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RF AMPS BOOST DEFENSE COMMS

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JULY/AUGUST 2024 | VOLUME 63, ISSUE 4

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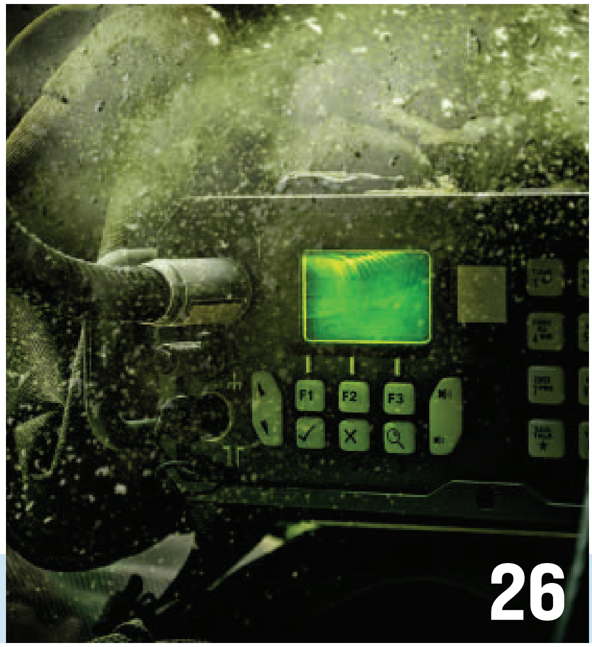

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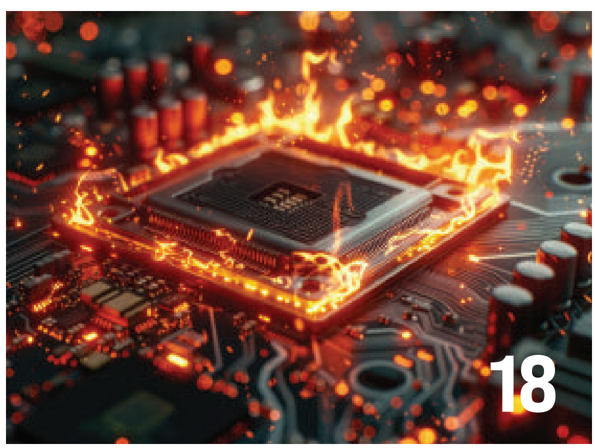

DAVID MALINIAK, Executive Editor

The Consumer Electronics **Post-Pandemic Boom**

The rapidly growing consumer electronics market has overcome the COVID doldrums and is rebounding nicely.

THINKING BACK TO the early days of COVID, I don't recall being drawn toward more use of consumer electronics because of self-imposed isolation. Sure, my family and I watched the news and doom-scrolled on social media a little more, but being trapped at home didn't make us want to gear up for other electronic diversions. Indeed, broad economic uncertainty and health concerns depressed the consumer-electronics market in largely the same way it did the economy overall.

Fast-forward to 2024, and we find a consumer-electronics market that's reawakened and poised for strong growth. According to a newly published whitepaper from ABI Research, global appetites for everything from gaming consoles to smart-home devices and augmented-reality/virtual-reality (AR/VR) smart glasses is on the upswing.

For example, let's consider smartphones. We've seen back-to-back years of contraction, but ABI forecasts 3.7% year-over-year growth for smartphone sales in 2024. By 2029, more than 50% of smartphones will be ready for mmWave 5G. On the way there, phones will increasingly incorporate edge-AI chipsets, and their on-device generative AI capabilities will help automate a lot of drudgery like scheduling, itineraries, managing home HVAC, and more.

Likewise, Bluetooth- and Wi-Fi-enabled devices are expected to resume their market-growth trends. With supply chains mostly back to normal, consumer demand for the convenience of wireless connectivity is on the rise. ABI sees annual shipments of Bluetooth-enabled devices growing by 40% in 2028 compared with 2023. For Wi-Fi-enabled devices, market research indicates 38% growth over the same timeframe.

On the AR/VR glasses front, while ABI cites the enterprise market as today's sweet spot, it foresees more practical and compelling consumer devices emerging in two to three years. With big names like Apple, Google, Meta, and Samsung driving that push, along with maturing software support, AR/VR smart glasses stand a chance of enjoying a huge market of 67.5 million units by 2030 compared with less than 2 million units shipped in 2023.

The consumer-electronics market promises to be a fun one to watch during the remainder of this decade and beyond. You can count on *Microwaves & RF* to cover it thoroughly to keep you up to speed—forewarned, even—on emerging technologies and trends. ■

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Video ► The Move into mmWave Frequencies (Part 2)

The first part of this three-video series covered the topics of frequency dispersion and interfering signals and their impact on wideband receiver performance. In Part 2, Giorgia Zucchelli, product manager for RF and mixed signal at MathWorks, discusses topics such as antenna array design, including element count, type, and spacing, as well as the assessment and minimization of grating lobes and antenna coupling.
www.mwrf.com/21281450

Video ► Modules Extend Matter Ecosystem in IoT/IIoT Apps

In a bid to provide IoT and IIoT connectivity in a greater swath of applications, Silicon Labs's xG26 lineup of connectivity and MCU modules picks up where its earlier xG24 devices left off, offering designers more flash and RAM memory as well as double the GPIO pins. As a result, the XG26 modules bring powerful capabilities to smart-home, smart-city, and industrial use cases.
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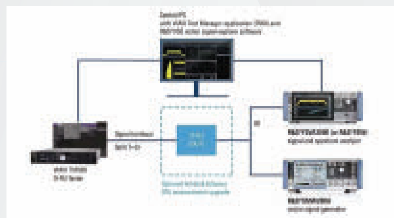
O-RAN Solution Offers an Efficient, Scalable, and Cost-Effective Platform for Development

Offering an innovative approach to open radio-access network design and integration, SynaXG's AI+5G O-RAN solution addresses critical market needs with a highly efficient, scalable, and cost-effective platform for network developers, systems integrators, and end users.
www.mwrf.com/55039347



Network Test Solutions Advance Open Radio Commercialization

Rohde & Schwarz and VIAVI Solutions are expanding their partnership in creating state-of-the-art O-RAN radio unit (O-RU) testing to address next-generation network development needs of radio manufacturers planning to bid for government funding.
www.mwrf.com/55057229

What You Missed at IMS 2024 (Part 2)

2024's edition of the International Microwave Symposium, held at Washington D.C.'s Walter E. Washington Convention Center, brought with it the typical panoply of new products and technologies.
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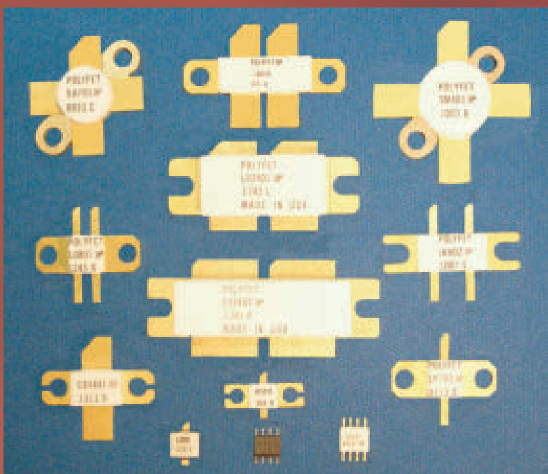
Broadband RF power transistors, modules, and evaluation amplifiers: Polyfet RF Devices offers them all.

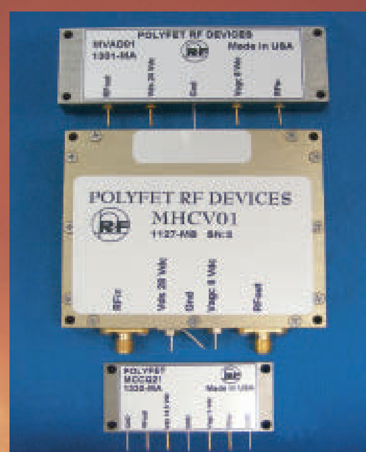


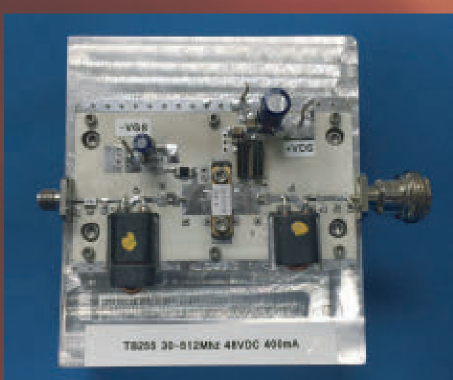
GaN: 28VDC and 48VDC, up to 3GHz, up to 160W, single-ended and push-pull.

LDMOS: 5-50VDC, up to 2.7GHz, up tp 2kW, single-ended and push-pull.

VDMOS: 12.5-50VDC, up to 1GHz, up to 400W, single-ended and push-pull.

Broadband RF power modules:
Utilize GaN and D-MOS technologies.
24-48VDC, up to 1260MHz, up to 350W CW,
various case sizes and RF connection types.
Custom design requests welcomed.





Various evaluation amplifiers available:
Displayed here is the TB255. It demonstrates the GX3442 (GaN) putting out 100W CW, 19dB across 30-512MHz with 48VDC supply.

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LATEST NEWS

Wi-Fi HaLow Phase-Two IoT Field Trials Deemed a Success

Wi-Fi HaLow promises to simplify networks, extend ranges, and enable increased device density in a variety of IoT use cases.

THE WIRELESS BROADBAND ALLIANCE (WBA) recently announced the successful completion of real-world phase-two field trials of IEEE 802.11ah Wi-Fi HaLow. Promising reliable, long-range, low-power connectivity, Wi-Fi HaLow addresses a variety of IoT scenarios. The trials took place in North America, demonstrating the scalability and efficiency of Wi-Fi HaLow to serve challenging applications like dense urban settings and large industrial complexes.

The evaluation confirmed Wi-Fi HaLow performance at extended ranges, its improved material penetration capabilities, extended battery life, enhanced device density, and high level of security. Additional benefits include ease of installation and management, as well as elevated data throughput in IoT scenarios when compared with existing Wi-Fi standards.

Conducted by WBA key members and other industry participants, the trials focused on large-scale implementations and testing Wi-Fi HaLow in challenging environments.

Harnessing HaLow

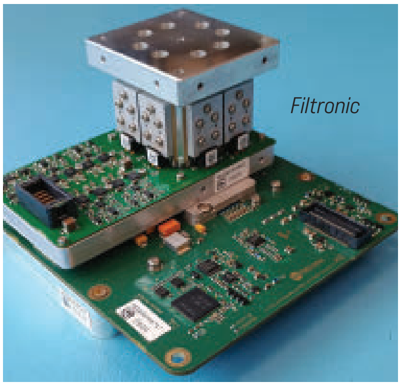
Operating in the sub-1-GHz radio band, key features of Wi-Fi HaLow include the use of narrow channel bandwidths, an increased number of supported devices, and operating modes for battery-operated devices. It also offers high levels of security and native-IP support.

The "Wi-Fi HaLow for IoT: Field Trials Report" offers insights to drive innovation and strategic decisions across the Wi-Fi industry, along with a roadmap to harness Wi-Fi HaLow for new products and markets. The report also presents evidence-based strategies for enhancing network capabilities and service offerings, aiding understanding of Wi-Fi HaLow's operational dynamics and advantages.

