability in this area.

At The Air Force Research Laboratory (AFRL) recently opened a new High-Power Electromagnetic Effects and Modeling Facility at Kirtland AFB. The new $6 million facility supports high-powered radio frequency weapons systems and contains a dedicated forensic lab for studying a range of HPEM targets after engagement. The new facility will allow for greater collaboration as the Air Force is set to advance directed energy technologies.

Other agencies are also expanding their research and programs as well. There seems to be strong consensus and widespread support in Congressional committee for programmatic funding for the past couple of years now, and this will likely last long into the future.

The House Armed Services Committee in their "Future of Defense Task Force 2020" [https://moulton.house.gov/imo/media/doc/FODTF%20Report.pdf] identified direct energy weapons as emergent technologies in defense that Congress must be aware and vigilant. This may have set the stage for the opportunity to further develop directed energy weapons technology in the years ahead.

In their report they justifiably listed, along with many technologies, directed energy weapons, giving good reason to believe that funding and support for research and development of directed-energy weapons is robust. The gravitas of this weaponry is characterized in the report's prologue to the listing of concerning technologies, indicating it is a priority:

"A sophisticated array of new weaponry [directed energy weapons] is changing the nature of conflict, and, while most of the technologies will require substantial funding and development by state actors."

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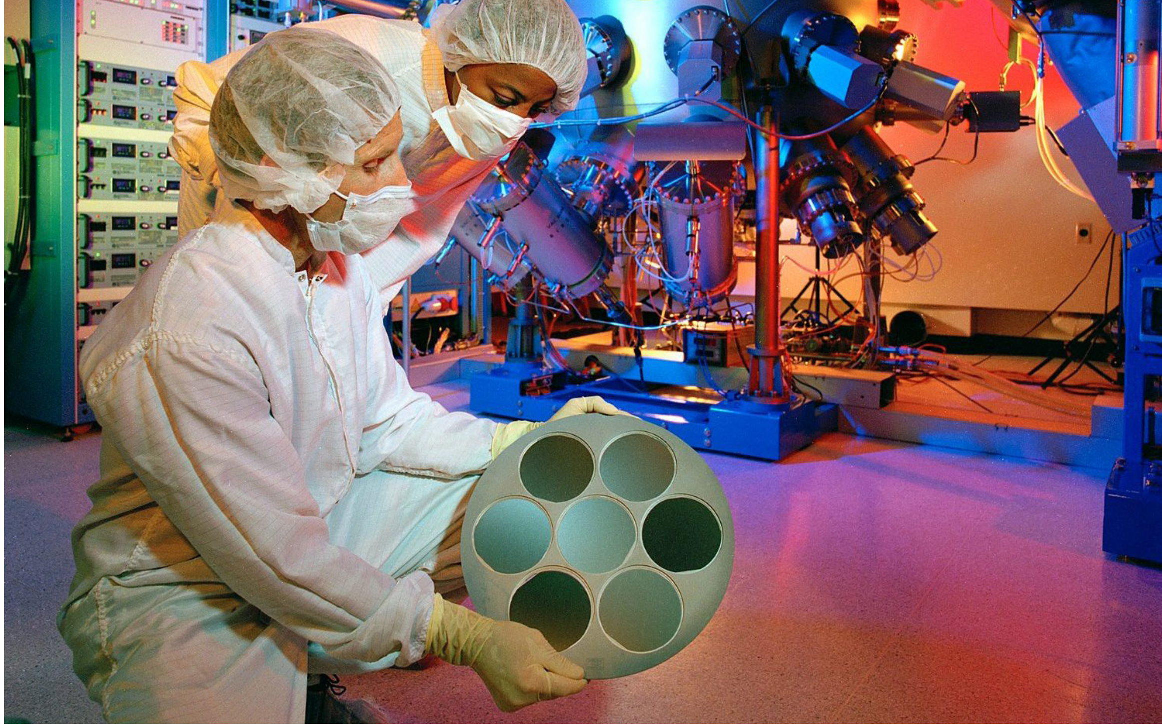

CHAPTER 5:

DARPA Chooses Teledyne to Design Advanced RF and Microwave MMICs for Communications and Sensing at G-band

JOHN KELLER, Editor-In-Chief, *Military Aerospace Electronics*

ELGAR seeks to develop circuits like compact efficient G-band power amplifier MMICs and transmit and receive array front-ends that operate at 220 GHz.

ARLINGTON, Va. – U.S. military researchers needed a company to develop fabrication and integration technologies to create compact, high-performance RF and microwave electronics to enable communications and sensing systems at G-band frequencies. They found their solution from Teledyne Technologies Inc.

Officials of the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va., announced an $18.6 million contract last week to the Teledyne Scientific & Imaging segment in Thousand Oaks, Calif., for the Electronics For G-Band Arrays (ELGAR) project.

Experts from the DARPA Microsystems Technology Office want Teledyne experts to develop monolithic microwave integrated circuits (MMICs) and receive array front-end test articles able to operate in the sub-terahertz G-band frequency range between 110 and 300 GHz for applications like radio astronomy, remote security sensing, and telecommunications.

The growing thirst for information in military and commercial applications is driving RF and microwave technologies towards increasingly higher data rates and wider bandwidths of operation, DARPA researchers say. This drives systems designs in higher operating frequencies to support large channel bandwidths.

Related: Navy asks Photonis Defense to build RF and microwave amplifier power modules for EW and avionics uses

Today's 5G cellular networks, for example, operate at 6 GHz and below, and researchers are considering future 5G communications at millimeter wave frequencies from 24.25 GHz to 52.60 GHz. 6G will push frequencies even higher for large-channel bandwidths and high-channel capacities.

The upper millimeter-wave G band of 110 to 300 GHz represents an attractive, underused portion of the electromagnetic spectrum for high-rate data communications -- particularly above 200 GHz, where atmospheric absorption is low.

