LTE IoT
Development Board p8

WiSUN: A Protocol for
Smart Cities p10

Radar for
Autonomous Driving p16

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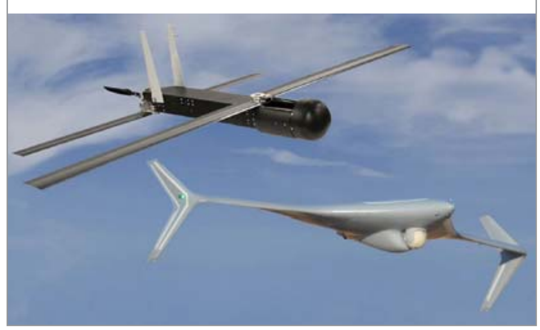
IN THIS ISSUE

FEATURES

23 defense electronics



NEWS & COLUMNS

30

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LL0120-2		- 5	-	- 6
LL0120-3		0	-	- 1
LL0120-4		+ 5	-	+ 4
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Editorial

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Time for **Unmanned Aerial Vehicles** to Shine

Unmanned aerial systems have become more critical than ever in maintaining vigilance over global trouble spots.

If you pay any attention to the news at all, then you're surely aware of the recent upheaval in Afghanistan, where the Taliban have seized power by capturing Kabul, a city of some 6 million people, almost without firing a shot (except at a few protesters here and there, but that's another story). This feat was accomplished, it seems, by roughly 500 Taliban fighters. How do we know how many Taliban fighters were involved in this siege?

Much of what we know about extremely dangerous and chaotic places like Kabul comes from our "eyes in the skies," namely satellite surveillance and, increasingly, unmanned aerial systems (UASs) that patrol places like Afghanistan from high altitudes. Scenes of this sort bring UASs into sharp relief; they're the topic of this issue's cover story written by Contributing Editor and long-time industry veteran, Jack Browne.

UASs such as Raytheon Technologies' Coyote and Lockheed Martin's Bat collect vast amounts of data from multiple distributed sensors using radar signals or infrared energy. That data comprises invaluable intelligence regarding the whereabouts and capabilities of potential threats (like a Toyota pickup full of Taliban fighters). To be actionable, that data must be gotten into the hands of analysts in near real-time. That's where technologies like mmWave, active electronically scanned array (AESA) antennas, and multiple-input, multiple-output (MIMO) antennas come into play.

These UASs are insanely complex, often comprising platforms that provide as many as four sophisticated functions—electronic warfare, electronic countermeasures, communications, and radar—in a form factor that once contained just one such function. With all that data being collected and disbursed from a single system, security is of paramount concern. Jack's cover story delves into the cybersecurity concerns surrounding today's UASs as they handle such sensitive data.

Further on the topic of unmanned aerial vehicles, our Editorial Director, Bill Wong, recently visited Atlanta for the Association for Unmanned Vehicle Systems Internationals' (AUVSI's) Xponential 2021 exhibition and conference. His coverage of the event, replete with lots of videos of extremely sophisticated UASs, is aggregated in a digital magazine on our website. Bill reports that the event emphasizes technology geared toward commercial and military markets. If it's consumer-oriented drones you're interested in, you'll have to wait for next year's Consumer Electronics Show. mw

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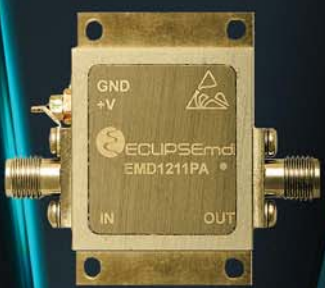

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News

HUMBLE AI STEERS UGV
Through Rough Terrain

This autonomous ground vehicle relies on a special type of AI technology to work its way through uncharted terrain and difficult environments.

U.S. Army researchers recently tested an unmanned ground vehicle (UGV) from GE Research that's capable of deciding on the best travel path through rugged, unstructured terrain. The prototype autonomous system is equipped with GE's so-called Humble artificial-intelligence (AI) technology for an awareness of risk if traveling different paths.

The Humble AI technology is an attempt to make a robotic system more human by giving it a sense of its own limitations and capabilities, a sense of humility. The Humble AI software has been applied by many renewable-energy companies for cost-effective management of wind turbines.

The intelligent UGV *(see figure)* was developed by the GE Research Robotics Team, led by Senior Robotics Scientist Shiraj Sen, during the first year of the Scalable Adaptive Resilient Autonomy (SARA) program with the U.S. Army. "One of the big challenges with autonomous systems is overcoming the risk factor, particularly when it involves equipment for complex military operations or critical infrastructure where safety and reliability are most important," said Sen.

He added, "with the successful demonstration of our 'risk-aware' autonomous ground vehicle in our project with the Army, we've made progress in removing some of those risks and, hopefully, provided a clearer path to more autonomous systems applications further down the road…or off road."

Eric Spero, SARA Program Manager, noted, "In future Army scenarios, autonomous systems will have to reliably plan in the presence of challenging features they encounter while maneuvering in complex terrain. Incorporating risk and uncertainty into the autonomy decision-making process enables our testbed platforms to show us what it looks like to plan a direct path instead of taking the long way around." The project was funded by the U.S. Army's Combat Capabilities Development Command Army Research Laboratory (ARL) as part of the Army's commitment to autonomous robotics technology.

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In rolling out the K-band waveguide components, Smiths Interconnect builds on a history of more than 30 years of producing space-qualified waveguide components. The WR51 waveguide products are tuneless and optimized to operate over broad assigned bands. They are provided with a standard clear passivation coating, but can be supplied with low-emissivity black paint finish if desired. Their design is optimized for reliability and to minimize cost and application risks.

The broadband, temperature-stable components require few part options to address the allocated frequency range. Among them are WR51 isolators, circulators, terminations, transitions, and loads that are available in mechanical variants on request. Sample data and test reports are available to assist the design and qualification process. ■

Smiths Interconnect

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LTE IoT 8 Click is a compact add-on board that features the SKY66430-11, a multi-band, multi-chip system-in-package (SiP) supporting 5G Massive IoT (LTE-M/NB-IoT) platforms. The pre-certified SiP, from Skyworks Solutions and Sequans Communications, integrates the entire RF front end, transceiver, power management, memory, and baseband modem for an LTE multi-band radio operating in the frequency range of 698 to 2200 MHz.

Click boards are based on the 16-pin mikroBUS standard for sockets on a development board invented by MIKROE 10 years ago. Click boards enable design engineers to easily change peripherals, cutting months off development time. The company releases a new Click board nearly every day at 10 am, and many leading microcontroller companies including Microchip, NXP, Infineon, Dialog, STM, Analog Devices, Renesas, and Toshiba now include the mikroBUS socket on their development boards.

LTE IoT 8 Click is supported by a mikro SDK-compliant library, which includes functions that simplify software development. This Click board comes as a fully tested product, ready to be used on any system equipped with the mikroBUS socket.

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Wi-SUN: A Protocol Built for Smart Cities

Wi-SUN is a low-power IoT mesh network targeting smart-city operations. Its scalability, security, interoperability, and breadth of existing and emerging apps it supports enable users to increase cities' sustainability and residents' quality of life.