According to Tiago Rodrigues, CEO of the Wireless Broadband Alliance, "Each of these real-world field trials has been a huge success demonstrating the readiness and the benefits the Wi-Fi HaLow standard can bring to a vast range of industries and use cases, improving performance and reducing complexity. We now move to the next phase, and are inviting industry players interested in participating in trials across EMEA and APAC to reach out. Your participation can help shape the future of IoT connectivity and drive innovation across various sectors." ■

The WBA announced the successful completion of phase-two field trials of IEEE 802.11ah Wi-Fi HaLow. Wireless Broadband Alliance

E-Band Transceiver and Amplifier Module Boost Backhaul Capacities



Filtronic

FILTRONIC ATTENDED IMS 2024 with its Hercules II system for E-band links. The turnkey package combines the company's Morpheus II transceiver and either a Cerus 4 or 8 solid-state power amplifier (SSPA) to bring high performance and versatility to high-speed backhaul networks and/or low-latency private networks.

By integrating the Morpheus X2 module, which contains all of the necessary transmit and receive functions for the RF section of an E-band link, with the Cerus power amplifier, the Hercules II offers seamless integration and a host of exceptional benefits. This combination facilitates a straightforward and efficient connection to a high data rate full-duplex modem while significantly boosting the available transmit power, ensuring extended reach and enhanced coverage.

The Hercules II also supports spectrally efficient modulation techniques, optimizing bandwidth usage and ensuring higher data throughput. Key features of the Hercules II include Tx saturated powers exceeding +35 dBm, low phase noise, and support for up to 512-QAM modulation.

The Cerus 32 is a high-performance, E-band SSPA designed to meet the growing demands of high-capacity wireless communication networks, such as low-Earth-orbit satellite communications. The Cerus 32 is said to be the most powerful commercially available E-band SSPA, with up to +43 dBm of transmit power. Each Cerus 32 module incorporates Filtronic's in-house MMIC chip design and power-combining techniques, delivering maximum linear power. The high-power SSPA can be used in a range of applications and is specifically suitable for commercial, military, and satcom applications.

Additionally, the Hades X2 E-band active diplexer specifically targets applications that demand high power and efficiency. The diplexer achieves high efficiency and minimal power consumption through advanced GaAs MMIC technology and state-of-the-art thermal management, equipping it for sustainable network deployments. ■

5G O-RAN Performance Testing Focus of Collaboration

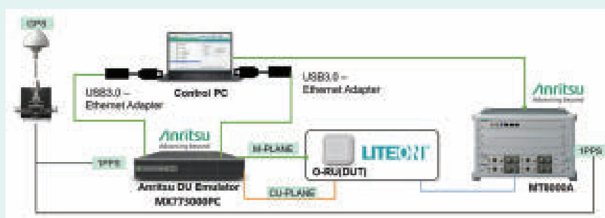
ANRITSU AND LITEON TECHNOLOGY are forming a partnership to advance performance testing for 5G New Radio (NR) Open Radio Access Network (O-RAN) solutions. LITEON will use Anritsu's MT8000A Radio Communication Test Station and MX773000PC Open Distributed Unit (O-DU) Emulator Platform Software Solution to help verify open radio units (O-RUs).

LITEON's 5G private network solutions include sub-6-GHz O-RUs compliant with O-RAN standards. They integrate software, firmware, and hardware to achieve greater flexibility within an open architecture, accelerating O-RAN deployment.

Open RAN interfaces are increasingly replacing legacy radio access networks in devices, enabling the creation of more cost-effective, flexible, and scalable RANs. As a contributing member of the O-RAN Alliance, Anritsu offers testing for both wireless and wired communications for mobile operators.

The MT8000A test solution, which supports non-signaling RF testing for 5G NR mmWave and sub-6-GHz base stations, is compliant with 3GPP TS38.141-1 and TS38.141-2 specifications, reducing time and cost in making 5G BTS radio units. The MX772000PC software enables automated O-RU testing, while the MX773000PC simulates O-DU operations, connects O-RUs, and performs O-RAN.WG4.CONF testing for O-RAN fronthaul requirements.

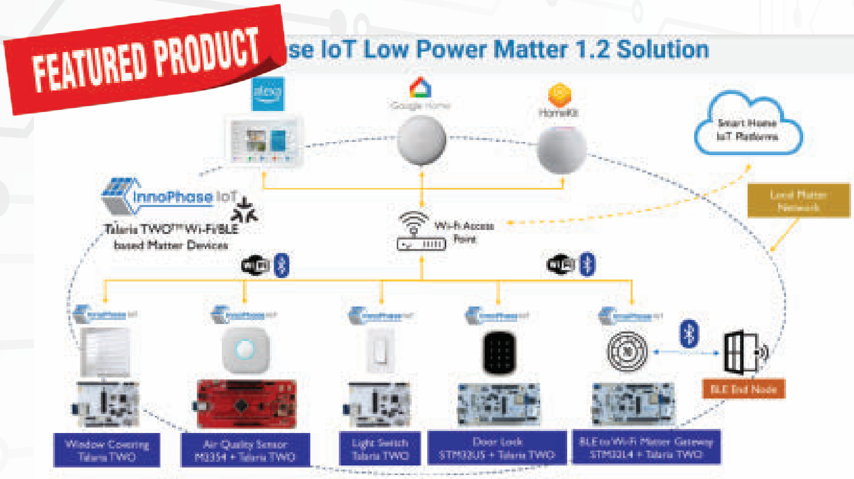
Antritsu



According to Richard Chiang, General Manager of Smart Life Applications SBU at LITEON, "Anritsu is an important partner for LITEON in advancing 5G base station from development testing to product verification. Anritsu's test equipment accelerates the quality and stability validation of our sub-6 RU M-Plane, CU-Plane, and automated testing. LITEON continues to be committed to delivering comprehensive 5G solutions to support the industry in promoting O-RAN open architecture and assisting customers in advancing commercial deployment."

Ivan Chen, General Manager of Anritsu Taiwan, added, "LITEON is a key partner for Anritsu in promoting O-RAN technology. This collaboration demonstrates Anritsu's ability to verify mobile communication technology, meeting various testing needs and fully supporting 5G O-RAN test solutions, continuing to lead at the forefront of testing technology." ■

Matter-Enabled Wi-Fi SoC Supports Device Interoperability



TO ADDRESS SMART-HOME IoT applications such as Wi-Fi-enabled smart locks, lighting, thermostats, and sensors, InnoPhase IoT announced the availability of its Talaria TWO Matter v1.2 certified Wi-Fi solution. The single-chip SoC device uses the Matter protocol to ensure vendor-independent device compatibility as well as easy setup and operation. The solution offers up to a 4X improvement in battery life and provisioning via Bluetooth Low Energy (BLE) while providing high levels of security.

Offering a standalone operation that provides the most power, size, and cost-efficient option, customers can also use an external MCU host. This would offload Matter protocol processing onto the Talaria TWO SoC so that developers can use MCU processing and memory resources for custom purposes. One can also select a Cortex-M0- to Cortex-M85-based processor appropriate for the application.

The Talaria TWO solution enables a Matter-over-lowest-power Wi-Fi approach, rather than Matter-over-Thread, eliminating the need for a bridge border router.

A full-stack software development kit uses FreeRTOS and provides edge-to-cloud software for custom IoT applications, with a GCC toolchain and an eclipse-based IDE for software development. It also includes Matter reference application profiles for smart lighting and door locks, with support for Amazon's AWS and Microsoft Azure platforms.

In addition, there's a standalone Talaria TWO Evaluation Kit, along with reference designs combining Talaria TWO modules with the Nuvoton M251 and Nuvoton M2354 MCU series hosts. The solution is scalable to other MCUs through a HAPI interface between Talaria TWO and MCU hosts.

"Nuvoton is excited to be working with InnoPhase IoT to deliver Matter 1.2 solutions," said Chad Wu, Nuvoton's Vice President of the Microcontroller Business Group. "Combining Nuvoton's highly secure NuMicro microcontrollers and microprocessors with InnoPhase IoT's ultra-low-power Talaria TWO Wi-Fi/BLE modules in a Matter reference design notably speeds up market entry for smart-home device customers, enabling a rapid launch advantage."

Wiren Perera, InnoPhase IoT President and COO, added, "Achieving Matter 1.2 certification is a game-changer in secure device connectivity, ensuring that smart-home devices work together seamlessly. Our Talaria TWO delivers Wi-Fi at ultra-low power levels synonymous with shorter-range technologies, unleashing truly untethered secure IoT devices.

"Next, it was important to provide manufacturer and ecosystem-independent interoperability for consumers. A scalable Matter 1.2 certified capability addresses this challenge for a wide range of smart-home applications from appliances through entertainment and comfort to utilities and services."

The First Gold-Plated Plastic Microwave Connector

AT IMS 2024, Corning Incorporated introduced what it called the world's first metal-plated plastic microwave connector ready to reduce costs and maximize installation flexibility in the telecom and aerospace sectors.

Based on its proprietary Polylink technology, the materials giant said the gold-plated plastic blindmate interconnects turn out to be lighter and less costly than traditional components manufactured out of beryllium copper. The parts also feature compatible interfaces and high performance that extends up to 26.5 GHz. The company also said that their inherently more flexible, which is increasingly vital to the microwave connectivity field.

The Polylink technology saves more than 30% of the weight of Corning's copper-based interconnects in a similar form factor, weighing only 0.06 grams with a center-to-center spacing of 0.0135 in. The new connector family is also ideal for 5G networks as well as aerospace, defense, and automotive systems due to its high degree of flexibility. More specifically, the Polylink technology features up to 0.005 axial compression.

Corning said Polylink also features a faster manufacturing process. The quick molding speed for plastic polymer materials accelerates fabrication times compared to its traditional interconnects. On top of that, the connectors offer cost advantages because they're based on plastic polymers instead of copper. All these features, said Scott Flint, business director of the aerospace and defense unit within Corning Advanced Optics, give it the edge in "low-to-medium frequencies, especially when payload and cost efficiency matter most."

The company's traditional metal blindmate interconnects will be on display at IMS, too. These are widely used in telecom and radar systems as well as naval, airborne, and ground-based missile programs for the defense industry.

Pulsed S-band Transmitter Leverages GaN-on-SiC

EMPOWER RF SYSTEMS was at IMS 2024 (Booth 1730) showing off its Model 2254 S-Band pulsed transmitter. This air-cooled, high-power transmitter operates from 2,900 to 3,500 MHz and meets the demanding requirements of radar, electronic-warfare, and directed-energy research applications.

With its peak power output of 15 kW, the 2254 is said to be one of the most powerful S-band transmitters in its class. Thanks to a duty cycle of up to 20% and pulse widths of up to 500 µs, this Class AB transmitter can drive sustained high-power pulses for extended periods, ensuring reliable performance in mission-critical scenarios.

The amplifier subsystem features multiple, high-power, gallium-nitride-on-silicon-carbide (GaN-on-SiC) power transistors that offer wide frequency response, high gain, high peak power, and low distortion. High reliability and efficiency are achieved through the use of advanced broadband RF matching networks and combining techniques, EMI/RFI filtering, and qualified components. Each drawer in the rack enclosure includes integral forced-air cooling. The system operates from 180 to 260 V AC, three-phase.

A built-in control and monitoring system includes protection functions, while remote management and diagnostics are handled via an Ethernet port to a LAN. Operators can manage functionality remotely using either a web browser or machine-to-machine interface, or they can use the system's built-in touchscreen.