Today, however, RF electronics adequate to support operation in this frequency band does not yet exist -- particularly for size, weight, and power (SWaP)-constrained applications. The efficiency of G-band electronics today is poor, and must be addressed to make G-band systems viable.

Related: Raytheon to build 19 advanced AESA radar sets for targeting and mapping on U.S. Marine Corps combat jets

RF and microwave experts can build G-band communications arrays with silicon-based RF integrated circuits or with III-V compound semiconductor MMICs. Each approach has advantages and limitations.

Through significant investment in programs such as Sub-millimeter Wave Imaging Focal-plane Technology (SWIFT), Terahertz (THz) Electronics, and Nitride Electronic NeXt-Generation Technology (NEXT), DARPA has developed III-V transistor technologies in indium phosphide and gallium nitride that can overcome the gain and breakdown voltage limitations of silicon- based transistors at G-band.

DARPA is interested in heterogeneous integration approaches that result in transmit and receive circuit compactness that enable a revolutionary increase in power density and power efficiency of MMICs and phased arrays at G-band.

Related: RF and microwave designers grapple with crowded spectrum

The ELGAR program seeks to develop integration technologies to implement demonstration and validation circuits and test articles including compact, high-efficiency G-band power amplifier MMICs and transmit and receive array front-end test articles that operate at 220 GHz.

DARPA anticipates that the most challenging performance aspects of these MMICs and array test articles will be achieving 30 percent power amplifier power-added efficiencies, and more than 34 Watts per square centimeter transmit array power density and 24 percent transmit array efficiency at the 220 GHz operating frequency.

For more information contact Teledyne Scientific & Imaging online at www.teledyne-si.com, or DARPA at www.darpa.mil.

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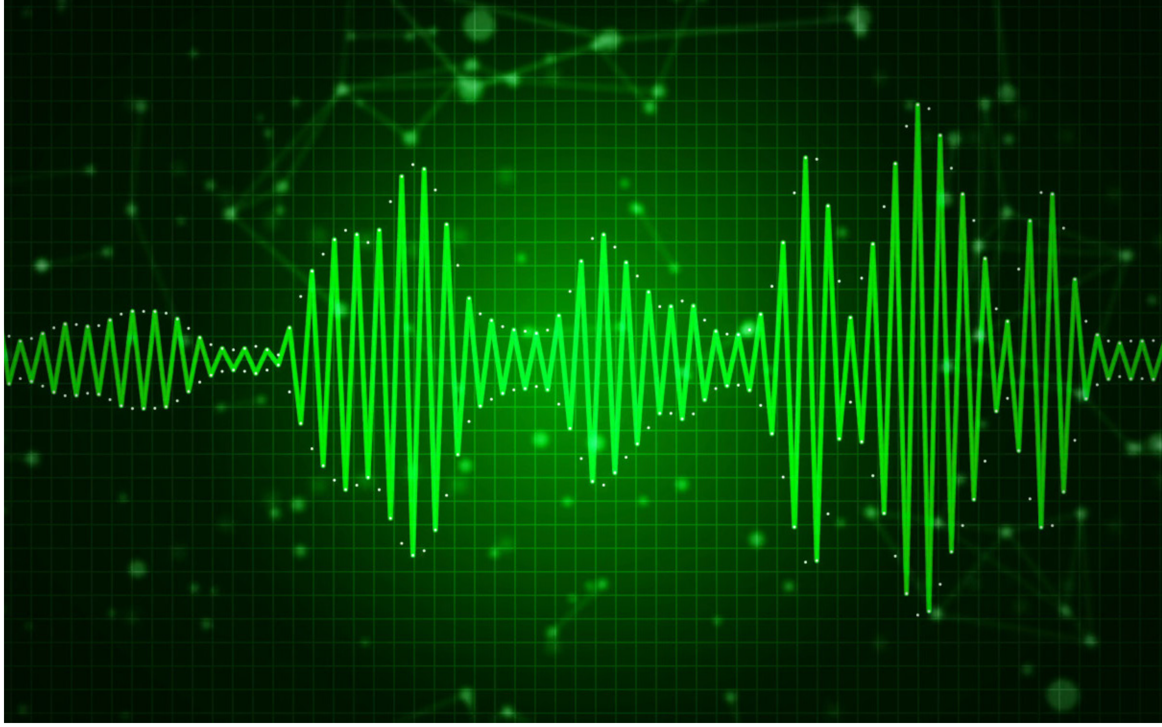

CHAPTER 6:

Spectrum Warfare System Seeks to Use Light, RF and Microwave Energy for Sensors and Electronic Warfare (EW)

JOHN KELLER, Editor-In-Chief, *Military Aerospace Electronics*

Electromagnetic maneuver warfare uses RF and microwave and light energy for wireless communications, sensors, situational awareness, and reconnaissance.

ARLINGTON, Va. – U.S. Navy researchers needed an experimental deployable system able to help U.S. military forces manage and protect their use of RF, microwave, and light energy. They found their solution from Systems Engineering Associates Corp. (SEACORP), a KAPCO Defense company in Middletown, R.I.

Officials of the Office of Naval Research (ONR) in Arlington, Va., announced a $24.5 million contract to SEACORP last month to develop the Electromagnetic Maneuver Warfare Modular Suite (EMWMS).

The EMWMS spectrum warfare system will be a mobile configurable system designed to help Navy, U.S. Marine Corps., and other U.S. and allied military forces ensure their use of the electromagnetic spectrum for command, control, communications, and intelligence uses, and help deny its use to the enemy.

Electromagnetic maneuver warfare describes the ways the Navy and other military forces take advantage of RF and microwave and light energy for wireless communications, sensors, situational awareness, and reconnaissance, and help jam enemy uses of electromagnetic energy.

Related: RF and microwave designers grapple with crowded spectrum

The EMWMS will take advanced of advanced sensors, digital signal processing, and other kinds of advanced computing technologies and software to monitor the nearby electromagnetic spectrum, as well as to jam or spoof enemy communications, sensors, and surveillance systems.