Driven by a global need for increased sustainability, reductions in greenhouse gas emissions and waste, and efficient resource usage, cities around the world are transforming into smart cities. Designed with the underlying goal of improving city operations and overall quality of life for residents, smart cities are urban areas utilizing Internet of Things (IoT) advances to efficiently manage city assets, resources, and services. Smart cities digitize aspects of modern urban life, including utilities, civic services, traffic control and public transport, and water and waste networks.

A key driver of widespread interest in the smart-city transformation is the rapidly growing global urban population. Each week, an estimated 1.3 million people move from rural to urban areas, and the U.N. projects a startling 68% of the world's population will live in urban centers by 2050. Growing urban populations put tremendous pressure on cities' infrastructures, and cities in turn significantly stress the environment and our limited natural resources.

Designing Human, Environmental-Centered Solutions

The foundational technological arsenal of smart cities is based on internet and communications systems. With more sensors and connectivity in the field and more algorithms running in data centers, the inevitable outcome is smarter and higher-efficiency decision-making.

However, we should be cautious regarding this vision of smart cities and avoid focusing only on the technological aspect of each problem at hand. Smart-city designs are trying to solve very complex, human problems. Cities are an interconnected web of infrastructure, organizations, and residents. As with every organic complex system, its dominant property is its complexity rather than its subdivisions or sub-entities.

As uncovered by the ecology pioneers of the 20th century, such complex systems (think ant colonies, topsoil, or American elections) should, for best outcomes, be treated holistically. Interacting with or modifying a part in isolation rarely induces full-system improvements. In other words, blindly throwing more technology at our urban conflicts does not—at best—guarantee solving them and could—at worst—cause more harm than good. We need to remember a city is a web of interconnected, interlocked entities: a social organism of mass scale.

Thus, a more constructive approach to smart cities begins with seeing and acknowledging the entire urban system as a whole. If a problem is resolved without consideration for its ecology, it can lead to further, more consequential problems. For example, a city may aim to reduce its greenhouse emissions by making its power networks more efficient to reduce energy consumption. Yet residents may see lower energy bills and become less stringent with their energy use, bringing the system back to its energy equilibrium point and consuming the same or more energy than it did before.

To that degree, smart-city technological pioneers need to emphasize the big-picture impact of their solutions as much as the one-to-one relationships. Therefore, a technology that reliably and sustainably disrupts the way in which a city operates must consider the vastness and depth of what comprises a city. While mythical idealizations of smart cities—abstract modern designs, flying delivery drones, and self-driving cars—could potentially become reality, this vision focuses on the technological solutions, leaving the human qualities out of the picture.

Connecting the Dots with Wi-SUN

The emphasis around human and environmental values doesn't undermine the richness offered by the technological solutions currently at hand, namely big data and IoT. IoT networks expose valuable leverage points that can trigger vast constructive impact, and city planners are just now starting to tap into their potential.

Technological players must serve as guides for smart-city development and ensure cities deploy adaptive wireless platforms that are flexible and encompassing. As more companies and organizations recognize the unique

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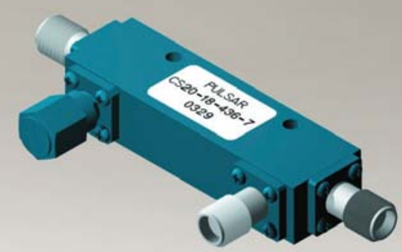

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2.0-8.0 GHz	0.35	± 0.40 dB	20	1.25:1	CS*-09
0.5-12.0 GHz	1.00	± 0.80 dB	15	1.50:1	CS*-19
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8.0-20.0 GHz	1.00	± 0.80 dB	12	1.50:1	CS*-21
6.0-26.5 GHz	0.70	± 0.80 dB	13	1.55:1	CS20-50
1.0-40.0 GHz	1.60	± 1.50 dB	10	1.80:1	CS20-53
2.0-40.0 GHz	1.60	± 1.00 dB	10	1.80:1	CS20-52
6.0-40.0 GHz	1.20	± 1.00 dB	10	1.70:1	CS10-51
6.0-50.0 GHz	1.60	± 1.00 dB	10	2.00:1	CS20-54
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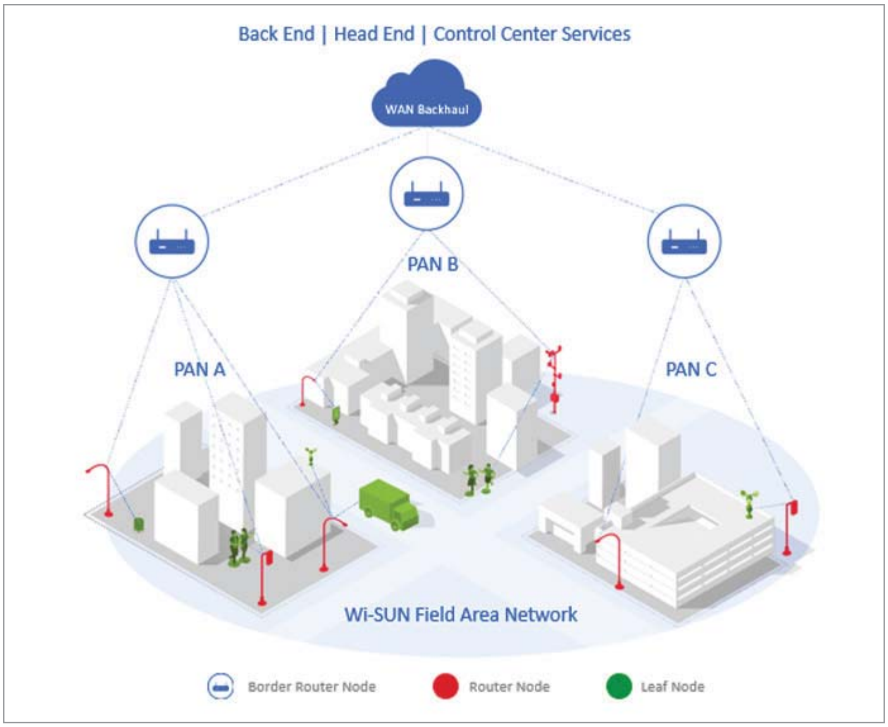

1. The Wi-SUN network architecture connects hundreds of nodes. *(Wi-SUN Alliance)*

nuances of designing efficient smart cities, a strong movement within the electronics industry is moving toward wireless standardization for smart-city applications.

In 2011, a group of visionary leaders initiated the idea of interoperable smart-city networks based on the IEEE 802.15.4g standard, leading to the formation of the Wi-SUN (Wireless Smart Ubiquitous Network) Alliance. With more than 300 member companies, Wi-SUN utilizes widely adopted and proven industry standards to enable an open ecosystem of interoperable solutions with endless possibilities to futureproof smart-city networks.

The Wi-SUN field area network (FAN) is a highly robust, low-power IoT wireless mesh network boasting numerous data-rate options to support large-scale IoT networks. What establishes Wi-SUN as a true smart-city protocol is its scalability, security, interoperability, and breadth of supportable existing and emerging applications. Wi-SUN also allows for mode-switching techniques to adjust data rates based on application needs.

Up until now, most smart-city applications have used proprietary networks that are typically designed for specific applications with limited security and flexibility to upgrade. They also typically employ a "star" architecture where devices communicate with a base-station receiver.