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MAXIMIZING BATTERY LIFE IN MEDICAL WEARABLES

Learn how efficient battery power management in medical wearables is of critical importance due to the increase in power-hungry features to make these devices smarter.

by ***John Varela Munoz,*** *Systems Manager, Medical Sector, System Engineering and Marketing, Texas Instruments*

Rogelio Armino, *Systems Engineer, Medical Sector, System Engineering and Marketing, Texas Instruments*

THE MARKET FOR wearable medical devices is rapidly expanding. Not only are more devices receiving government-standard clearance to diagnose illnesses and monitor life-critical biomarkers, but more users are interested in more personal data to improve their lifestyles. The capability to track metabolic performance, stress, and sleep quality are especially popular features sought by consumers.

Makers of wearable medical devices strive to achieve smaller size, lighter weight, longer operation times, and smarter feature sets. Often, though, these traits outpace battery advances, so designers must develop novel ways to use batteries with greater efficiency, and thus increase overall functionality.

Regardless of power topology, the challenges are constant—wearable medical devices require:

- Low quiescent current (I_q) and shutdown features to increase their shelf life.
- High efficiency to extend their lifetime in active mode.
- The ability to tolerate and manage dynamic fast transient loads typical of radio transmissions.

Low-power microcontrollers (MCUs), edge artificial-intelligence (AI) processing, and analog integrated circuits (ICs) are available, but it's not always possible to leverage these technologies in a design without optimizing power management. It's important to choose the right power architecture for the application to increase efficiency and extend battery run times.

In this article, we'll highlight different power schemes and new technologies in load switches, DC-DC converters, and battery chargers that can maximize battery life in disposable and reusable wearable medical devices for both shelf/ship-mode and active mode.

Types of Batteries Used in Medical Wearables

Devices such as heart-rate monitors, multiparameter patches, blood-glucose monitors, blood-pressure monitors, pulse oximeters, fitness monitors, activity monitors, and drug-delivery patches can be portable and wearable. Many of these devices are disposable or use batteries that need replacing. Furthermore, current wearable medical devices can connect to an increasing number of smart devices and support multiple protocols, resulting in higher power consumption.

Alkaline, lithium-manganese-dioxide ($LiMnO_2$), and lithium-ion (Li-ion) batteries have been staples in wearables because of their high energy density, lifespans, and rechargeability. But recent advances in newer chemistries are now enabling new possibilities and implementations. Silver-zinc and zinc-air allow for longer active-mode capacities, while silver-oxide adds low self-discharge rates of approximately 10% a year or less, leading to a longer shelf life.

Battery chemistry	Cell voltage (V)	Energy density (Wh/L)	Self-discharge rate (%/month)
$LiMnO_2$ (CR1220)	3	146	5-10%
Silver-oxide (SR716SW)	1.55	262	<1%
Zinc-air (10)	1.4	1,225	0.2%
LiPo	3.7	90	5%-10%
NiMH (HR-4U)	1.2	210	30%

Table 1: How cell voltage, energy density, and self-discharge rate vary with battery chemistry. Images courtesy Texas Instruments

In this article, we'll highlight different power schemes and new technologies in load switches, DC-DC converters, and battery chargers that can maximize battery life in disposable and reusable wearable medical devices for both shelf/ship-mode and active mode.

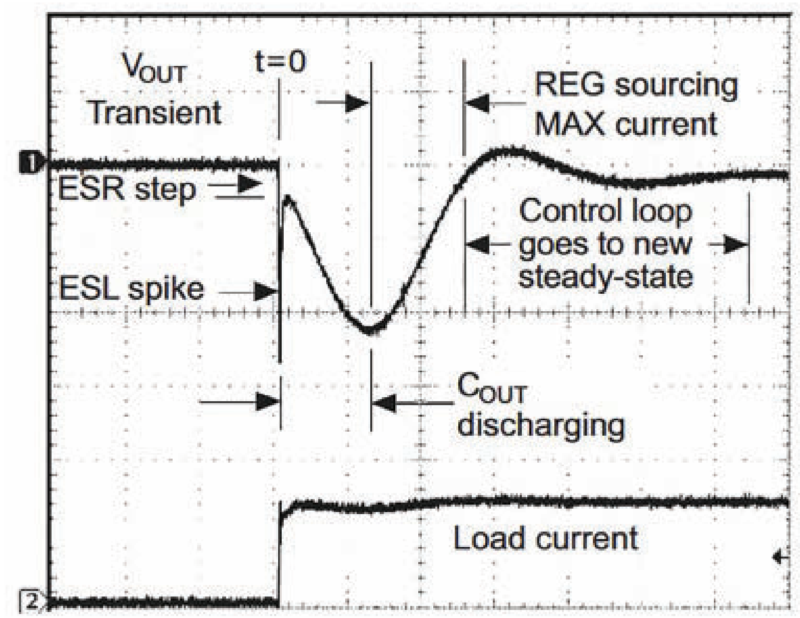
There are also new developments in rechargeable battery technologies. Lipolymer (LiPo) batteries allow for flexible battery designs that can be molded to small wearables. And solid-state batteries are becoming affordable enough to implement into wearables, bringing high energy densities and flexible form factors without safety concerns. Nickel metal hydride (NiMH) remains popular for continuous use and long lifetimes at a lower cost. Low-discharge-rate NiMH is available, too.

One trend with high-energy-density battery chemistries is to lower cell voltages *(Table 1)*, which requires power solutions operating at higher efficiencies without high headroom under peak loads. Unfortunately, the high peak currents, from functions like RF data transmission or turning on a motor, could cause the battery voltage to dip low enough to trigger brownout for critical ICs.

Designers must carefully select the battery chemistry based on several system-level requirements, while also complying with safety and regulatory standards. One example of a tradeoff is optimizing batteries with different AC and DC internal impedances for applications with specific high or low drain profiles while balancing the self-discharge rate based on the wearable's expected lifetime. For disposable wearables, low self-discharge is an important requirement versus rechargeable wearables.

Optimizing Active and Standby Mode Transitions in Wearable Medical Devices

While in active mode, medical patches (electrocardiograms, temperature, and glucose) will typically spend a short amount of time to take a measurement, process or pre-process the data to send to



1. Fast load transitions cause large voltage transients in the main voltage supply line.

a remote terminal, and then go back to sleep. In this situation, the batteries see loads quickly transitioning from hundreds of nanoamperes to a few tens of milliamperes in sensing patches, or even higher currents for drug-delivery patches with motors and pumps.

Such a scenario is shown in *Figure 1*, where a step load in the bottom waveform causes large voltage transients in the main supply line shown in the top waveform. The primary challenge is when systems that can operate efficiently across different loads also must handle transients as fast as a few microseconds.

Consider the example in *Figure 2*, which illustrates the use of Texas Instruments' (TI) CC2340R5 Bluetooth Low Energy (LE) MCU with a low-voltage battery chemistry in a wearable application. Because the input voltage of the Bluetooth LE device only goes down to 1.7 V, you can use a boost converter (for example, TI's TPS61299).

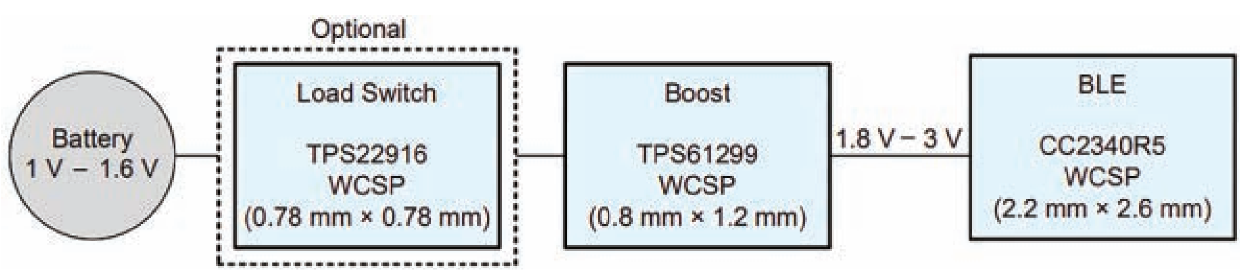
Typically, as the Bluetooth LE device goes from sleep mode to a connection event, the load currents will increase very rapidly and cause a large voltage dip at the main supply rail. This is especially the case when using a battery chemistry with high equivalent series resistance and equivalent series inductance. To sustain these dips and not have parts of the circuit go into brownout, devices like the TPS61299 incorporate a fast-mode detection control loop that can stabilize the supply voltage and reduce settling times down to 8 µs for typical Bluetooth LE loads.

In applications like insulin pumps and drug-delivery patches, the load transients from the dosing pumps might be too high for traditional compensation methods. In this scenario, large supercapacitors can quickly provide the energy needed by high-drain components. TI's TPS61094 is a 60-nA IQ buck-boost converter with supercapacitor management that seamlessly transitions between battery and supercapacitor power.

In addition to solving transient response challenges, it's imperative to achieve high efficiency across multiple decades of current loads. TI's DC-DC switching regulator portfolio has several devices designed to address specific challenges present in wearable medical devices.

Pass-through mode allows for buck, boost, and buck-boost devices to connect the load directly to the battery when the input voltage closely matches the chosen output for improved operational efficiency. As the voltage drops, the devices will go into active mode and have several modes of operation. Intelligent switching between pulse-width modulation (PWM), pulse frequency mode (PFM), and burst mode as the load changes from high to low helps the overall system efficiency stay above 85%, from microampere levels to hundreds of milliamperes.

Besides automatically changing between PWM and PFM, TI's TPS62840 buck converter has a 100% PWM mode that only draws 120 nA of IQ. This lets



2. Implementing a boost converter like the TPS61299 can stabilize the supply voltage for typical Bluetooth LE loads.

the system keep operating with high maximum efficiency even when the battery is near depletion.

Another way to solve the transient problem is to increase efficiency during both low- and high-current modes. TI's TPS63900 buck-boost converter has two different programmable voltages. For example, the device can boost to 3 V as the CC2340R5 is about to wake up, thus enabling the radio to operate more efficiently. The converter can then drop to 1.8 V in standby mode when only a few IC blocks are turned on.

Table 2 lists the devices mentioned in this section along with their unique current consumptions in different modes.

Converter type	Part number	I_Q	Shutdown
Boost	TPS61299	155 nA	60 nA
Boost plus supercapacitor	TPS61094	60 nA	200 nA
Buck	TPS62840	60 nA	25 nA
Buck-boost	TPS63900	75 nA	60 nA

Table 2: How Iq and shutdown current consumption vary with different voltage converter topologies.

Prolonging Battery Life Through Low-Power Ship Mode and Smart Load Switches

Most wearable medical devices aren't active while packaged because weeks or months can pass before they make their way to the user (or patient). A dedicated low-power mode helps preserve battery life while the product travels from the manufacturer to the consumer.

In what is also known as "ship mode," the device is placed in a high impedance state and current leakage is effectively suppressed. Only a few extremely low-I_q devices remain powered in ship mode to detect when the device will begin active use.

In addition, a ship mode with minimal shutdown currents helps maximize the power available when the product eventually goes into active use. This becomes exceptionally important if the device is designed to work with disposable batteries.

Consider an example of a wireless patch using a 1.5-V silver-oxide battery with 150 mAh of capacity. To last a year while inactive, a wearable medical device could use a load switch to minimize current consumption. If the product's system components draw approximately 1 µA when disabled, that amount is consuming at least 8.76 mAh (1 µA × 24 hours × 365 days) of the 150-mAh budget.