The EMWMS is for long-term use in one location, or for roll-on/roll-off deployable missions aboard manned and unmanned aircraft, land vehicles, surface ships, and submarines.

The system will be built into a container, express (CONEX) box that will facilitate future scalability, modularity, reliability, maintainability, and security, Navy researchers say.

Related: Air Force researchers pick BlackHorse Solutions for autonomous RF and microwave sensors and software project

The CONEX box design also will address space, weight, and power requirements to support intelligence, surveillance, and reconnaissance capabilities, and to deny those capabilities to the enemy.

On this contract, SEACORP will do the work in Middletown and Narragansett, R.I.; Norfolk and McLean, Va.; and Rochester, N.Y., and should be finished by May 2023. The contract has options that could extend work until September 2027, and the contract's value to $79 million.

For more information contact SEACORP online at www.seacorp.com, or the Office of Naval Research at www.nre.navy.mil.

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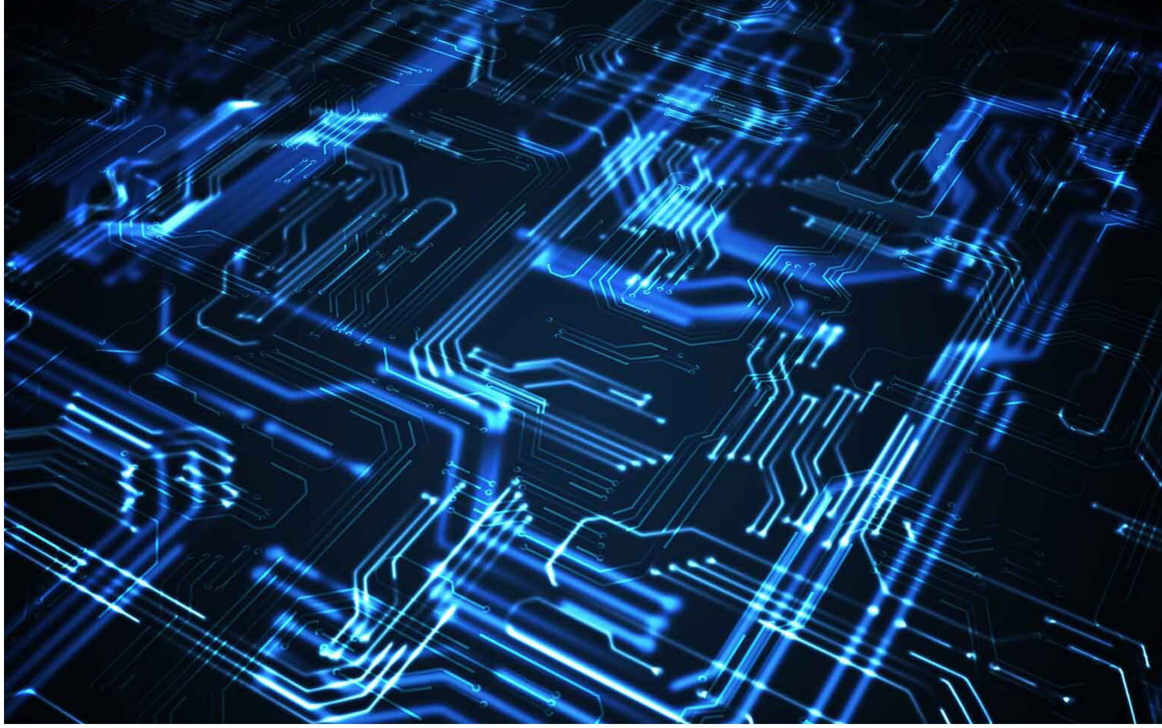

CHAPTER 7:

Wanted: Diamond Semiconductors for RF, Microwave, and Power Electronics to Operate in Harsh Environments

JOHN KELLER, Editor-In-Chief, *Military Aerospace Electronics*

LADDIS focuses on diamond semiconductors substrates with diameters larger than 50 millimeters with good electrical, thermal, and mechanical properties.

ARLINGTON, Va. – U.S. military researchers are asking industry find new ways of fabricating device-grade, large diameter, single crystal diamond substrates for radio-frequency (RF) and power electronics that must operate in harsh environmental conditions.

Officials of the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va., issued a solicitation Tuesday (DARPA-PA-21-05-03) for the Large Area Device-Quality DIamond Substrates (LADDIS) project.

LADDIS seeks to develop techniques for substrates for diamond semiconductors with diameters larger than 50 millimeters, dislocation density below 103 square millimeters, surface roughness below 0.2 nanometers, and good electrical, thermal, and mechanical properties.

Diamond is an ultra-wide bandgap semiconductor that offers a path for developing harsh-environment power electronics and RF and microwave components that are able to operate at high power levels and at high temperatures.

Related: Endwave makes microwave systems for Raytheon sat-coms

At the same time, conventional electronics built on silicon, gallium arsenide, or wide band-gap materials are limited in breakdown voltage, power handling, and operating temperature. Diamond's large bandgap and thermal conductivity can overcome these limitations.

Semiconductor fabrication technologies, however, remain a challenge. Reproducible large-diameter device-quality diamond substrates have hindered the demonstration of electronics with higher breakdown voltage or current compared to existing technology.

Diamond substrates today are no larger than 5 to 10 square millimeters and have dislocation density as high as 105 square millimeters, which degrades device performance and manufacturability.

Commercially available substrates also have large variability in material quality such that previous attempts at wafer size scaling exhibited dislocation density as high as 109 square millimeters, and can crack due to stress.

Related: UES to develop new electronic and electro-optical materials for Air Force sensors and communications

Some chip fab technologies have been promising. Seed tiling, for example, has been used to incrementally scale the diameter of diamond substrates. Seed tiling is a variation of homoepitaxy in which individual diamond seeds are arrayed together, followed by lateral overgrowth using CVD to connect the individual seeds into one larger, single crystal seed.