However, Wi-SUN is a self-forming, self-healing mesh network with thousands of nodes rather than depending on one base station, which improves its reliability and resilience *(Fig. 1)*. The Wi-SUN FAN architecture can constantly reroute data across these thousands of nodes in the case of connection issues. This allows devices to receive full network connectivity and continuous support of services across the city when they need it most, such as during extreme storms, cyberattacks, and/or power-usage constraints resulting in rolling blackouts.

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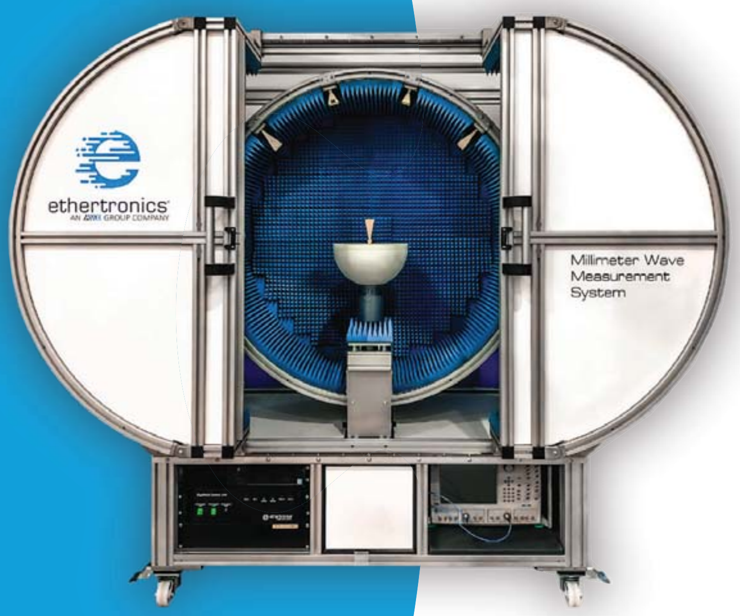

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When compared to traditional low-power wide-area networks (LPWANs), Wi-SUN offers higher data rates and lower latency *(see table on right)* along with low power, security, and interoperability.

Furthermore, Wi-SUN FAN provides flexibility in data rates and energy consumption, allowing users to address smart-city and other applications more broadly. Smart-city applications place high demands on the underlying network infrastructure, requiring a high degree of security, reliable connections, resilience in the event of faults or changing conditions, and much more. Wi-SUN FAN provides secure, cost-effective, and resilient connectivity in a wide variety of topographical environments with minimal additional infrastructure, from rural areas to dense urban neighborhoods.

Smart-city developments today are oriented toward smart metering, smart street-lighting systems, public safety, traffic monitoring, noise detection, and pollution monitoring, all of which Wi-SUN is designed to accommodate *(Fig. 2)*. Wi-SUN also is well-suited to handle the integration of smart-city sensors (waste management, vending machines) and distributed energy resources (DERs) onto the grid.

IoT NETWORK DATA RATES AND LATENCIES

IoT network	Data rate	Latency
Wi-SUN FAN	Up to 2.4 Mb/s	0.02-1 second
LoRaWAN	300 bits/s to 62.5 kb/s, depending on spreading factor	1-16 seconds
NB-IoT	Up to 140 kb/s uplink, up to 80 kb/s downlink	2-10 seconds

2. A Wi-SUN network can connect various smart-city operations. *(Silicon Labs)*

Securing Our Cities' Most Vulnerable Assets

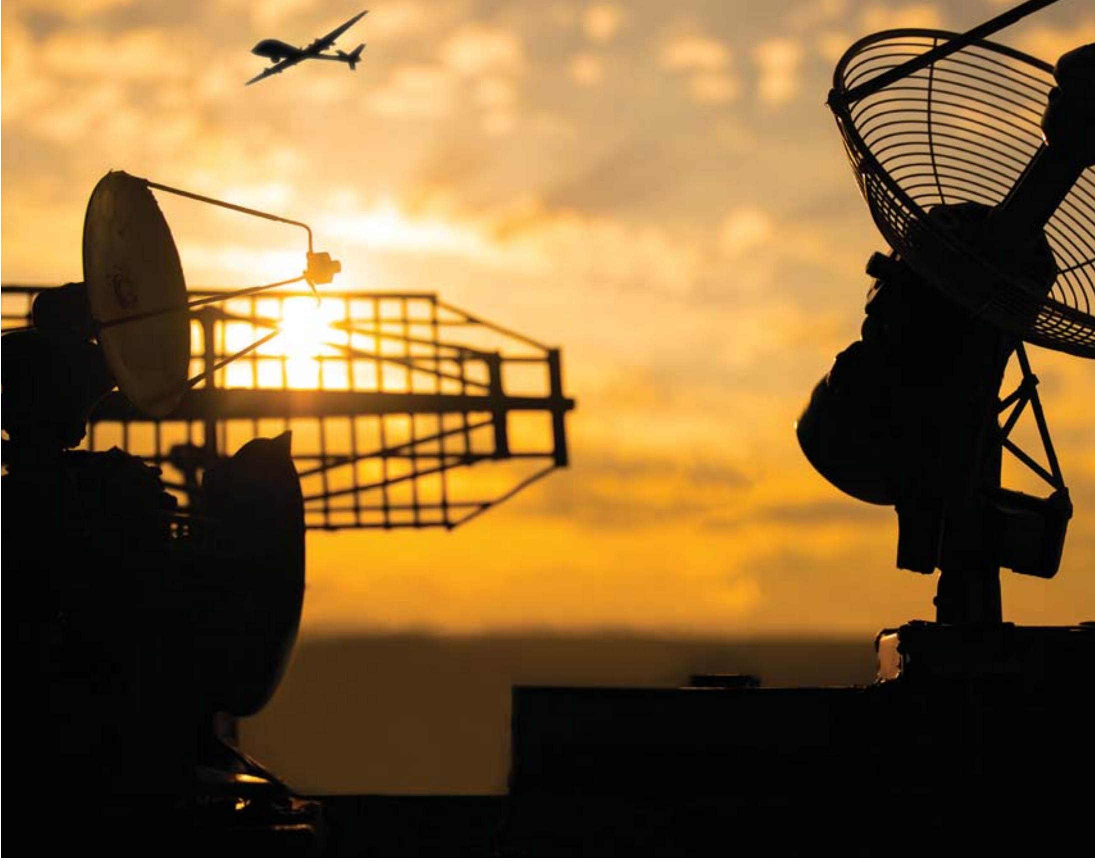
Yet another differentiator of Wi-SUN is its security benefits, creating tremendous opportunity in the design of smart cities. With hospitals, government agencies, public transport, business organizations, and power grids becoming more vulnerable to cyberattacks, zero-risk-tolerance security standards must be set in place. Cities are becoming nodes within networks of interconnected cities, and a system of interconnected cities is as weak as its weakest link, making network cybersecurity non-negotiable.

Created with its users' safety and security in mind, Wi-SUN has several built-in security functions to ensure operational security. One of the most significant functions is that security authentication goes all the way back to the cloud provider, which isn't the norm for most protocols today. Wi-SUN also observes cybersecurity rules in designing a network to ensure reliable operations, including end-to-end security, encryption, key management, and network isolation in the event of a security breach.

A unique feature of Wi-SUN is its native public-key-infrastructure (PKI) integration, certificate-based mutual authentication, and proven data encryption and key exchange algorithms. Wi-SUN FAN access control is based on PKI and modeled after a Wi-Fi security framework. Each Wi-SUN device also has a unique certificate signed by a Certification Authority at its point of manufacturing.