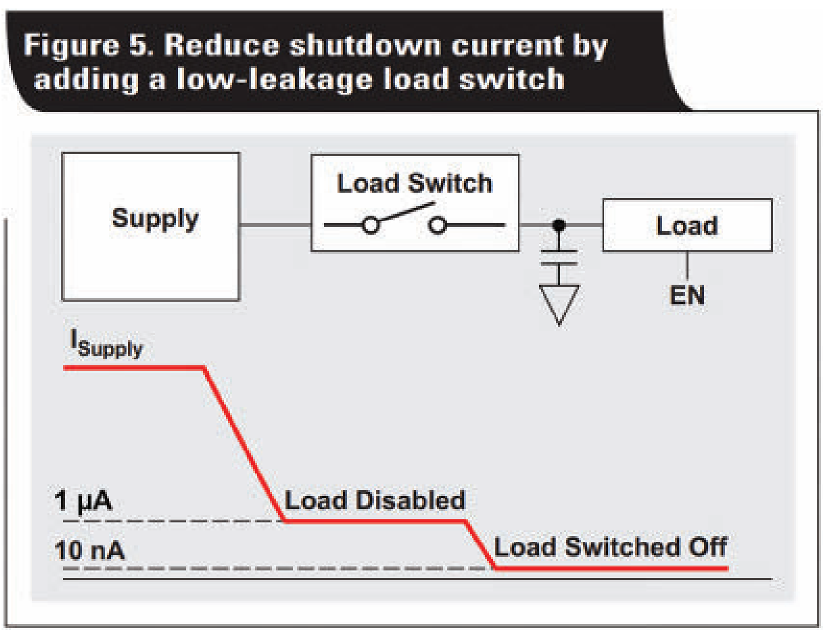
In other words, device inefficiencies could contribute around 5.84% (8.76 mAh/150 mAh) to overall battery loss. These inefficiencies may originate from losses such as minimum and maximum specifications over temperature, efficiency loss through the power components, and radio modules leaking current.

Devices such as load switches with shutdown currents down to nanoampere ranges help save power over long periods. Load switches work as electrically controlled switches, capable of significantly decreasing current from the supply when a module doesn't need to be active *(Fig. 3)*.

A load switch like the TPS22916 (0.8 × 0.8 mm) can cut the shutdown leakage current down to 10 nA, an amount that will have virtually no effect (0.058%) on battery life while the system is disabled *(Table 3)*.

If there are multiple individually powered modules in a single product, it's possible to have more than one load switch disable individual loads and modules. This increases the power architecture's ability to tightly manage power consumption on an as-needed basis.

Other integrated low-I_q devices include DC-DC converters with shutdown features such as true disconnect, which can



3. A load switch like the TPS22916 can reduce current consumption to as low as 10 nA.

Input source	Capacity	Shutdown period	Shutdown current	Loss of capacity	Loss percentage
Silver-oxide battery (1.5 V)	150 mAh	365 days	1 µA	8.76 mAh	5.84%
			10 nA	0.0876 mAh	0.0584%

Table 3: The impact of lower shutdown currents on effective battery capacity after long shelf/ship-mode time periods.

minimize leakage currents to prevent power losses during shutdown. Most DC-DC converters can now reach shutdown currents of 60 nA or lower, which facilitates device selection and reduces cost by eliminating the need for an additional load switch IC. Although not always as effective as a load switch, the ability of a DC-DC converter to act as a load switch may be the deciding factor when size is an important consideration.

Getting Charge into Batteries

Battery charging for wearable medical devices is a challenging subject because batteries in these products must be small in both size and capacity. Charge currents and patterns vary greatly depending on battery capacity and chemistry. The ability to charge wirelessly also introduces a higher level of complexity.

While it's important to charge quickly, it's also crucial to get as much energy into the battery as possible. This can be accomplished with specific techniques such as low termination current and careful monitoring of the battery level. Maximizing the charge of each battery cycle is achievable through careful selection of devices designed for the specific application.

Although disposable wearables are most common right now, the convenience of reusability is important to consumers, who prefer fast charging with a wireless charger or easily attachable cable. Environmental considerations also drive the transition toward more rechargeable devices for their reusability.

One major advantage of battery-charging devices is their high level of integration. It's possible to employ varying levels of power integration, depending on a design's available space and power needs. Battery-charge-management solutions for wearables such as TI's BQ25125 (2.5 × 2.5 mm) and the BQ25155 (2 × 1.6 mm) can provide efficient battery current draw by integrating various power solutions into one small chip.

Although disposable wearables are most common right now, the convenience of reusability is important to consumers, who prefer fast charging with a wireless charger or easily attachable cable. Environmental considerations also drive the transition toward more rechargeable devices for their reusability.

Useful features such as integrated ship mode and low-I_q DC-DC converters further preserve battery life. Battery monitoring is also very accurate in these devices, which can help in the design of more efficient systems.

There are multiple ways to improve battery life in wearable patient monitors and medical patches. The key to long battery life is to select devices that operate with the lowest current consumption and effectively reduce system activity to when it's not needed. The power architecture plays a significant role in achieving longer battery life. ■

Improve RF System Reliability by Understanding Thermal Analysis

Understanding how thermal analysis and design is critical to meeting reliability standards for semiconductor technology translates into more robust and reliable RF system designs.

By David Schnaufer, *Technical Marketing Manager, Qorvo*

WE ALL EXPECT semiconductors to work reliably in the harshest environments with device failures kept to an absolute minimum. But problems inevitably arise—and from an environmental perspective, temperature is the primary reason for most semiconductor field failures *(Fig. 1)*.

Thus, thermal design and analysis are critical to improving component reliability, with higher temperatures generally reducing component life. This can be due to a harsh operating environment without adequate system-level protection, which in turn can result from an incomplete understanding of the thermal aspects of semiconductor devices, packaging, layout, and heatsinking. In addition, it can be difficult to make thermal measurements on RF devices at the design-verification stage.

This article looks at the basic concepts of thermal behavior in semiconductors and how to practically measure and analyze temperature and thermal properties. And it covers some of the fundamentals that design engineers should understand to ensure they can create reliable systems.

Fundamentals of Thermal Properties

Let's begin with some thermal basics. Temperature is a measurement of hot or cold—and heat is simply the product of the atoms' energy. Thermal conduction is the transfer of internal energy by microscopic collisions of particles and movement of electrons within a material.

In any semiconductor component or system design, we must consider the thermal aspect to ensure the end-product is reliable, performs optimally, meets certification criteria, and works in all of the required environments. This means that we need to know the device temperature and how to control it.

Heat will always move from hot to cold or cooler temperatures. In addition, the amount of heat passing through something like a semiconductor or printed circuit board (PCB) depends on the thermal conductance of the material and the temperature on either side. The lower the thermal conductance of the material, the less heat will pass through for a given temperature drop.

In a semiconductor application, we always try to provide the highest thermal conductance possible for efficient heat removal from the semiconductor or heat source. The reciprocal of thermal conductance is called thermal resistance, which we wish to minimize.

In our product designs, we want to control or keep the semiconductor device as close to room temperature (about 75°F or 25°C) as possible. But as is known, this is rarely possible without a controlled environment.

Understanding Thermal Resistance and Heat Transfer

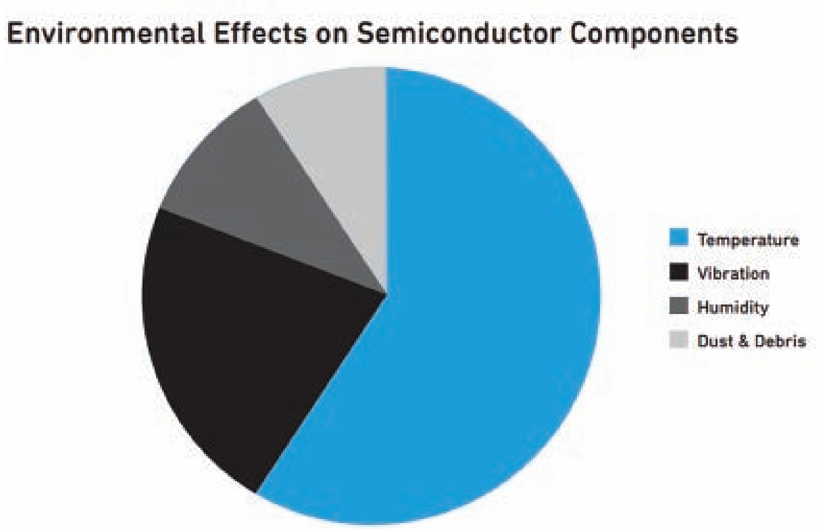
Thermal resistance is the measure of a material's ability to resist heat flow. In general, when talking about semiconductors, we would like our semiconductor material, bonding material, PCB material, and so on, to have a very low thermal resistance (R_{th}), so that heat flows freely to the ambient air. *Figure 2* illustrates some of the formulas associated with heat transfer and thermal measurement.

- *Thermal conductivity:* The ability of a given material to conduct/transfer heat.
- *Thermal resistivity:* The ability of a given material to resist the conduction/transfer of heat.
- *Thermal resistance:* Like resistivity, but it takes the shape and size of the material into account.
- *Thermal impedance:* Like resistance, but it doesn't factor in the footprint size of the material and often includes interfacial resistances to provide an effective value for a layer within a stack.

The analogy of an electrical resistor network in *Figure 2* illustrates the thermal resistance of a packaged semiconductor device. This represents the electrical resistor equivalent circuit, starting from the heat source (transistor junction or channel) through the two possible pathways for heat transfer.

In this electrical resistor model, the electrical resistance is defined by the potential difference (voltage) across the resistor divided by the current through that resistor. In thermal resistance, the thermal potential difference (temperature) divided by the thermal current (heat flow) through the thermal resistor defines the thermal resistance R_{th}.

In the first pathway, heat transfers from the transistor junction or channel through the mold compound by conduction, and then to the air surrounding the device by convection. In the second dominant pathway, which is parallel with the first, heat flows from the junction or channel of the device through the lead, through the PCB, into the chassis by conduction, and finally to the surrounding air by convection. Because most of the heat generated in the device is transported through this second pathway, it's the primary focus for calculating the junction (or channel) temperature.



1. This pie chart of environmental effects in semiconductor component applications reveals that temperature is the main culprit in device failures in the field. Images courtesy Qorvo

Three Methods of Estimating Device Temperatures

1. ***IR imaging:*** Used to measure the temperature of a semiconductor surface. It measures electromagnetic radiation emissions, primarily in the IR wavelength unseen by the naked eye. It deals with light wavelengths in the 0.7- to 2.0-µm range of the electromagnetic spectrum.
2. ***Thermoreflectance:*** Measures the relative changes in reflectivity of the semiconductor induced by periodic variation of temperature. The basic idea is to modulate the semiconductor sample temperature and register the changes in reflectivity. The spatial resolution depends on the excitation laser spot size. The smallest size for a 630-nm probe beam wavelength is diffraction limited, therefore providing a spot diameter of about 0.5 µm.
3. ***Micro-Raman spectroscopy:*** This measurement is the most accurate. It's used for the identification of different molecules and functional groups present within larger molecules and greatly enhances the spatial resolution. Micro-Raman spectroscopy measures into the epitaxial layer with a spot size of 0.15 µm, which provides a more accurate maximum junction temperature measurement.