This technique requires optimizing growth conditions to minimize defects at the tile boundary. In addition, new heteroepitaxial growth approaches have been developed, in which diamond grows from nucleation layers deposited on a different substrate.

Innovations in reactor design, substrate holders, and growth processes also have been shown to minimize thermal gradients and ensure a uniform growth rate, which lowers the built-in stress of the diamond material.

Related: Raytheon to develop next-generation Gallium Nitride devices

Exploration of these techniques will provide insights into creating viable approaches for the manufacturing of large-diameter single-crystal diamond substrates.

The LADDIS program will provide the basis for developing a domestic, commercial source for diamond substrates to enable manufacturing of high power and high temperature microelectronics. These devices would support several U.S. Department of Defense (DOD) platforms and arrays by enabling kilowatt-class low-loss front end receiver protect circuitry, as well as 10-kilovolt-class low-loss switches necessary for future electric ship power systems.

The total award value for the 18-month LADDIS program is limited to $1 million. The program has one technical area developing diamond growth and polishing techniques. Proposals are limited to a single growth and polishing method, yet proposers may submit several standalone proposals for different growth approaches.

Related: Merging the functionalities of silicon, and III-Vs: two promising approaches

Proposers will develop growth approaches such as homoepitaxial or heteroepitaxial to fabricate diamond substrates and demonstrate more than 30 millimeters diameter, single crystal substrates with low dislocation density.

Companies interested should upload proposals no later than 14 April 2023 to the DARPA BAA website at https://baa.darpa.mil.

Email questions or concerns to Thomas Kazior, the LADDIS program manager, at LADDIS@darpa.mil. More information is online at https://sam.gov/opp/45fd25a01b9949c4bddff3f35a6e3291/view.

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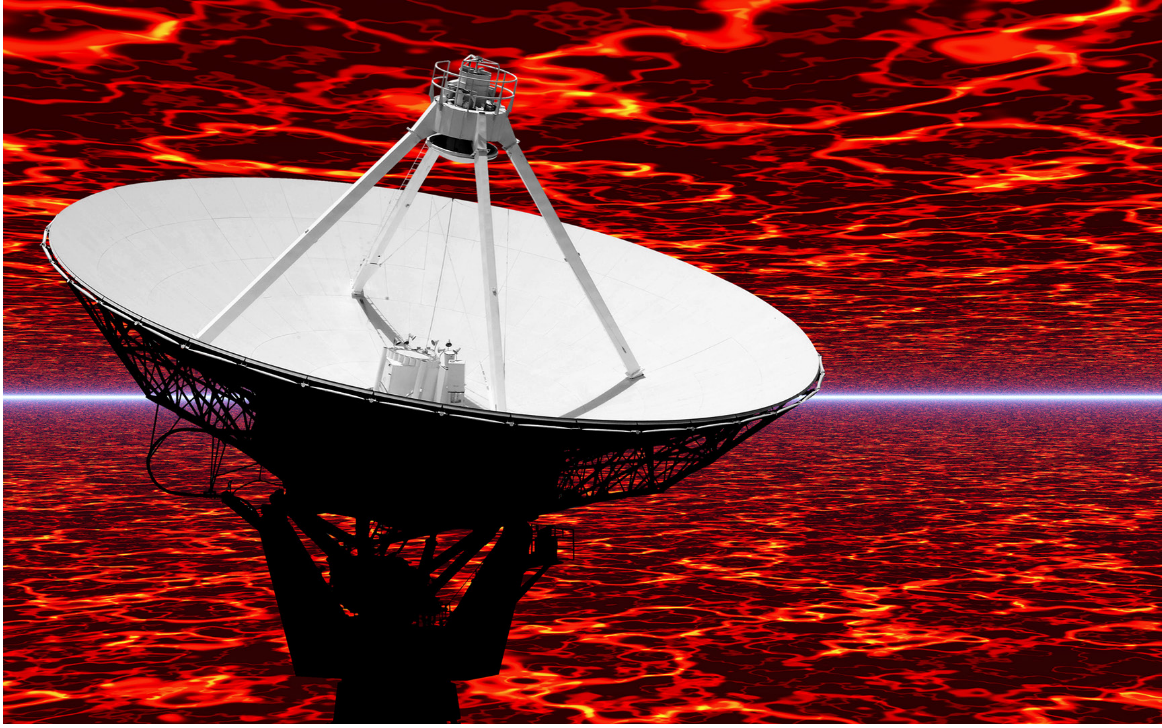


CHAPTER 8:

Software-Defined Front End Empowers Next-Gen Wireless Solutions

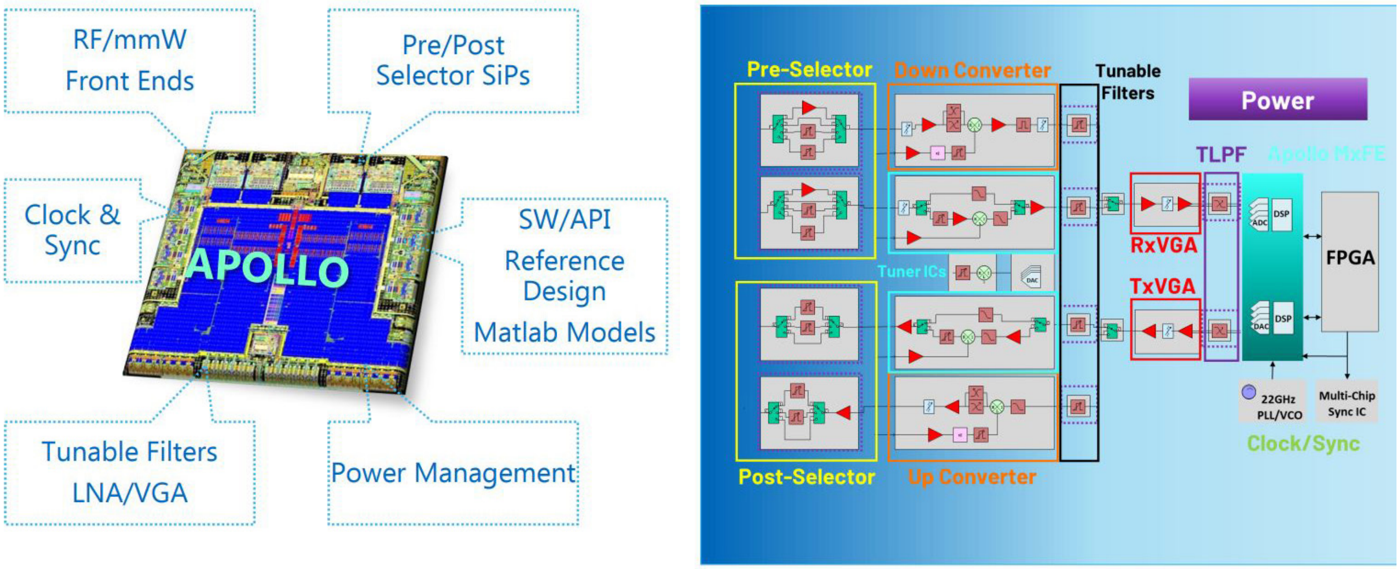
ALIX PAULTRE, Editor-at-Large, *Microwaves & RF*

Developed by Analog Devices, the mixed-signal platform brings flexibility and speed to intelligent-edge design while simplifying electronic test.

As wireless solutions become ubiquitous, the need for advanced RF infrastructures and systems becomes more pressing. The growth of advanced portable devices to address the needs of business, industry, and society in data-intensive applications is pushing demand for wider bandwidths and more rapid processing and analysis of data in wireless systems, especially at the network edge. Designers today need to accelerate design cycles and bring products to market faster and more cost-effectively, while future-proofing their product designs.

To address this demand, Analog Devices launched the Apollo MxFE, an advanced software-defined, direct RF-sampling, wideband mixed-signal front-end platform. The solution enables higher-speed data conversion and processing capabilities, while reducing electronic testing complexity. Apollo MxFE helps empower next-generation applications like phased-array radar, signals intelligence, industrial IoT, advanced test and measurement, aerospace & defense, and remote instrumentation.

Embracing issues like application versatility and rapid customization, the Apollo MxFE provides instantaneous bandwidths up to 10 GHz while directly sampling and synthesizing frequencies up to 18 GHz. The 16-nm CMOS device leverages high-dynamic-range RF analog-to-digital converter (ADC) and RF digital-to-analog converter (DAC) cores, and the company claims it has the best spurious-free dynamic range and noise spectral density available.



Features of the Apollo MxFE 4T4R include on-chip DSP, real-time FFT sniffer, full-rate programmable FIR filter, 128-tap complex FIR filter, fast-hopping NCOs, DDCs/DUCs, and fractional sample-rate converter.

According to Bryan Goldstein, Vice President, Aerospace and Defense, at ADI, "The flexibility and simplicity designed into the Apollo MxFE platform has the potential to transform future engineering design for intelligent edge devices. Demand for higher data rates with shorter latencies at lower overall system power is accelerating across industries. Apollo MxFE gives design engineers the flexibility to design for those requirements today, as well as an ability to enhance performance over time using simple, software-defined design changes."

Apollo MxFE Product Details

Presented as the industry's first integrated radio capable of directly serving the emerging 6G frequency bands from 7 to 15 GHz, the Apollo MxFE 4T4R product has four 12-bit RF ADCs with a sample rate up to 20 Gsamples/s, four 16-bit RF DACs with a sample rate up to 28 Gsamples/s, an RF input bandwidth from dc to 18 GHz (Ku-band), and an instantaneous bandwidth up to 10 GHz. Features include on-chip DSP, a real-time FFT sniffer, a full-rate programmable FIR filter, a 128-tap complex FIR filter, fast-hopping NCOs, digital up/downconverters, and a fractional sample-rate converter (see figure).

The DSP is dynamically configurable to enable rapid changes between narrowband and wideband profiles without taking down the JESD link. The Apollo MxFE 8T8R offers eight RF ADCs with a sample rate up to 8 Gsamples/s, eight RF DACs with a sample rate up to 16 Gsamples/s, an RF input bandwidth up to 16 GHz, and an instantaneous bandwidth up to 3 GHz. The on-chip DSP offers similar features and functionality to the 4T4R device with double the number of digital blocks, which are all dynamically configurable.

Forming the core of a larger ecosystem of recently released ADI hardware and software products, Apollo MxFE is augmented by high-performance variable-gain amplifiers, ultra-low noise LDO and Silent Switcher regulators, clocking, and multichip synchronization. Its ecosystem includes subsystems like a PLL/VCO synthesizer with a fundamental frequency output of up to 22 GHz, offering noteworthy noise performance, temperature stability (0.06 ps/°C), and less than 1-ps alignment resolution.

The Apollo MxFE integrates the LTM4702 8A µModule regulator with Silent Switcher 3 technology to achieve high efficiency and excellent wideband noise performance. It also has a 10-channel precision synchronizer for time alignment of SYSREF signals to within 5 ps, for simultaneous sampling across multiple Apollo MxFE units on the same card or across different chassis.

On top of that, the Apollo MxFE can support two-dimensional system synchronization (fanout and/or daisy-chain architectures) for very large systems. Companion TxVGA and RxVGA solutions provide +15 dB of gain and the transition from single-ended to differential on Rx as well as differential to single-ended on Tx, to simplify the connection to the RF front end.