Smart-city initiatives hold human quality of life and the environmental impact to a higher standard. Enterprises working with and within the ecosystem of city infrastructure are likely to reap the largest rewards, as their projects have higher chances of sustainable success. Wi-SUN has been built with this philosophy in mind—its technological features enable city planners and technology architects to connect and futureproof the city's infrastructure successfully, with the ultimate benefits aimed at residents and environmental resources.

In the coming years, we will continue to see IoT advances influence the transition to smart cities worldwide. It will remain imperative to balance the numerous elements of a city when transforming its infrastructure and the lives of its citizens, and just as critical to balance the priorities of advancing technology, promoting sustainability, and increasing quality of life at the individual and group levels.



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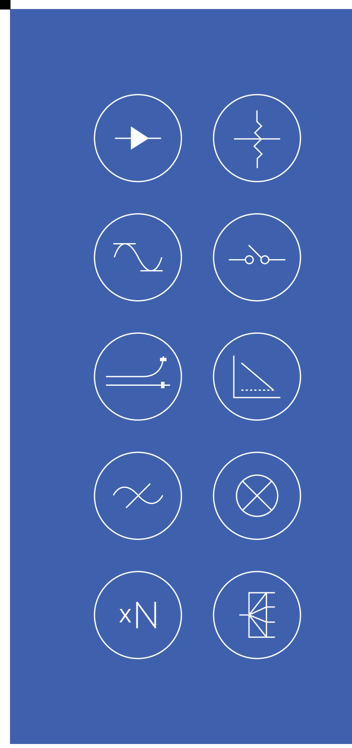

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Radar Systems for Autonomous Driving—at L2/L2+ and Beyond

The hot next trend in automated driving is L2+, with semi-autonomy guided by both camera and HD radar sensing. What demands does radar add, and how can they be addressed?

It's a technology that feels like it's been nearly there for years, but we're still waiting for full autonomy in cars, and it's much further out than we originally thought.

Industry body SAE defines six levels of driving automation *(see table)*, from no automation up to full self-driving at level 5. As vehicles become more automated and reach higher levels, they're more tightly regulated and require more sophisticated systems to provide a safe, reliable solution.

SAE'S SIX LEVELS OF DRIVING AUTOMATION
Level 0: No Driving Automation
Level 1: Driver Assistance
Level 2: Partial Driving Automation
Level 3: Conditional Driving Automation
Level 4: High Driving Automation
Level 5: Full Driving Automation
Source: SAE, https://www.sae.org/standards/content/j3016_202104/

The automotive industry has been looking to a move to level 3 (L3), but right now this seems unrealistic. Instead, there's a very active push from SAE level 2, conventional advanced driver-assistance systems (ADAS), to something now being called L2+. This is a chance for OEMs and tier 1s to monetize their investments in full autonomy systems, in car models that will come to production as early as 2023.

L2+ is a little short of L3, in that redundancy continues to depend on the human driver. Thus, the number of additional sensors compared with L2 systems is limited, but it would still enable supporting advanced new safety features in affordable ADAS systems. In L2+, radar sensors are expected to be added to the basic suite of camera sensors. Radar is affordably priced and provides significant complementary benefits to the known weaknesses of camera sensors in extreme lighting and weather conditions.

L2+ offer significant advances over current L2 ADAS in urban driving, highway automation, lane changes, and merges. And it can arrive much sooner than L3, without the need for fundamental changes to regulation, infrastructure, and social acceptance.

1. 360-degree radar coverage is needed for L2+ autonomy and beyond.

Time is Now for L2+

Autonomous-driving compute platforms will eventually migrate to central computing architectures doing the heavy lifting, with sensor fusion from myriad 360-degree coverage sensors and sensor types. In the shorter term, L2+ systems will come in various form factors, some anticipating future central computing platforms doing early fusion of various sensors.

Mostly, they will still use discrete smart sensors with most of the sensor processing load handled on the edge, and specifically for radars that will complement basic camera-based systems. Therefore, it's

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In-building distributed networks and outdoor wireless networks call for robust antennas that offer wide bandwidth coverage, low PIM ratings as well as MIMO and SISO technology support.

To address these requirements, Fairview Microwave launched a new series of low PIM rated indoor wall mount and ceiling antennas as well as a series of outdoor rated omni-directional antennas. Fairview Microwave is ready to support 5G innovation, testing, and deployments, through an expansive product offering, product support, and a commitment to same-day shipping.

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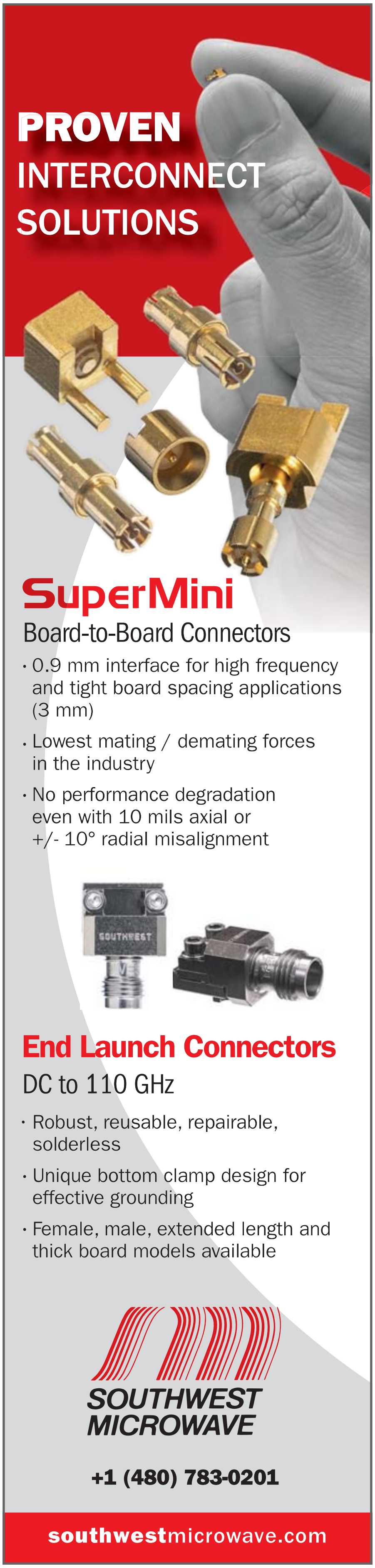


expected that the majority of radar devices in the upcoming years would still execute most of the radar chain processing within the radar device itself, and they will require strong compute platforms.

Market forecasts expect mass production ramp-up of L2+ ADAS systems starting from 2023, with initial deployment of higher autonomy levels—L3 and above—starting no earlier than 2026-2027. As for radar, HD radars will mostly be used for L3 and higher autonomy levels, at least until their price point drops enough to be integrated in L2+ ADAS systems, which isn't expected before 2028.

Thus, there's a significant market window of at least six years when standard radar devices will still dominate the market. And they will play a vital role in L2+ ADAS systems, with more radar nodes per vehicle to implement more ADAS features and 360-degree coverage *(Fig. 1)*.

How Does It Work?

The basic principle of radar is interferometry. Signals are transmitted from an array of transmit antennas and received through an array of receive antennas. The range, velocity, and direction of objects and obstacles can be estimated from the relative phases of the received signals, which have bounced back off them.