Making Thermal Measurements

In electronics, engineers use terms like junction or channel temperature, maximum temperature, heat dissipation, and power dissipation, all of which describe heat generation or the impacts thereof. When reviewing any datasheet, it's important to understand these terms and how the thermal data lines up with your application.

The first step in understanding system thermal measurements involves looking at the semiconductor device itself. The device datasheet will provide valuable device thermal information, which can be used to determine the highest temperature or power dissipation it can handle. The datasheet reference is a good start, but in an application setting, all device interactions must also be considered.

On the device datasheet, manufacturers can use several methods of measuring and providing device thermal data. From a semiconductor perspective, manufacturers can optically measure junction or channel temperature (Tj or Tch) using one of three main methods: infrared (IR) image, thermoreflectance, and micro-Raman spectroscopy. In addition, companies will employ computer models to estimate device and system-level temperatures in a given application. *Figure 3* shows the way these three methods are applied.

All three approaches in *Figure 3* measure temperature without touching the surface of the semiconductor *(see "Three Methods of Estimating Device Temperatures")*. IR imaging simply measures the thermal radiation coming off the surface of the semiconductor. Thermoreflectance provides its own radiation at the surface and then detects it in addition to the surface's natural radiation (which then gets subtracted out).

Micro-Raman is a more expensive and time-consuming measurement technique. However, it's the most accurate because it measures the temperature within the epitaxial layer with extreme resolution. In some instances, such as measuring gallium-nitride (GaN) semiconductors, this level of precision is required.

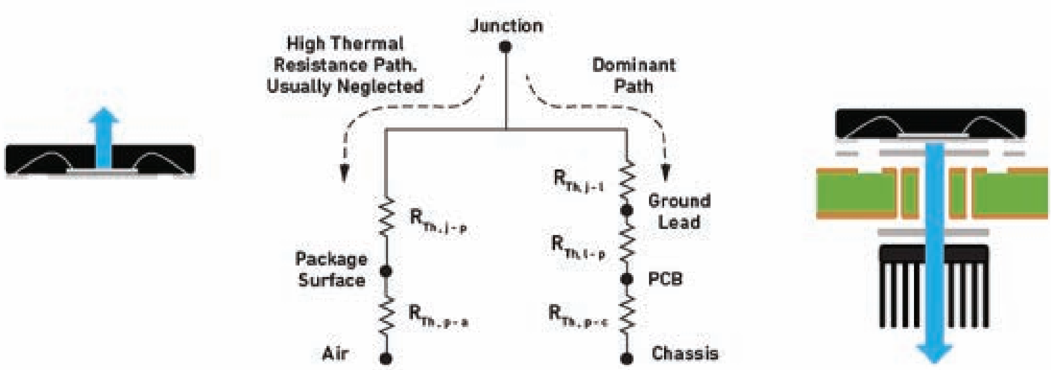
Most companies use IR imagery to make this Tj or Tch determination. It's the easiest to use, cost-effective, and most accessible, but it provides a lower measurement value due to averaging across the surface region above the channel.

In an application, several methods are utilized to determine the temperature. One is modeling; another is IR imaging as described. Models are often used to determine temperatures in applications, but at times empirical measurements are required. Also in the mix are thermocouples or thermistors. A thermocouple measures with a voltage while a thermistor uses electrical resistance, changing its physical resistance when exposed to changes in temperature.

To perform thermal analysis of GaN devices and GaN MMICs, it's recommended to use an integrated approach that combines device modeling, empirical measurements (including micro-Raman thermography), and finite-element-analysis (FEA) simulations.

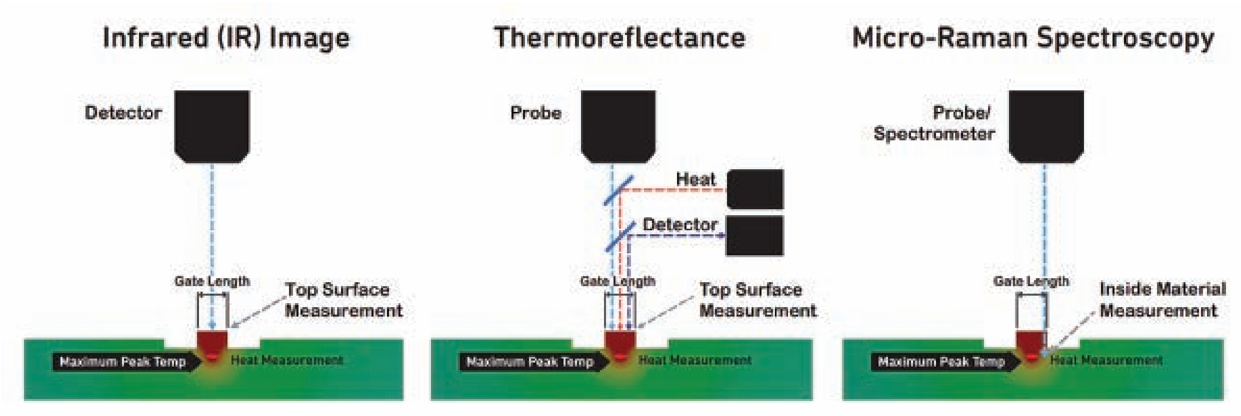
This methodology has proven to be the most effective and accurate. With this approach, once the baseline thermal model development is completed, FEA is employed to accurately predict channel temperature and thermal resistances at the device level.

- Thermal Conductivity = k
- Thermal Resistance = $\frac{l}{(k)(A)}$
- Thermal Resistivity = $\frac{1}{k}$
- Thermal Impedance = $\frac{l}{k}$



- Temperature Change °C = Rth Junction to Case × Pdiss Watts
- Max. Junction Temperature at Max. Case (Tbase) Temp = Temp Change °C + Max. Case Temp°C
- Tbase = Interface Between Part and PC Board/Heatsink

2. Shown are some of the formulas associated with heat transfer and thermal measurement.



3. These diagrams outline IR imaging, thermoreflectance, and micro-Raman thermal measurement methodologies.

Semiconductor reliability is partly defined by estimating a device's maximum junction or channel temperature to determine a projected lifetime. These values are gathered by measuring and modeling thermal resistance, power dissipation, and heat transfer.

Performing System-Level Thermal Analysis

A successful system-level design relies heavily on having a good heat path from the semiconductor to the external environment. Careful consideration of the heat-flow path is needed at all levels—device, package, PCB, and final heatsink. High-power GaN devices will require fan-cooled, finned heatsinks or liquid-cooling systems for adequate cooling.

Semiconductor reliability is partly defined by estimating a device's maximum junction or channel temperature to determine a projected lifetime. These values are gathered by measuring and modeling thermal resistance, power dissipation, and heat transfer.

In an application, the maximum junction or channel temperature is a key metric. Depending on a single method isn't good practice—thermocouple/thermistor measurements, modeling, and IR imagery should all be employed. In a package, we should use a model to determine the maximum case temperature under the device to estimate the junction temperature based on package thermal resistance.

Another nice-to-have element in system-level thermal analysis is a bulk thermal model of the semiconductor component. Obtaining this model from a semiconductor supplier will help customers mimic the output heat flux of the component. It assists with customers' estimates of maximum backside temperature of the product and what it will experience when operated in the customer's system design. In addition, the bulk thermal model provides greater insight into how neighboring devices are impacted by the waste heat from the supplier's product.

Thermal Analysis and Modeling Are Critical

Understanding and determining the thermal performance of both semiconductor devices and system designs are critical to ensuring your product functions optimally, reliably, and without problems, as well as maximizing its useful lifetime.

Thermal analysis and modeling is a complex subject, with methods such as FEA required for sophisticated design work. However, understanding the basics, as explained in this article, does help system engineers with design considerations and thermal measurements, enabling them to better understand the component data provided by suppliers. ■

What You Missed at IMS 2024 (Part 1)

This roundup recaps our coverage of this year's International Microwave Symposium.

By MWRF Staff

HERE, WE OFFER roundups of coverage from the 2024 edition of the International Microwave Symposium (IMS) in Washington, D.C. This is Part 1 of 4. Check out Parts 2, 3, and 4.

Reactel (Booth 814) offers its full line of application-specific RF, microwave and mmWave filters, multiplexers, and multifunction assemblies, with an emphasis on devices at up to 67 GHz. The AS9100-accredited vendor's devices are well-known among prime military contractors such as Lockheed Martin, L3Harris Technologies, BAE Systems, and Northrop Grumman in ground, airborne, and space applications.

At the booth (or online), we were able to grab the company's new short-form catalog of bandpass, lowpass, highpass, and notch filters in various topologies, including tubular, LC, cavity, waveguide, ceramic, and suspended substrate.

Analog Devices (Booth 1239) had its typically dominant presence at IMS, both

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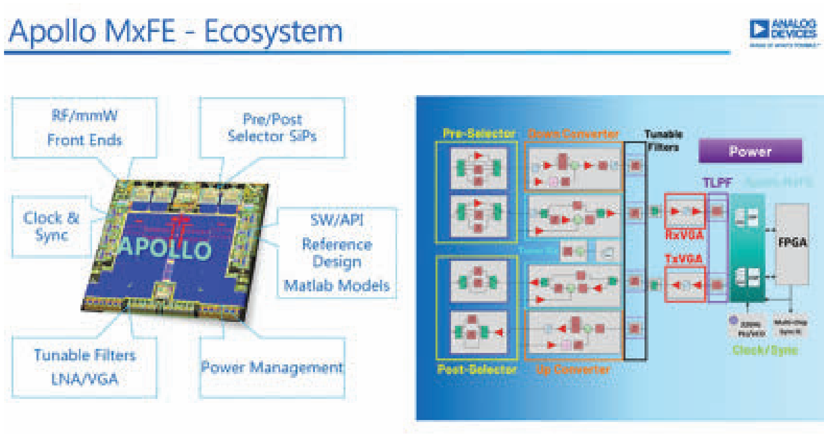


ADI's Apollo MxFE mixed-signal front end was demonstrated in a variety of contexts at IMS 2024. Analog Devices

on the show floor and in the technical sessions. The booth was bursting with demos of products for the aerospace/defense, instrumentation, power, and cloud/communications markets. One that looks particularly interesting is an 8T8R Open RAN radio-unit reference design. Aimed at helping reduce design times, the Kerberos reference design is for O-RAN-compliant split 7.2A applications.

On the aerospace/defense side, a selection of demos involved ADI's Apollo MxFE, a mixed-signal front-end that was the talk of IMS 2023 in San Diego. One year hence, ADI is primed to show off the device's depth and breadth of application versatility. It offers sampling rates of up to 40 Gsamples/s.