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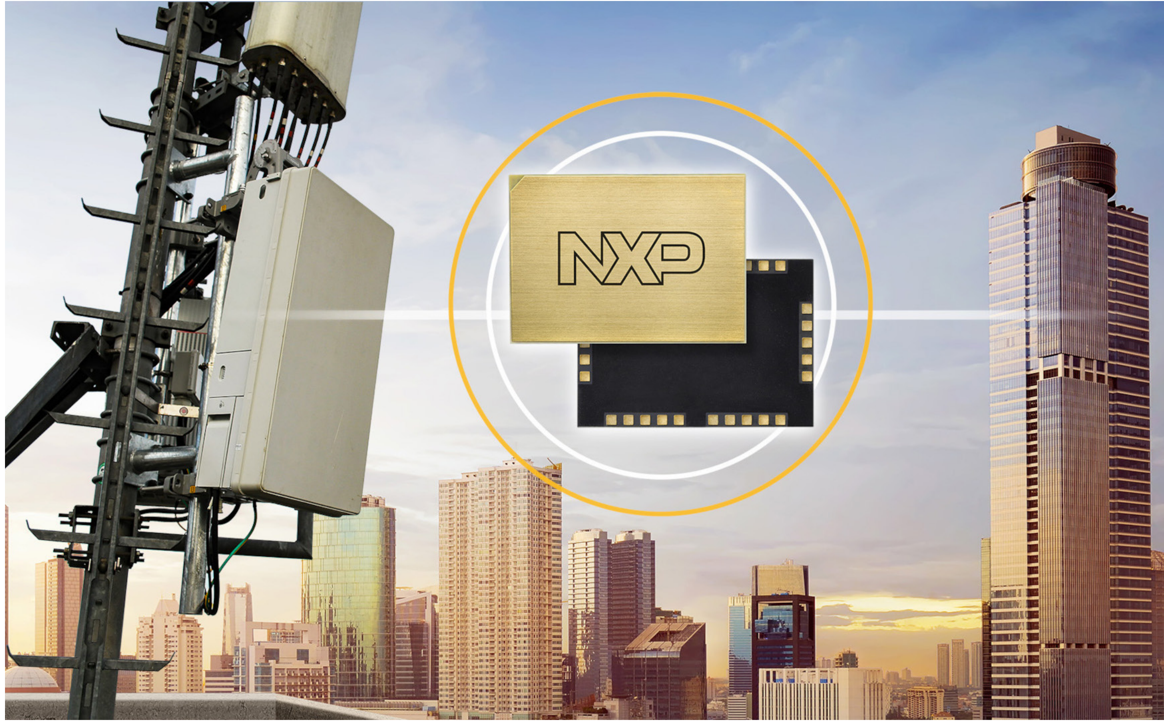


CHAPTER 9:

RF Power Amplifiers Beat the Heat in 5G Base Stations

JAMES MORRA, Senior Staff Editor

This article is part of our IMS 2023 coverage.

Thermal management can make or break 5G base stations. According to NXP, top-side cooling can help prevent them from overheating.

NXP rolled out a family of gallium-nitride (GaN)-based RF power amplifiers (PAs) that uniquely leverages top-side cooling to reduce the thickness and weight of radios in 5G base stations by more than 20%. The new series of RF modules unites the company's LDMOS and GaN technologies in multichip modules (MCMs). Top-side cooling handles the higher power levels of 5G base stations without overheating.

The new RF offerings feature a high gain of more than 30 dB and high efficiency of 46% over 400 MHz of instantaneous bandwidth. Per NXP, they're ideal for 5G radios that cover frequency bands from 3.3 to 3.8 GHz. The LDMOS-based power IC acts as the driver in the dual-stage power amp, while the GaN device plays the role of the secondary power stage, giving signals a final push through the RF signal chain.

Telcos are buying base stations by the millions to expand 5G networks around the world. As a result, NXP and other semiconductor firms are fighting to supply more of the RF chips at the heart of the systems.

In 2020, NXP ramped up mass-production of RF GaNat its U.S. fab to meet rising demand for 5G chips, which must handle millimeter waves and other high-frequency bands, where LDMOS on its own hits the wall.

Power-Handing Properties

GaN, which belongs to a class of wide-bandgap semiconductors, can handle 10X higher breakdown voltages than alternatives, while it beats silicon in terms of efficiency, too, leading to less power loss.

Other unique properties of GaN are very high electron mobility and a reduction in temperature coefficient, which keeps on-resistance (RDS(on)) in check. Thus, it improves performance in cases where conduction losses tend to dominate.

GaN can also run at high switching frequencies along with large voltage transients (dV/dt) due to improvements in parasitic capacitance. The result is that GaN power devices lose less power during turn-on and turn-off. Reverse-recovery charge (QRR) is limited or even wiped out completely as well.

The power-handling qualities of GaN are giving it the edge in power electronics. But they're also relevant to RF power amplifiers, one of the core building blocks of a base station that boosts RF power signals.

The latest 5G base stations are equipped with from 32 to 64 antennas, giving them more lanes to communicate with devices on the cellular network at once. This translates to faster data transfers and wider coverage.