As such, radar delivers direct perception-related inputs, using highly deterministic processing techniques to extract depth-related features. This is contrary to camera sensors, which require complex (though well-known and tried) computer-vision (CV) and artificial-intelligence (AI) processing to achieve the same kind of outputs.

The number of effective "virtual" radar channels is the product of the number of transmit (TX) and receive (RX) antennas. For example, a typical radar device used in today's L2/L2+ vehicles includes 3TX and 4RX antennas, for an overall total of 12 virtual channels. This is enough to support basic L2/L2+ features like automatic emergency braking (AEB) and adaptive cruise control (ACC).

The radar devices we will see in future L2+ and above systems will include 12Tx16R (for an overall 192 channels), and even as much as 48Tx48R (for a staggering 2304 channels). These larger configurations are referred to as HD imaging radar, or 4D radar (being able to extract the four parameters of range, velocity, azimuth, and elevation).

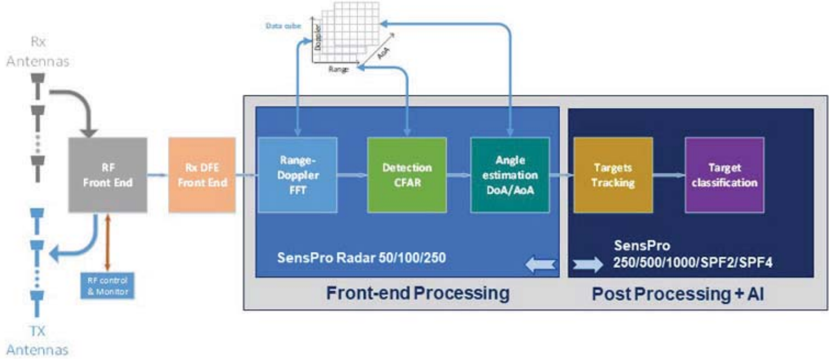
The main benefit of more channels is to increase the radar accuracy, and specifically the angular resolution in both azimuth and elevation. HD radar can achieve angular resolution of below 1 degree for a long-range object, which can be as far as 200 meters away. Azimuth resolution enables object detection (such as pedestrians), while elevation resolution allows a system to distinguish between vehicles and overhanging street furniture. Increased resolution allows us to reduce false positives resulting from wide side-lobes, which is a known issue in common small-scale radar devices.

Radar Chipsets—Sensors and Signal Processors

Radar chipsets are usually comprised of two main components: the sensor, or radar transceiver, handling the RF signals from the millimeter-wave (mmWave) antennas down to the baseband signal, and the radar microcontroller (MCU) handling the digital radar signal processing.

The radar transceiver and MCU are typically two different chips, each manufactured in its optimal and cost-effective process node. While the complexity of the radar transceiver is linearly proportional to the number of antennas, or physical RF chains, the complexity of the signal processing performed in the radar MCU is related to the number of virtual channels. Hence, it's quadratic with the number of antennas (and rises much faster as the system becomes more complex).

Figure 2 shows a typical radar processing chain. The RF front end is implemented in the radar transceiver. After analog-to-digital conversion, the signal is processed in the radar MCU.



2. The radar processing chain is divisible into front-end and post-processing.

The radar processing chain is typically divided into two main parts:

- The radar front-end processing, which outputs the radar point cloud.
- The radar post-processing, which is handling object classification and tracking.

These two disparate workloads require different kinds of processing elements and techniques. Depending on the MCU architecture, both front-end and post-processing can be integrated into a single MCU, or else the latter parts of the chain can be processed in a central electronic control unit (ECU).

After pre-processing by a time-domain digital front end (involving mainly filtering), the signal is processed by the radar front-end module. Processing is typical of common frequency-modulated continuous-wave (FMCW) types of radars.

The front-end processing first involves the range-Doppler fast Fourier transform (FFT) and constitution of the radar data cube (accumulating data from multiple antennas and radar pulses), followed by first target detections using constant false-alarm-rate (CFAR) algorithm variants, and then degree-of-arrival/angle-of-arrival (DoA/AoA) angle estimation. The output of the radar front-end processing is called the radar point cloud, and for each detected point it includes the 3D or 4D range/Doppler/angle information.

For HD radar, the radar front-end processing can be extremely computationally heavy, and will typically be implemented in optimized hardware. However, small-scale radar front ends (for example, with 12 to 16 virtual channels) lend themselves to a more software-oriented implementation and a more flexible partitioning between hardware and software.

The processing engine needs to cope with various types of computations. FFT and CFAR can be efficiently implemented using fixed-point arithmetic, while angle-estimation algorithms typically make extensive use of matrix decomposition and require floating-point arithmetic.

After the point cloud, the radar post-processing involves target recognition, segmenting, tracking, and classification. This uses heavy matrix operations in high-accuracy floating-point arithmetic, implementing algorithms such as Kalman filtering, involving operations like matrix inversion, Cholesky decomposition, and nonlinear operations. This type of processing is typically implanted on DSP cores, to allow for maximum flexibility and enable different vendors to differentiate and innovate.

Finally, target classification and sensor fusion uses AI inferencing techniques and requires heavy processing of neural networks.

Pulling It All Together—a DSP-Based Radar Processing Platform

As discussed, modern radar processing involves significant computational and implementation challenges to build an end-to-end chain. As this is a still-evolving technology, with consideration of future autonomy levels, designers need both the flexibility of software and a scalable

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high-performance computing platform. This lends itself to platforms based on powerful vector DSPs.

We've seen that the scale and dimensioning of modern automotive radar devices can vary significantly, between common 12-channel devices and a high-end imaging radar with thousands of channels. In addition, each device must perform a wide variety of algorithms and support different arithmetic processing engines to cope with different workloads.

An example of a scalable vector architecture suitable for this application is CEVA's SensPro-Radar. Building on CEVA's second-generation SensPro2 IP family, it can handle the wide variety of required workloads for radar chain signal processing. This means that developers can use the same platform, and same development tools, for all parts of their solution, and across different generations.

For radar front-end processing, there is the optional SensPro-Radar ISA, which adds special instructions for accelerating the range/Doppler FFT and complex arithmetic operations. The SensPro-Radar ISA can efficiently map a significant part of the radar front end to the DSP core, which improves implementation flexibility, and reduces time-to-market.

A typical radar chain implementation must process huge amounts of data, depending on the number of virtual channels. The SensPro architecture uses CEVA's advanced memory subsystem that provides easy access to the radar data cube with "tiles" across different dimensions.

To complement the computing platform, CEVA offers software libraries, including Eigen Linear Algebra. CEVA's Radar SDK for SensPro makes extensive use of the dedicated Radar ISA and gives software developers a complete radar chain reference implementation.

Conclusion

As cars add new autonomous-driving capabilities, and specifically as they move from L2 to L2+ and beyond, there's a growing requirement for them to add radar to their suite of sensors. This does place new demands on the on-vehicle processing architecture, particularly as more channels and HD radar massively increase the complexity of the data captured and analyzed.