Nuvotronics (Booth 427) showed its line of mmWave/RF systems for high-frequency applications. The company presented demos of:

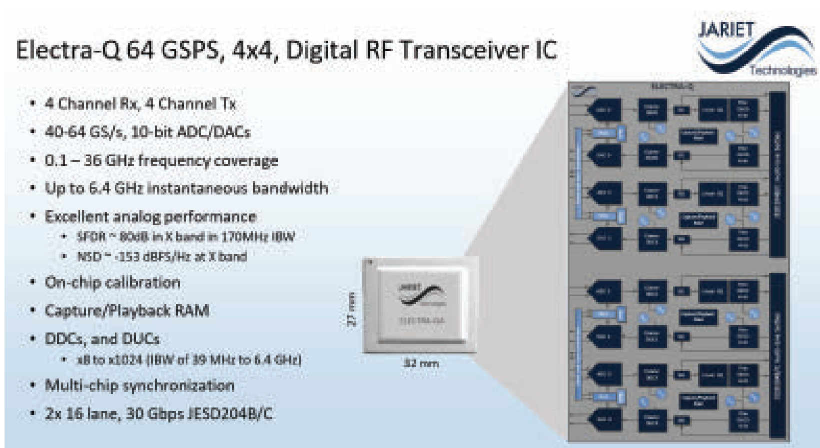
- *Filters* delivering narrowband machined filter performance or wideband performance using the company's PolyStrata suspended substrate technology. The easy-to-integrate devices come in an SMT form factor with a 100X smaller volume than conventional filters,
- *Combiners* for solid-state power amplifiers in ultra-broadband and mmWave applications; these devices come in a connectorized fixture that is 100X smaller at 1% of the weight compared to conventional waveguide combiners, and
- *Couplers* that provide size, weight, and performance advantages in SMT form factors with 6X to 10X size reductions.

Jariet Technologies (Booth 2326) is expanding its flagship Electra-MA family of data-converter transceivers. The expanded portfolio addresses the needs of radar, satellite communications, test equipment, and quantum computing with offerings from 100 MHz to 36 GHz and increased port density. The Electra platform provides direct RF sampling from VHF to Ka-band at ADC/DAC sample rates up to 64 Gsamples/s.

The devices' 36-GHz bandwidth enables software-defined-radio (SDR) applications at double the frequency previously possible and with signal instantaneous bandwidth (IBW) up to 6.4 GHz per converter. Electra is said to more than triple the clock rate of the nearest competitor's ADC, and more than double the nearest DAC. The 10-bit, 64-Gsample/s ADCs deliver 10 dB better noise spectral density (NSD) and 17 dB better noise figure (NF) at 9.5 GHz than the best 14-bit ADCs.

Keysight Technologies (Booth 721) offered several demonstrations of its capabilities in test methodologies and EDA tools:

Wideband active load-pull: Showcases Keysight's newly introduced wideband active load-pull (WALP) capability using a dual-channel VXG-C vector source and a PNA-X network analyzer to demonstrate the error-vector-magnitude performance of a power amplifier when presented with arbitrary frequency-dependent load impedances created without an impedance tuner.



Jariet's Electra family of transceiver ICs includes the Electra-Q, a 64-Gsample/s device with up to 6.4 GHz of instantaneous bandwidth. Jariet Technologies

AI/ML-enabled EDA: Demonstrates Keysight's ADS 2025, which offers 3D Circuit-EM-Thermal multiphysics co-design, high-performance automation enabling AI/ML and robust design validation for RF and millimeter wave. It provides support for wideband power-amplifier design techniques, including nonlinear load pull.

Phased-array antenna test: Showcases Keysight's phased-array control and calibration test solution inside the Vertical Compact Antenna Test Range (CATR), which accommodates a wide variety of phased-array antenna performance verification tests including fast gain and phase calibration, effective isotropic radiated power (EIRP), antenna radiation pattern, antenna gain-to-noise-temperature (G/T), modulation distortion, and radio frequency to direct digital measurements.

Signal-source characterization: Demonstrates how to perform sub-terahertz phase-noise measurements with Keysight's new E5058A 54-GHz SSA-X signal source analyzer and an E5051AW phase-noise measurement downconverter for 6G applications and microwave amplifier residual phase-noise and AM-noise measurements.

Keysight's F9652A vertical compact antenna test range performs several phased array performance verification tests. Keysight Technologies

Quantic Electronics displayed EMI/RF filters, frequency control devices, magnetics, passive waveguides, coaxial components, passives, and much more. Quantic Electronics

IQ data characterization: Highlights how Keysight's vector signal analysis software uses a new feature to precisely characterize a homodyne (IQ) system by characterizing and digitally correcting the frequency-dependent dispersion and imbalance of a Marki IQ mixer.

Quantic Electronics (Booth 1251) presented its bevy of brands spanning electromagnetic-interference/RF filters, frequency-control devices, magnetics, passive waveguides, coaxial components, passives, and much more.

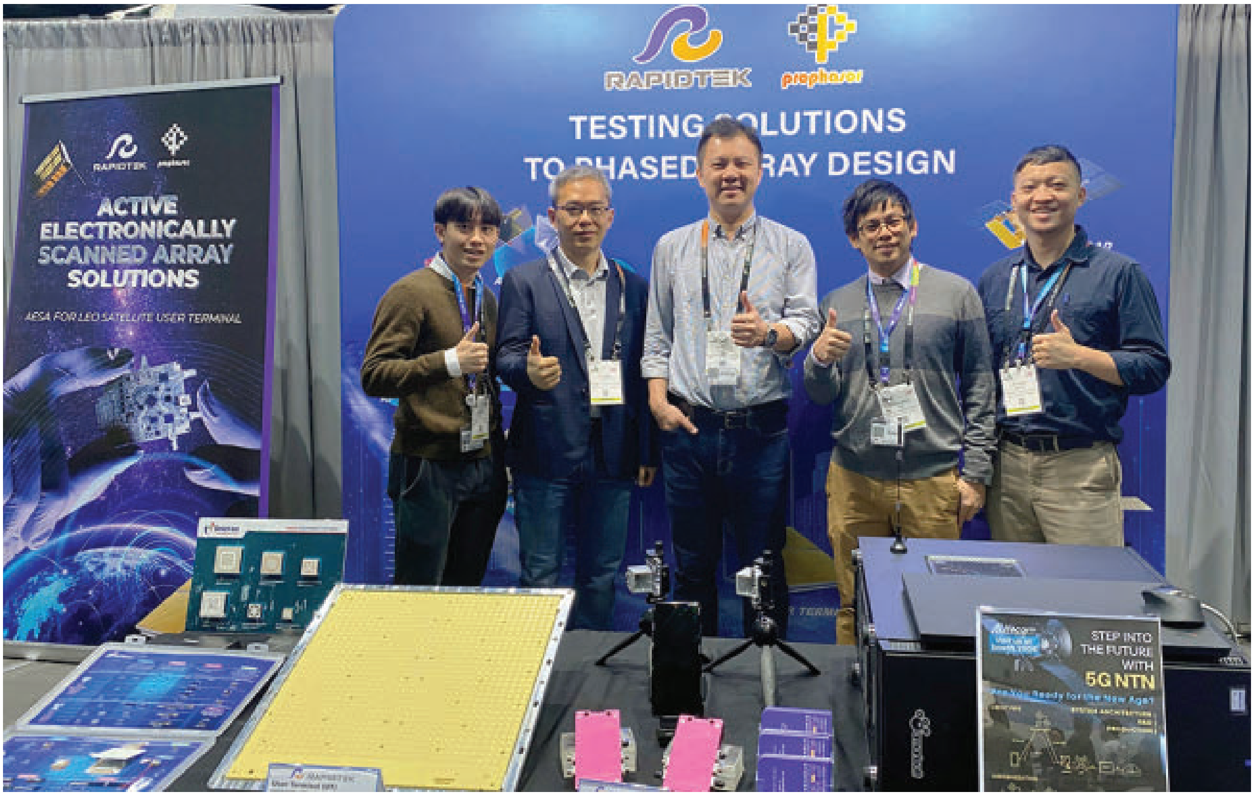
Intended for mission-critical systems, Quantic's off-the-shelf and custom products bring benefits in terms of speed, power handling, and density.

In the booth, the company demonstrated the performance under vibration of its ultra-low, phase-noise frequency-control and timing components. Visitorsalso tried out Quantic X-Microwave's layout tool for signal chains built with its X-MWblock elements, as well as analyzed measured data for the devices.

Rapidtek Technologies (Booth 2249), which designs active electric-scan antennas (AESAs), conducted live joint demonstrations of its next-generation test solution. The demo involved generating a sub-6G baseband signal using Amarisoft's AMARI Callbox and the jointly developed up/downconverter (UDC) system, which enables the generation of mmWave communication test frequency bands ranging from 6 to 48 GHz. It supports testing in frequency bands such as Ku-band, Ka-band, and n257~n262 while offering advanced signaling control. The solution has completed numerous 3GPP standard communication test verifications, including Wi-Fi 6E/7, 5G FR2, and B5G.

In addition, Rapidtek displayed its AESA designs and RF testing solutions, including phased-array antennas, communication payloads, and up/downconverters. These solutions offer reliable and high-performance connectivity for a wide range of low-Earth-orbit (LEO) satellite applications.

On top of that, Rapidtek showcased passive solutions and products in collaboration with its strategic partner, Unictron Technologies Corp. Unictron Technologies offers antennas, antenna modules, and piezoelectric ceramic elements, widely used in various applications such as automobile parking sensors, weaving machine actuators, ultrasonic nebulizers, ultrasonic sensors, and a wide range of ultrasonic transducers.



Rapidtek (Booth 2249) demonstrated its AESA prowess as well as a new mmWave communications test platform. Rapidtek Technologies

TransEON (Booth 2343), a Canadian stealth-mode startup, has developed a new MOSFET-based GaN-on-SiC foundry process that enables fabrication of cutting-edge transistors and MMICs with significant benefits over existing GaN HEMT technology. Key advantages include up to 4X higher operating voltage and RF power density at frequencies ranging from HF up to W-band.

The process includes standard MMIC features to provide turnkey compatibility with existing GaN processes, including through-substrate vias, integrated passives, and Au-plated microstrip on thinned SiC. Among other advantages of the devices are full process customization, design and NRE services, ITAR and ITAR-free compatibility, as well as multi-project wafer access.

TransEON's MOSFET-based, GaN-on-SiC foundry process is said to provide benefits over GaN HEMT technology in discrete devices and MMICs. TransEON

Altum RF (Booth 510) showcased its lineup of broadband Q/V/E-band low-noise and medium-power amplifiers, which are intended for next-generation, high-capacity networks. Applications include test and measurement, SATCOM, sensing applications, and point-to-point wireless communication for 5G and 6G networks. These high-frequency amplifiers use advanced GaAs technology, which delivers a low noise figure and linear amplification with less signal distortion at medium power. ■

POWER AMPLIFIERS Fuel Mil/Aero Ground and Space Systems

Aerospace and defense systems rely heavily on RF/microwave power amplifiers to send often complex-modulated signals to their destinations. Learn more about key specifications and the top RF PA suppliers to defense contractors.

By Jack Browne, *Technical Editor*

HIGH-FREQUENCY SIGNAL LEVELS must be raised to extend the reach of critical electronic systems, such as in radars and tactical communications links. RF/microwave power amplifiers (PAs) provide this function for continuous-wave (CW) and pulsed signals in electronic-warfare (EW), radar, radio, and satellite-communications (SATCOM) systems of many shapes and sizes, drawing upon a variety of active-device technologies.

Some aerospace and defense (A&D) and SATCOM systems still rely on vacuum electronics like traveling-wave tube amplifiers (TWTAs). But most A&D systems count on solid-state power amplifiers (SSPAs) to boost their signal levels. Regardless of technology, higher output power requires larger PA sizes.

Depending on the PA's efficiency, some of the power applied to it will end up as heat needing dissipation. Adding a cooling mechanism, such as a heatsink, can make the overall PA larger. In general, as PA efficiency improves, more power can be produced from smaller packages and less heat must be dissipated. For A&D and many other applications, RF/microwave PAs are available from a multitude of suppliers in myriad shapes and sizes and for a range of frequencies and bandwidths.