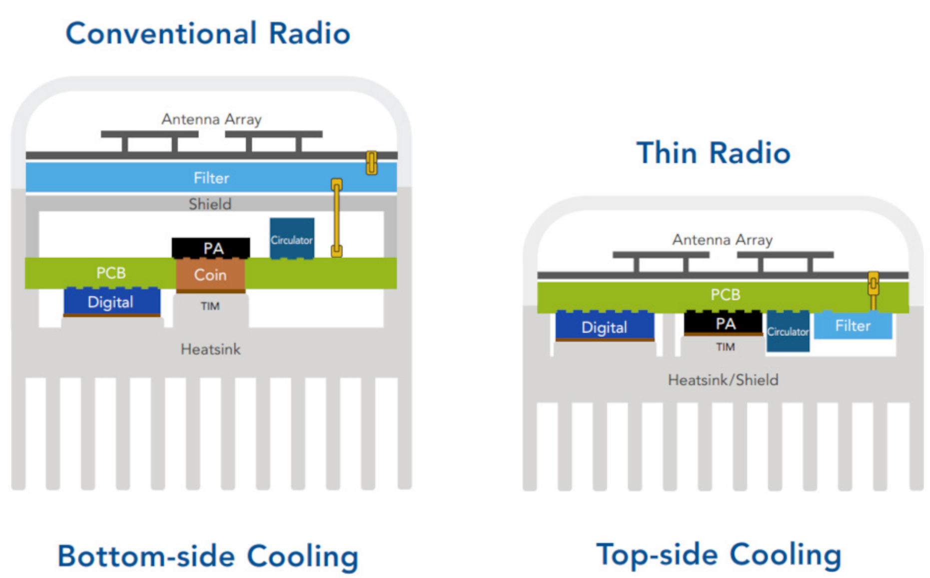
These antennas are also required to tap into another technology: massive MIMO. Using it, 5G radio units can use beamforming to connect many more devices, which in turn boosts the capacity of a base station.

But bundling all of these antennas into a single box requires the use of more RF power amps. As a result, challenges emerge when it comes to managing power and heat in the radio unit, which can consume from 200 W to more than 300 W.

High thermal conductivity means that RF GaN power devices themselves are relatively easy to cool. But care must still be taken to transfer heat that can impact performance or lead to faults away from the chip. The amount of heat encountered by the device can vary significantly, depending on how it's packaged and how it's mounted on a circuit board (PCB). Thus, it becomes mandatory to correctly manage the removal of heat.

Staying Cool for 5G

For the most part, RF GaN power devices are housed in bottom-cooled packages. The heat is dissipated through the underbelly of the package and then the PCB acts as a



The differences between bottom-cooled and top-cooled RF modules. credit: NXP heatsink, resulting in excess loss.

But there's a limit to the amount of heat that can be taken out from under the RF module. When handling the higher power density of 5G radios, staying cool is a serious challenge without using bulky packaging.

To better manage thermals, NXP is bringing high-side cooling technology to RF power devices for the first time **(see figure**). The first products in the new family are the A5M34TG140-TC, A5M35TG140-TC, and A5M36TG140-TC.

The advantage of top-side cooling is that it reduces the complexity of 5G radios, said NXP. It enables all components to be mounted on the same side of the PCB and then cooled directly with the heatsink, opening the door for more compact radios. The cooling technology saves weight and reduces bulkiness, leading to greater power density. These smaller base stations can be more easily and economically installed, according to the company.

The internal heatsink in the module also serves as the RF shield—previously a separate component in the MCM—that blocks out interference and helps with the performance of the PA. This, in turn, saves real estate in the radio.

"Top-side cooling represents a significant opportunity for the wireless infrastructure industry, combining high power capabilities with advanced thermal performance to enable a smaller RF subsystem," said Pierre Piel, NXP's VP and GM of Radio Power.

For more information, visit the company's website.

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credit: Filtronic

CHAPTER 10:

Active Diplexer and E-band Amplifier Enhance Long-Range Communications

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

This article is part of our IMS 2023 coverage.

Filtronic's second-generation active diplexer follows the first-generation launch at IMS 2022.

Two new product ranges—Taurus, a high-power E-band amplifier, and Hades X2, a next-generation active diplexer—will be showcased by Filtronic in IMS Booth 315.

The Taurus amplifier provides a highly linear mmWave power boost and typical P_{SAT} of 38 dBm. The Hades X2 active diplexer delivers a typical P_{SAT} of 30 dBm and sports dual high-power amplifiers. It also boasts a pair of performance-matched gallium-arsenide (GaAs) MMICs that are power-combined in a waveguide to deliver maximum power and linearity. The Hades X2 launch follows the launch of the first generation of Hades products at IMS 2022.

For more information, visit the company's website.

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CHAPTER 11:

High-Power SSPAs Serve Commercial and Defense Applications

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

This article is part of our IMS 2023 coverage.

With their optimized output power, gain, and power-added efficiency over their respective frequency ranges, this trio of solid-state power amplifiers supports the growing industry need for modular, scalable, reliable, and fully tested products.

Along with a host of other products debuting at IMS, Qorvo will be in Booth 935 with three new solid-state power amplifiers (SSPAs) for commercial and defense communications, radar, electronic-warfare (EW), and other wideband applications. The QPB2040N, QPB0220N, and QPB0618N, part of Qorvo's Spatium SSPA portfolio, provide an excellent alternative to traveling-wave-tube amplifiers (TWTAs).

Qorvo's QPB2040N SSPA operates from 18 to 40 GHz, spanning the K and Ka bands. With its wideband output power performance (100 W CW) in a compact size of less than 50 in.^{3}, it's a suitable building block for various mmWave subsystems in wide-ranging applications. The QPB2040N is equipped with an integrated bias card, which reduces electrical losses in the bias networks and provides individualized bias settings for each amplifier blade in the SSPA, as well as drain pulsing for superior power savings and noise performance.

The new QPB0220N and QPB0618N SSPAs are solid-state, spatial combining amplifiers operating in the S, C, X, and Ku bands. With their optimized output power, gain, and power-added efficiency over their respective frequency ranges, these Spatium SSPAs further expand the company's family of products to support a growing industry need for modular, scalable, reliable, and fully tested products.

Over the wide frequency bands and over temperature at CW conditions, Spatium SSPAs are claimed to provide higher output power and efficiency than any other known solid-state products in the industry. Compared to TWTAs, the QPB0220N covers a wider frequency band than any other available product, said Qorvo.

According to the company, its Spatium SSPAs provide a more reliable, easier-to-use solution with reduced size, weight, and total cost of ownership, as compared to solutions based on their closest TWTA counterparts.

For more information, visit the company's website.