Having a single platform that can effectively process all radar-related workloads, both front-end and post-processing, allows the radar architect to freely choose the optimal hardware/software partitioning, while still reserving enough software flexibility for future-proofing the solution. Furthermore, the balance between the different kinds of workloads can be changed dynamically, post-silicon production. This kind of architecture is ideally suited for over-the-air (OTA) updates, which will be important in future autonomous platforms and autonomy-as-a-service. mw

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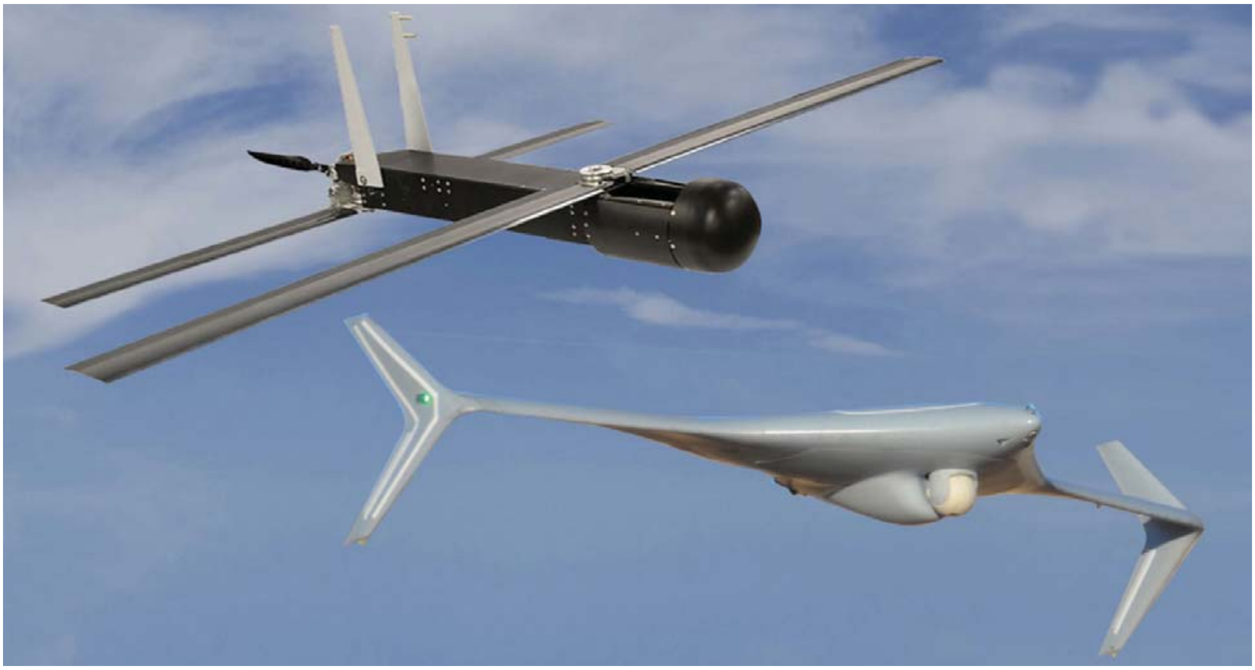


EW Systems Form Fit to UAS Requirements

Advances in electronic-warfare systems are packing more performance into smaller packages in attempts to keep a step ahead of the adversary.

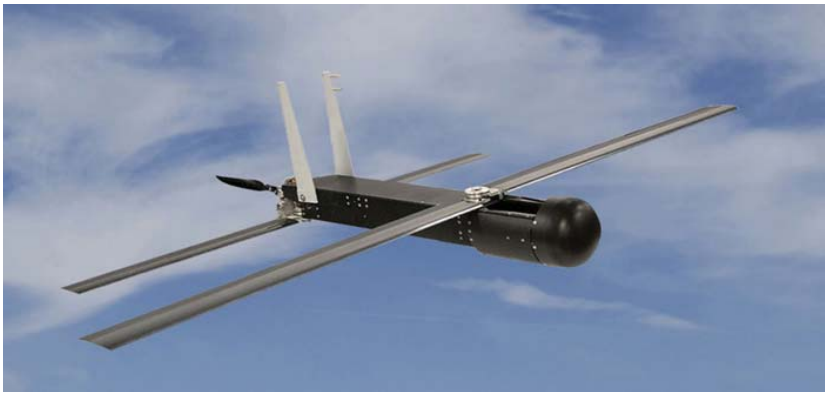
ELECTRONIC-WARFARE (EW) systems play important roles on the modern battlefield, on land, at sea, and in the air—including outer space. By virtue of U.S. Department of Defense (DoD) requirements for smaller size, weight, and power (SWaP), what were once rooms filled with racks of equipment are being shrunk to mobile, portable systems that must stand up to rough treatment under harsh operating conditions.

In recent years, EW system designers have counted on RF/microwave component and subsystem suppliers for smaller, lighter hardware to keep pace with customer demands for more electronic functions in smaller spaces. They're also faced with EW systems handling more data from more sensors, requiring wider operating bandwidths that push into the millimeter-wave (mmWave) frequency range to handle the huge amounts of data at faster transfer rates. The emergence of 5G cellular wireless networks may aid both commercial and military users.

EW system design has long been about maintaining an advantage over an adversary, to track their weapons systems and develop responses to stop them. Most EW systems provide a combination of functions based on electronic-attack (EA) and electronic-support (ES) modes, processing large amounts of data from their antennas and multiple sensors. EW receivers must be capable of detecting and identifying potential threat signals.

Electronic-countermeasures (ECM) systems must block an adversary's attempts at communication and transmit false signals. These include radar signals that imitate what might be the reflected return signals from a large airborne fighting force.

Various forms of EW detection and response systems have traditionally been designed and constructed as discrete systems typically for specific operating



1. Miniature Coyote drones are flown in swarms by the U.S. Navy to collect large amounts of EW data while appearing to an adversary's detection systems as a single vehicle. *(Courtesy of Raytheon Technologies)*

domains, such as air, sea, or land. But pressures to equip modern mobile fighting forces with smaller, lighter, and more capable EW systems are driving higher levels of EW integration. It's even reached the point of building single-system platforms that can provide EW, ECM, communications, and radar functions within a form factor that once supplied only one of the functions.

Although multifunction military electronic systems have been in development for more than 50 years, SWaP requirements are now pressuring system designers to achieve much smaller footprints. Expansion of EW systems beyond the traditional frequency range of 2 to 18 GHz provides EW system designers with additional bandwidth at mmWave frequencies. However, it makes circuit fabrication more difficult as linewidths and spacings shrink with increasing frequencies.

The signal-processing requirements for multifunction systems are more complex than for single-function systems, too. Greater computing power is required in a resource allocation manager (RAM) to coordinate the use of a combination system's different capabilities, such as radar signal detection and signal generation for jamming in response.

Start with the Antenna

Low-profile antennas are essential components for multifunction EW systems. Advances in active electronically scanned array (AESA) antennas and their supporting integrated circuits (ICs) have made possible smaller multifunction military electronic systems capable of transmitting and receiving signals for EW, radar, and communications. AESAs use multiple antenna elements in conjunction with multiple transmit/receive modules (TRMs) to form and steer beams electronically, without physical movement of an antenna.

To achieve an antenna with a low profile, the antenna ICs, such as beamsteering ICs, are mounted on the same plane as the antenna elements. However, this design approach becomes more challenging at higher frequencies, such as mmWave frequencies, because the spacing between antenna elements becomes tighter with increasing frequency, degrading the isolation between antenna elements.