RF/microwave PAs are based on several electron-tube and transistor technologies.

Transistors typically provide lower output-power levels in smaller packages, while traveling-wave tubes (TWTs) and TWTAs are capable of higher power levels but in larger enclosures.

For many applications, including airborne data links, communications satellites, EW systems, and radar systems, transistorized SSPAs are gradually replacing tube amplifiers using numerous transistor technologies, including devices based on silicon (Si), gallium-arsenide (GaAs), gallium-nitride (GaN), and silicon-carbide (SiC) substrates.

Key Specifications for RF Power Amplifiers

Selecting a PA for a mission requires sorting through many electrical and mechanical parameters. Electronic performance usually starts with a PA's output power and gain over a given frequency range, which may be narrowband and less than an octave, or wideband and multiple octaves, such as 2 to 18 GHz. Every A&D application carries a set of electronic performance requirements for what's needed in a PA. Tradeoffs can make it challenging to achieve the required values for many performance parameters.

A PA considered linear in behavior provides an output power level as a function of the amplifier's input signal that's raised in level by its gain. Gain varies according to frequency, temperature, and other factors. However, it can be controlled to achieve gain that remains flat, as minimal as ±0.1 dB or less, with changes in operating conditions.

A linear PA must also exhibit minimal distortion so that an input signal's fidelity, such as modulation or pulse characteristics, is maintained as the signal's power level ramps up. Amplifier linearity is denoted by classes, such as highly linear Class A and B amplifiers to more efficient but less linear Class C and D amplifiers (take a Quick Poll on your favorite PA topology).

Achieving high linearity may require extensive testing and additional compensation circuits, but it can impact other PA characteristics like efficiency. Efficiency is a measure of how well an amplifier converts power from the supply to RF power. It's typically specified as drain efficiency or power-added efficiency (PAE). Drain efficiency is the difference between the power from the DC supply and the amplifier's output power, while PAE considers the contributions of the amplifier's input signal power and gain to the PA's output power.

Efficiency is a measure of how well an amplifier converts power from the supply to RF power. It's typically specified as drain efficiency or power-added efficiency (PAE).

When evaluating the efficiency of PAs, similar versions should be compared for similar frequencies, signal types, and other operating conditions. Higher efficiency contributes not only to lower power consumption, but also lower heat generated within the amplifier.

PAs can be characterized for a variety of waveforms in CW or pulsed operation with the output level referenced in some way to the input signal level. Output power at the 3-dB compression point, for example, is the power level at which the amplifier's gain decreases by 3 dB from the linear gain. The output power at 1-dB compression is the output level at which the gain is 1 dB lower than the amplifier's linear gain. Saturated output power is the maximum amount of output power available from a PA, where it doesn't rise even with increases in input level (gain decreases accordingly).

TWTs and TWTAs are widely used in pulsed and CW PAs for A&D applications. And improved manufacturing methods are constructing them to last longer than earlier TWTs and TWTAs. As applications make greater use of mmWave frequencies, TWTAs become attractive for their high output-power capabilities at high frequencies.

Brawny Tube-Based PAs Deliver High Power

dB Control, suppliers of TWTAs and microwave power modules (MPMs) based largely on GaN SSPAs, recently earned several U.S. Department of Defense (DoD) contracts for secure SATCOM amplification fueled by its TWTA technology. As an example, its dB-3860 Ka-band TWTA, introduced in 2015, provides as much as 750 W of peak output power from 34.5 to 35.5 GHz by boosting pulse-modulated signals. It channels pulse widths from 0.2 to 20.0 µs at duty cycles to 10% with 60-dB minimum gain.

The TWTA contains a wideband, periodic-permanent-magnet (PPM)-focused, conduction-cooled TWT and an embedded microprocessor for control functions. The rackmount enclosure, complete with forced-air cooling, measures 24.5 × 19.0 × 7.0 in. and weighs 85 lbs. with WR-28 waveguide input and output ports.

TWTAs in the 9100 series from Quarterwave Corp. provide 100 W to 40 kW of output power from 0.8 to 40.0 GHz. PAs like the 9108/96306 F40H80 are available for octave-band and multiple-octave-band coverage. The model 9108 *(Fig. 1)* provides 2 kW (+63 dBm) of output power and 35 dB of gain from 4 to 8 GHz for pulses as long as 50 µs.

1. Powered by TWT technology, Quarterwave's PA provides 2-kW peak pulsed output power from 4 to 8 GHz for long pulses at short duty cycles. Quarterwave

The TWTA operates at duty cycles to 6% and repetition rates to 1 MHz, suffering only ±1-ns jitter for pulses with 12-ns rise/fall times. It contains female Type-N input and output connectors, RS-232, and Ethernet ports for computer control, and is available with RS-422, RS-485, or GPIB interfaces as options. Despite its high output power, it fits within a 19-in.-wide rackmount housing weighing just 75 lbs.

The T251-500 from Instruments for Industry is a rackmount TWTA developed for test-and-measurement purposes. It's available from T&M rental specialists Axiom Test Equipment and delivers 500 W CW and pulsed output power from 1.0 to 2.5 GHz. It features 57-dB typical gain across the frequency range and is equipped with GPIB and RS-232 interfaces for computer control.

Teledyne e2v, with fast-growing families of SSPAs (especially based on GaN), offers TWTs and TWTAs from 4.5 to 18.0 GHz. Its MTA2000 series of microwave power modules (MPMs) combine the best of both technologies *(Fig. 2)*. The MPMs integrate a mini-helix TWT with a solid-state preamplifier, high-density power supply, and control circuitry. The result is 125 W of output power for frequency bands from 2 to 18 GHz.

2. Teledyne e2v's MPM combines a TWT and solid-state preamplifier for 125-W output power from 2 to 18 GHz. Teledyne e2v

Teledyne e2v also supplies PAs based solely on solid-state technology. The firm produces packaged GaN field-effect transistors (FETs) and switches as well as several high-voltage GaN high electron mobility transistors (HEMTs) in plastic packages with bottom-side cooling for space applications.

SSPAs Encompass Wide-Bandgap Devices

While TWTAs and other vacuum-tube equipment are still widely used in maritime, space, and terrestrial defense systems, the latest trend has been replacing tube amplifiers where possible with SSPAs. For some years, GaAs field-effect transistors (FETs) were explored as active devices for RF/microwave PAs. But more recently, GaN device technology has become a clear favorite in SSPAs meant as TWTA replacements. Combining multiple GaN SSPA modules or stages within a machined enclosure or rackmount chassis can deliver tube-like power.

For example, the model 2221 amplifier system from Empower RF Systems combines multiple GaN-on-SiC SSPAs to reach 8-kW peak pulsed output power at X-band from 9 to 10 GHz. The rackmount system, which measures 17.50 × 26.25 × 27.05 in. and weighs 600 lbs., includes control and monitoring functions, EMI/RFI filters, and forced-air cooling.

The 2221 features Class AB linear operation for radar and EW applications and typical gain of 70 dB with ±1-dB gain flatness for 500-µs pulse widths at duty cycles from 0.5 to 20.0% and pulse repetition frequencies (PRFs) to 50 kHz. It operates from three-phase power supplies from 180 to 260 V AC. Also serving X-band radar, TTI Inc. offers its model PTX8501 MPM capable of 1 kW of peak output power (10% duty cycle) from 9 to 10 GHz.

CTT Inc., a Kratos Co., produces narrowband and wideband GaN-based amplifiers in compact housings. For pulsed use, the 8.5- to 9.8-GHz AGN/099-6060-P PA delivers 1-kW (+60-dBm) peak output power in an SP package. It maintains 60-dB gain running on a +50-V DC supply and exhibits low noise figure of 7 dB. For broadband use, the company's AGM/180-4655 GaN PA provides +46-dBm saturated output power with 55-dB gain from 6 to 18 GHz while fitting within an SAT package.

Since its acquisition of Hittite Microwave Corp., Analog Devices has offered high power, efficiency, and wide bandwidth from 0.3 to 6.0 GHz via a GaN PA capable of 35 W of pulsed or CW output power. Available in chip form measuring 4.8 × 3.4 × 0.1 mm (HMC8205) or in a 10-lead LDCC flange package (HMC8205BF10), it operates from a +50-V DC power supply with 35% to 40% PAE and about 20-dB power gain. The PA is well-suited for portable jamming applications.

To develop several lines of GaN-based SSPAs as TWTA replacements, Qorvo draws upon its Spatium RF power-combining technology. The QPB2040N GaN MMIC SSPA generates 100-W CW output power from 18 to 40 GHz in a package measuring just 3.9 × 2.9 × 4.0 in. For tight control, it features an integrated bias card with programmable settings.

At lower frequencies, the firm's model QPB0220N provides 120 to 263 W of output power from 2 to 18 GHz in a package measuring 11.3 × 3.4 × 3.4 in., while the QPB0618N delivers 162 to 288 W of output power from 6 to 18 GHz in a housing measuring 12.5 × 3.4 × 3.4 in. On another front, Chengdu Microwave offers compact coaxial PAs based on GaN and GaAs technologies for broadband and narrowband use from 1 to 18 GHz.

For GaN-based PAs in either modular or rackmount formats, Aethercomm provides rugged amplifiers at lower frequencies. Developed to handle tight spaces, the SSPA 0.001-6.000-5 maintains 5 to 10 W of saturated CW or pulsed output power from 1 to 6000 MHz in a 2.5- × 6.4- × 1.0-in. package with SMA female connectors. Meanwhile, the SSPA 0.001-1.000-500-RM delivers 500 W of saturated output power from 1 to 1000 MHz in a 19-in. rackmount enclosure with touchscreen display for monitoring and control.

Exodus Advanced Communications produces GaN RF/microwave PAs in many shapes and sizes. Its AMP2043 PA is available with 60 dB of gain and 1 kW of output power or 63-dB gain and 2-kW output power, both from 1 to 2 GHz. Both versions fit within a 19-in. rackmount enclosure with forced-air cooling *(Fig. 3)*. The company's much smaller AMP2065E-

LC is a Class A/AB linear GaN PA developed as a SSPA replacement for wideband TWTAs. It delivers more than 500 W of output power and 57 dB of gain from 6 to 18 GHz.

3. Depending on the choice of gain (60 or 63 dB), Exodus's PA provides 1- or 2-kW output power from 1 to 2 GHz. Exodus Advanced Communications

Model REMC08G11GE from RF-Lambda is a rackmount SSPA with more than 300 W (+55 dBm) of saturated CW output power from 8 to 11 GHz. It weighs 35 lbs. and operates on 110/240-V AC power supplies, providing 56-dB gain. Well-suited for EMC testing, it employs a Type-N female input connector and WR-90 waveguide RF output port. The firm also offers a wide range of modular coaxial and waveguide PAs with frequency extending to 100 GHz.

At lower power levels, AR Ametek also supplies rackmount PAs for EMC testing, with as much as 125-W output power from 30 MHz to 3 GHz.

Comtech PST Corp., now known as Stellant Power Systems Technology, also offers GaN-based SSPA replacements for TWTAs. The PAs are available with output levels from 5 W to more than 30 kW at frequencies from 1 MHz to 18 GHz.

For example, the BMC928958-1000 is a pulsed GaN SSPA module capable of 1-kW output power at X-band frequencies. It incorporates several protective functions, including for load-mismatch and thermal protection, and can be specified with various digital interfaces for computer control. The company also offers larger, rackmount PAs to 18 GHz, with 8- to 16-kW peak output power available at X-band frequencies.