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credit: Keysight Technologies

CHAPTER 12:

Keysight, Nokia Bell Labs Demo 6G Sub-THz Component Characterization

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

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Keysight's vector component analyzer and mmWave signal analyzer enable Nokia Bell Labs to better characterize component performance for 6G D-band comms and E-band backhaul systems.

Visitors to Keysight Technologies' Booth 835 at IMS 2023 can see the company's demos (with Nokia Bell Labs) of component and RFIC characterization for 6G sub-THz RF applications in the D- and E-bands.

For 6G technology to deliver on its promised extreme data speeds, ultra-low latency, and near-infinite bandwidth, sub-THz spectrum will have to come into play. But sub-THZ frequencies haven't traditionally been used for cellular communications due to their propagation characteristics, which present signal-integrity and path-loss challenges that can negatively impact performance.

To help mitigate those challenges, Keysight and Nokia Bell Labs have been collaborating to develop characterization techniques to test active sub-THz components, such as amplifiers, mixers, and frequency converters. The goal is to ensure that the components don't introduce additional signal distortion into communications systems.

At IMS, the collaborators' demo, built on Keysight's PNA-X vector component analyzer, involves characterization of a Nokia power amplifier (PA) developed for use in 6G D-band wireless communications systems and designed to operate with a low error-vector magnitude (EVM).

Using Keysight's N5290A PNA mmWave system, Nokia Bell Labs can accurately detect the PA's low EVM, which is a measure of the signal distortion introduced into the communications system by the component. With these measurements, Nokia Bell Labs can better understand the PA's performance to optimize its 6G transmission system design.

In a separate demo, Keysight and Nokia Bell Labs are showing an E-band test solution that features Keysight's N9042B UXA signal analyzer used in combination with its V3050A signal analyzer frequency extender. It measures a Nokia transceiver RFIC designed for use in an E-band system for backhaul applications.

Finallly, to help network equipment manufacturers, semiconductor companies, and device makers address the bandwidth and performance demands of 6G, Keysight will display a 6G sub-THz R&D testbed. The wideband testbed features an arbitrary waveform generator (AWG) that generates a wideband intermediate frequency (IF), which is upconverted to H-band (220-330 GHz). The signal is downconverted to an IF, digitized with a UXR high-performance oscilloscope, then demodulated and analyzed using PathWave vector-signal-analysis (VSA) software.

For more information, visit the company's website.

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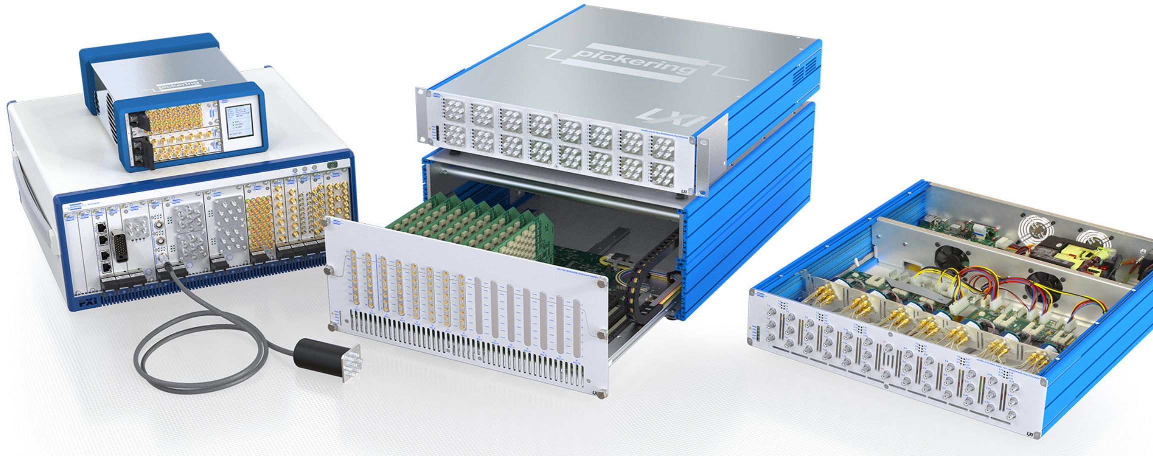

credit: Pickering

CHAPTER 13:

Pickering to Showcase MEMS-Based PXI/PXIe Multiplexers

DAVID MALINIAK, Senior Editor, *Microwaves & RF*

This article is part of our IMS 2023 coverage.

The new multiplexers are said to provide longer operational life, faster speeds, and higher bandwidths than electromagnetic relay alternatives.

In its IMS Booth 1415, Pickering Interfaces will display its extensive range of RF and microwave switching products, including the first modules in a new MEMS-based RF PXI/PXIe multiplexer family.

The RF multiplexer family, which is well-suited for wireless communications and semiconductor test, is powered by Ideal Switch MEMS devices from Pickering's partner, Menlo Microsystems (Booth 450). These are among the first MEMS components on the market with the performance characteristics to support demanding RF testing requirements.

The new MEMS-based RF multiplexers are claimed to deliver vastly increased operational life (up to 300X), faster operating speed (up to 60X), and higher bandwidth (with no reduction in RF power handling) versus traditional electromechanical relay (EMR) alternatives. Insertion loss also remains comparable with EMR switches and much lower than solid-state options.

In addition to the new RF multiplexer family in PXI/PXIe, Pickering will also highlight:

- Its new 110-GHz PXI/PXIe microwave switch supporting 5G and semiconductor test.
- The new Microwave Design Tool, a free online tool for configuring flexible LXI microwave switch products.
- A flexible LXI microwave switch platform and turnkey services for LXI microwave switch and signal-routing subsystems (including a custom 12x12 LXI microwave switching matrix demo).
- A selection from Pickering's portfolio of other switches, along with its PXI, PXIe, and LXI/USB modular chassis, simulation products, and cables and connectors.

For more information, visit the company's website.

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