AESAs have become the antenna of choice for many air-to-air and air-to-ground radar systems on high-speed aircraft like the F-35 fighter jet. The electronic tuning and control of these antennas also makes them viable choices for multifunction EW systems covering wide surveillance ranges, as well as for

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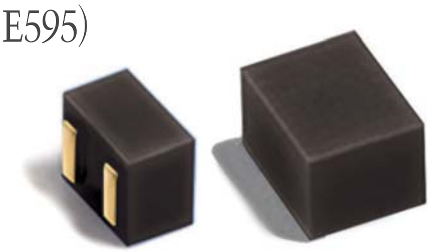

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Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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2. The Outrider, a compact UAS, can be launched from canisters that fit inside submarine missile tubes. *(Courtesy of Lockheed Martin Corp.)*

providing reception of radar signals and high-speed data communications.

As system designs move to higher levels of integration, employing multiple system-in-package (SiP) devices to enable multiple EW functions within compact modules, EW and other military electronic systems are relying on modular architectures for flexibility. Modular design approaches simplify system upgrades and help speed the production of complex systems. The growing density of ICs supports SWaP goals, as IC designers look at a single device where once there were many, such as field-programmable gate arrays (FPGAs) with analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) within the same package.

Modern EW systems rely on many distributed sensors to capture details about an opponent's capabilities, e.g., sensors using radar signals or infrared (IR) energy for threat detection and targeting purposes. As EW systems grow in complexity, gathering data from increasing numbers of sensors on manned and unmanned systems, EW system designers are faced with processing more data at higher speeds, to minimize latency and enable an instantaneous response to a threat. In addition, data interoperability (DI) among various EW and other military electronic systems is essential for different branches of the armed forces to seamlessly work together.

Automated Pilots

Growing use of unmanned aerial systems (UAS) with EW and ECM capabilities drives the need for smaller, lighter EW systems as payloads. UAS equipment is being developed for all military branches for single-use (expendable) and multiple-use (survivable) missions, including surveillance, signal intelligence (SIGINT), and carrying munitions to a target.

Two such examples are the Coyote UAS *(Fig. 1)* from Raytheon Technologies, which is part of the U.S. Navy's Low-Cost UAV Swarming Technology (LOCUST) program, and the compact Fire Shadow UAS from Lockheed Martin that's been used for loitering munitions missions. Low-cost Coyote drones can fly in highly coordinated swarms of thousands under the control of a single computer. The flight paths of all those many drones are closely mapped so that they can appear as a single flying vehicle while collecting data with separate sensors.

The U.S. Navy also has worked with Lockheed Martin on the Outrider UAS *(Fig. 2)*, which can be launched from canisters that fit inside submarine missile tubes. The small drones are part of the work done by the Naval Research Laboratory (NRL) on all-electric drones with folding wings. They can launch from torpedo tubes but are also robust enough to carry numerous sensor payloads, including electromagnetic (EM), electro-optical (EO), and infrared (IR) sensors for intelligence, surveillance, and reconnaissance (ISR) missions.

Somewhat larger, the "Bat" family of UAS aircraft features vehicles with 12- and 14-ft. wingspans *(Fig. 3)*. Flown by means of an IP-based ground control station, the Bat UAS drones have deployed a variety of payloads, including EW and aerial intelligence, surveillance, and reconnaissance (AISR) systems.

Rather than AESA antennas, many UAS drones employ multiple-input, multiple-output (MIMO) antennas for medium-range communications with command stations and other UAS EW systems. For applications that require it, MIMO antennas *(Fig. 4)* are capable of higher transmit power levels than AESA antennas and are rugged enough to survive air speeds more than 350 mph. They also can be designed to meet the SWaP requirements of medium-sized aircraft.

These few examples represent the growing numbers of UAS applications and their EM, EO, and IR sensors at work in the battlespace to provide full-motion videos and data related to battlefield conditions. On top of that, the U.S. Army is pursuing UAS capabilities including AISR platforms that remain competitive during multidomain operations (MDOs) on land, sea, and in the air. This includes a multilayered approach with sensors on unmanned platforms as part of very-low-altitude, very-high-altitude, and low-Earth-orbit satellite (LEOS) systems.

With its recent launch of two CubeSat nanosatellites into low Earth orbit, the U.S. Missile Defense Agency (MDA) is establishing the foundation for a CubeSat-based missile defense system. The MDA is planning for low latency

3. The Bat series of UAS devices are constructed with large wingspans to handle multiple EW sensor payloads. *(Courtesy of Lockheed Martin Corp.)*

in communications between sensors on CubeSats, LEOS, drones, and missile defense systems for full EW coverage and protection against missile attacks.

Still, the large amounts of data produced by thousands of drones and their sensors poses new challenges for EW system designers in maintaining data integrity, cybersecurity, and high reliability under signal-congested and environmentally changing operating conditions.

While EW sensors on land, at sea, in the air, and in space continue to generate data, modern EW systems will be tasked with converting massive amounts of sensor data into usable command, control, and communications (C3) information. The use of technologies such as artificial intelligence (AI) and machine learning (ML) backed by more powerful digital-signal-processing (DSP) power can help to organize large amounts of real-time data. In addition, this data must be usable among the different branches of the armed forces and among any joint forces like the North Atlantic Treaty Organization's (NATO) troops.

Such DI is more easily achieved when EW systems are designed as open system architectures rather than proprietary system designs. When data is controlled and defined according to standards established by industry organizations, such as the Sensor Open Systems Architecture (SOSA) or the Modular Open Systems Approach (MOSA), data from multiple sensors can be more freely and accurately shared by multiple systems and users. A modular systems architecture simplifies upgrades and the addition of

new functions to an EW system while helping reduce costs.

Keep It Safe

Modern EW data management involves maintaining the integrity and security of sensor data via a form of EW now known as "cyber EW." Major contractors have developed systems in response to the many forms of an adversary's cyber warfare, such as malware intrusions and distributed denial of service. For example, Lockheed Martin's Spectrum Convergence systems are integrated defensive approaches to safeguarding information within networked infrastructures against intrusion.

Effective cyber-EW systems also can be used to gather intelligence on an intruding adversary. "Silent CROW" is an example of a cyber-EW system that can be configured for ground and airborne systems, including on wing-mounted pods for UAS applications.

Deon Viergutz, vice-president of Spectrum Convergence at Lockheed Martin, says, "Silent CROW is the next evolution of our cyber-EW systems. It's a great example of the type of new technologies we're focusing on—scalable, affordable, and designed to help our DoD customers overcome advances in adversary technologies to effectively support warfighters in joint, all-domain operations."

By investing in internal R&D, Lockheed Martin is applying newer technologies like AI and machine-to-machine (M2M) communications to identify potential threats across the spectrum in real-time. The company's support of open system architectures and standards such as SOSA have helped achieve DI and data protection against cyber threats.

Embedded Computing

Increased embedded computing power will play an important role in future EW systems, with distributed processing performed across an EW platform as much as possible to reduce the data workload from so many sensors. Integrated mixed-signal devices, e.g. FPGAs with integrated data converters, will make this practical.

In pursuit of such integrated computing power for EW applications, Lockheed Martin recently revealed support for a new technology from Intel Corp. It represents a major step toward fabricating a single component incorporating the functions of an FPGA, DAC, and ADC. Having achieved sampling rates to 64 Gsamples/s, such a technology would enable direct digitization of RF/microwave signals for markets including EW, radar, test and measurement, and 5G communications systems.