Mini-Circuits, perhaps better known for its smaller components, supplies robust PAs for A&D, test and measurement, and other applications. The HPA-272+ delivers 100 W of typical saturated output power from 0.7 to 2.7 GHz housed within a 3U rack-mount enclosure with cooling fans and Type-N connectors *(Fig. 4)*. It features 48-dB gain with ±1.7-dB gain flatness across the frequency range.

4. Mini-Circuits's rackmount SSPA delivers 100-W typical saturated output power from 0.7 to 2.7 GHz. Mini-Circuits

In a smaller package, the company's ZHL-2425-250X+ PA builds on silicon (Si) LDMOS semiconductor technology to deliver 300-W pulse and CW output power within the 2.4- to 2.5-GHz industrial, scientific, and medical (ISM) band. It measures 6.75 × 2.20 × 0.80 in. (171.45 × 55.88 × 20.32 mm) and operates with 60% power efficiency, drawing 16 A from a single +32-V DC supply. It includes MCX and Type-N coaxial connectors and I2C and TTL interfaces for computer control, with integrated forward and reverse power detectors providing circuit protection for the PA *(Fig. 5)*.

5. To boost signal levels in the 2.4- to 2.5-GHz ISM band, this coaxial SSPA from Mini-Circuits employs Si LDMOS devices to generate a 300-W pulse and CW output power. Mini-Circuits

AMCOM Communications offers GaN PAs in miniature flange packages, such as model AM253845WN-SN-R with 30-W (+45 dBm) saturated output power from 2.5 to 3.8 GHz. It operates with 27% PAE at saturation with 22-dB gain across the frequency range. The compact PA comes in a RoHS-compliant (lead-free) ceramic package with flange and straight RF and DC leads, although it should be kept cool with an additional heatsink. Suitable for drop-in assembly, its input and output ports are matched to 50 Ω and it operates from a +28-V DC supply.

Mercury Systems has numerous compact GaN-based PAs on tap. One is the pulsed model DM-HPL-1K-102 PA with 60-dB gain and as much as 1600-W saturated output power from 1.2 to 1.4 GHz *(Fig. 6)*. It can handle pulsed input signal levels as high as +10 dBm and boosts 0-dBm input signals to the rated output level with typical PAE of 40%. The PA measures 14.0 × 10.0 × 1.72 in. with a SMA female input connector and Type-N female output connector, and it consumes 7.5 A from a +50-V DC supply.

6. Designed for pulsed operation, Mercury's PA delivers as much as 1600-W saturated output power from 1.2 to 1.4 GHz. Mercury Systems

For higher frequencies, Mercury's DM-HPX-400-102 PA provides 450 W (+56 dBm) saturated output power from 9.4 to 10.1 GHz with 50-dB small-signal gain. Supplied in a hermetic package measuring just 7.0 × 4.5 × 1.65 in. with a female SMA input connector and female TNC output connector, the coaxial PA consumes 3.5 A from a +50-V DC supply with typical PAE of 30%. And the company's DM-

Numerous RF/microwave PAs debuted at the 2024 IEEE International Microwave Symposium (IMS) exhibition in Washington, DC (June 18-20, 2024; see our coverage here) as PA developers continue to refine SSPAs for more extended use in A&D systems.

HPX-800-101 PA provides twice the saturated output power, 900 W or +59 dBm, from 9.4 to 10.1 GHz using the same coaxial package but with higher, 60-dB small-signal gain.

To reduce SWaP, Microchip Technology developed its ICP3049P GaN-on-SiC MMIC amplifier for commercial and military S-band radars from 2 to 4 GHz. The PA generates 70-W output power from 2.7 to 3.5 GHz, taking advantage of 60% PAE to fit within a plastic QFN package measuring just 7 × 7 × 0.85 mm.

RF Power Amplifiers Debuted at IMS

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Newcomer Ampegon came to the 2024 IMS with several TWTAs and SSPAs for broadcast, industrial, and medical applications from 100 MHz to 100 GHz. Power levels range from 0.1 W to 10 kW, and they leverage almost all solid-state technologies, including Si LDMOS, GaAs, and GaN. Its pulsed PAs reached output levels to 12 kW at S-band frequencies and 1 kW at X-band frequencies. Additional PA suppliers at IMS included Communications & Power Industries LLC, ERZIA, and Nxbeam with GaN MMIC PAs.

As an alternative to TWTAs, dB Control unveiled its modular dB-8048 GaN PA at the 2024 IMS exhibition. It delivers 1.5-kW peak output power for pulsed duty cycles to 10% from 2.9 to 3.3 GHz. A scalable, modular architecture with built-in cooling fan permits close placement and phase combining of multiple units to achieve as much as 10-kW peak output power *(Fig. 7)*.

7. Based on GaN transistors, dB Control's SSPA provides 1.5-kW peak pulsed output power from 2.9 to 3.3 GHz. dB Control

MIcable Inc. presented its model MPAR020060S50 at IMS. The rackmount GaN PA provides 100-W saturated output power from 2 to 6 GHz. The housing includes amplifier control, monitoring, and PA protection, operating with 20% typical efficiency.

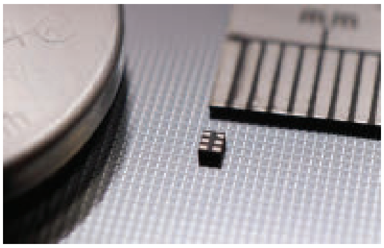
In smaller packages, RFHIC showed wideband PAs powered by its GaN-on-SiC technology, including the model RWP2060050-48 PA. It provides 65-W output power from 2 to 6 GHz in a package measuring just 175 × 90 × 23 mm *(Fig. 8)*. The PA operates from a +28-V DC supply with 25% PAE and 48-dB gain, flat within ±1.5 dB. Its high power from such a small package makes it a candidate for counter-unmanned-aerial-vehicle (counter-UAV) applications, including for jammers.

Built using on GaN-on-SiC technology, this SSPA from RFHIC provides 65-W output power from 2 to 6 GHz in a package measuring just 175 × 90 × 23 mm. RFHIC

Also at IMS, MACOM, which produces a wide range of GaN-on-SiC and GaN-on-Si devices, presented several of its GaN-on-SiC PAs. An X-band GaN-on-SiC PA for marine, defense, and weather radar provides more than 300-W pulsed output power at 9 GHz. The firm also showed a lower-frequency, C-band, GaN-on-SiC PA with 100-W output power and 57% PAE from a 7- × 7-mm package.

MACOM recently introduced its model MAPC-A1511 GaN-on-SiC D-mode amplifier for CW and pulse use from 30 to 700 MHz. Operating from a +100-V DC supply, it delivers 3-kW peak output power (+64.8 dBm) from a compact air-cavity ceramic package.

This represents a small sampling of PAs that are steadily moving higher in frequency in support of the growing use of mmWave frequencies. And they're not just for defense systems, but will find extensive use in commercial, industrial, and medical applications as IoT and robotic devices must communicate and process growing amounts of data. Tube amplifiers will still have their niches, but for most A&D and other applications, GaN and other SSPAs will be called upon to boost the high-frequency signals as needed. ■



Tiny Programmable Oscillator Touts Stability and Efficiency

The SiT1811 oscillator from SiTime operates at 32.768 kHz and offers the lowest power performance available in a 1211 QFN package to reduce power operation, shrink the footprint, and offer greater stability in consumer products. Manufactured with silicon MEMS technology, it operates at half the power of competing 32-kHz oscillators with a MTBF of over 2 billion hours. Features include 510-nA current and 0.6-µW typical power consumption, an integrated phase jitter of 3 ns RMS with a ±20-ppm frequency stability, mechanical shock resistance at 20,000 g, vibration resistance at 100 g, and an operating temperature range from -10 to +85°C.

SITIME

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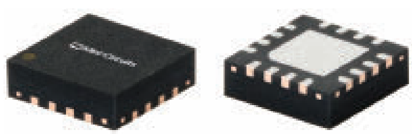


Surface-Mount LNA Quiets 5.5 to 15.5 GHz

Mini-Circuits' model PMA3-5153+ is a surface-mount MMIC low-noise amplifier (LNA) with 1.5-dB or better typical noise figure from 5.5 to 15.5 GHz. Gain is typically 21.2 dB at 5.5 GHz and 19.9 dB at 15.5 GHz, while output power at 1-dB compression is typically +16.1 dBm at 5.5 GHz and +18.3 dBm at 15.5 GHz. The 50-Ω LNA, with voltage-controlled shutdown to conserve power, runs on +5 VDC and is supplied in a 3 × 3 mm, 16-lead QFN-style package.

MINI-CIRCUITS

https://tinyurl.com/2946agtq

Source Module Powers 900-MHz ISM Band

Mini-Circuits' model RFS-G90G93750X+ is a solid-state signal source module for the 902- to 928-MHz industrial-scientific-medical (ISM) band. It delivers pulsed or continuous-wave (CW) outputs from 2 to 750 W (+3 to +58.75 dBm) with 0.25-dB resolution. It also serves as a power amplifier with 59-dB gain, with as much as 750-W pulsed or CW output power for 3-dBm input signals. The signal source module features built-in monitoring and protection functions and operates from +50 V DC with 63% typical efficiency.

MINI-CIRCUITS

https://tinyurl.com/25oz8x85

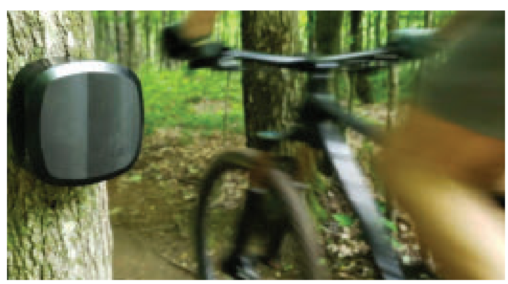
Active Multiplier Generates 18 to 36 GHz

Mini-Circuits' model ZXF90A-3-34X+ is an active frequency multiplier that converts 6- to 12-GHz input signals to 18- to 36-GHz output signals. Ideal for backhaul radios, 5G, radar and EW, and SATCOM systems, it provides -5-dB typical conversion gain for input levels from -35 to +1.5 dBm. Integrated filters reduce harmonics by at least -35 dBc and fundamental levels by -55 dBc. Based on GaAs HBTs, the tripler draws 175 mA from a +15-V DC supply and incorporates SMA female input and 2.92-mm male output connectors.

MINI-CIRCUITS

https://tinyurl.com/2ad4xhf9

Bluetooth Module Performs People and Vehicle Counting for Smart-City Apps



Eco-Counter used Insight SiP's ultra-miniature RF Bluetooth module for its EVO family of counting devices, which are solutions for accurately counting pedestrians and cyclists in cities, parks, and open spaces in nature. Eco-Counter provides a wide range of sensors under their "EVO" family, coupled with intelligent software systems to monitor the number of users, the type of transport, and the speed and direction of travel. Different models of sensors are available depending on the environment (urban, parks, nature, etc.) and the type of traffic to be counted. Insight SiP's Bluetooth Module is at the heart of the solution, reading the sensors, storing the data, and providing Bluetooth connectivity, which also enables system commissioning and updates as well as uploading of stored data, depending on connectivity options available.

ECO-COUNTER | INSIGHT SiP | EVO COUNTING DEVICES

https://tinyurl.com/2xwzkkgq