4. For high-speed flight missions, MIMO antennas are often installed on UAS vehicles to handle higher levels of vibration and signal power than AESA antennas. *(Courtesy of Southwest Antennas)*

Frank Ferrante, director of Military Aerospace and Defense at Intel Corp., says, "This breakthrough technology offers more than 5X higher bandwidth than alternative offerings and supports ADC sample rates up to 64 Gsamples/s, which open new design possibilities for communications and high-end test-and-measurement applications. It also enables radar designers to architect their systems in a completely new way—reducing the number of analog components required and creating more responsive systems."

The new FPGA technology was developed in part from research funded by the DARPA CHIPS program. Lockheed Martin was instrumental in co-defining critical requirements and use cases to make the technology mission ready. According to Deon Viergutz, "This technology allows us to integrate our latest-generation electronic-warfare systems into smaller airborne platforms and air-launched effects that were previously unattainable due to size constraints of the air vehicle. As a result, we've created the Ultra Small Affordable Electronic Warfare (USAEW) sensor that provides the 21st century warfighter advanced capabilities while substantially reducing the systems' size, weight, power, and cost by an order of magnitude."

Hold the Phone

Raytheon Intelligence & Space (RI&S) is exploring a networking approach to use 5G cellular wireless systems that provide secure data access for armed forces around the world. "The services must be able to share and access data at any time from any location," says David Appel, vice president of Defense & Civil Solutions for Space & C2 Systems for RI&S. "Being able to operate secure applications on 5G gives everyone up and down the command chain the ability to see the same thing at the same time. 5G networks provide the speed and resiliency needed to take the command center virtual, so no matter where you're located, you know what's going on around you." With 5G networks available for real-time data transfers when needed, command responses will be quicker and more informed, based on as much in-field sensor data as possible.

According to Chris Worley, director for Defense & Civil Solutions at RI&S, "We can enhance applications to run on 5G, so even if you lose your connection or it's spotty, the latest data is already downloaded. Operators will be able to access imagery and data faster for smarter mission decisions, mitigating the risk of casualties in close contact."

The additional bandwidth at mmWave frequencies that helps commercial customers download files quickly will provide near instant data access for military users, at backplane speeds approaching 10 Gb/s. mw

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MINI-CIRCUITS, www.minicircuits.com/WebStore/dashboard.html?model=RCDAT-50G-30

Multi-Range XRR Chip Boasts 300-Meter Range

Vayyar Imaging recently launched its multi-range XRR chip, outfitted with a single RFIC with a range of 0 to 300 meters and designed for passenger cars, trucks, and motorcycles. The chip is outfitted with a 48-antenna MIMO array and provides radar imaging with increased accuracy for various safety applications without requiring external processors. The XRR chip offers an ultra-wide field of view with 4D point-cloud imaging. It provides multiple modes of functionality on a single chip, supporting dozens of advanced driver-assistance systems (ADAS), advanced rider-assistance systems (ARAS), and autonomy features. The multi-range XRR chip can differentiate between static obstacles such as dividers, curbs, and parked vehicles, along with different types of VRUs, such as moving vehicles and other hazards. In low-speed environments, the chip's uSRR and SRR sensing supports advanced parking assistance and scans the vehicle's surroundings for pedestrians and obstacles. While on highways, MRR and LRR capabilities support a variety of ADAS and autonomy applications, including lane-change assist (LCA), adaptive cruise control (ACC), blind-spot detection (BSD), collision warnings (fCW/rCW), cross-traffic alerting (CTA), and autonomous emergency braking (AEB).

VAYYAR IMAGING, www.vayyar.com/auto/

Magnetic Encoder IC Performs Rotational or Linear Measurements

TE Connectivity's KMA36 magnetic encoder IC performs rotational or linear measurements at resolutions up to 15 bits. The IC offers a reduced-power sleep mode and features programmable parameters for a wide range of configurations, providing flexibility for design and functionality. In addition, the chip takes advantage of anisotropic magnetoresistive (AMR) technology for precise and contactless 360-degree measurement and can determine incremental positions on a magnetic pole strip. The KMA36 magnetic encoder IC also has large air-gap tolerance, enabling measurements to remain reliable over wide temperature ranges and increasing protection against thermal stress. In addition, maintenance-free operation and high bandwidth of the magnetic sensor make it ideal for dynamic applications in harsh environments, including industrial machine control, robotics, and medical-device feedback.

TE CONNECTIVITY, www.te.com/usa-en/product-CAT-MRS0001.html

Mesh Kit Simplifies Test of IoT Solutions

Fujitsu's IoT Connectivity Solutions Mesh evaluation kit simplifies testing of all use cases for wireless IoT platforms driven by Wirepas mesh technology and Fujitsu hardware. The kit contains everything needed to get up and running, including 5X FWM8BLZ07Y sensor nodes outfitted with temperature, humidity, barometric pressure, accelerometer, luminance, and sound level. It also features 5X FWM8BLZ07P mesh nodes (set as asset tags), 20X FWM8BLZ07P mesh nodes (set as Wirepas), and 1X FWM8GWZ01 Wi-Fi gateway with 2X Wirepas sink nodes. The mesh evaluation kit contains all necessary settings and cloud setup for quick and easy installation.

FUJITSU, www.fujitsu.com/us/

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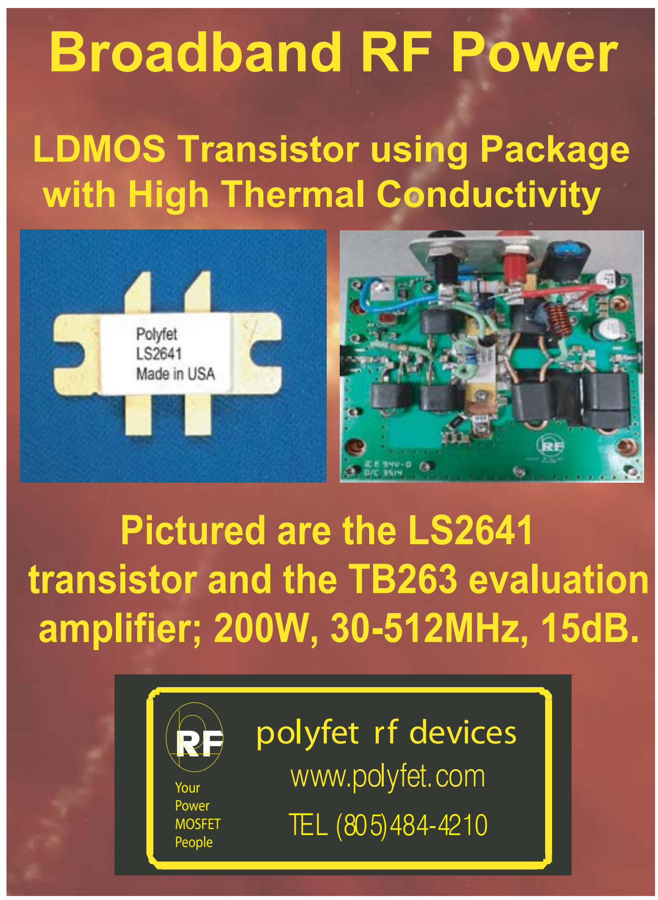

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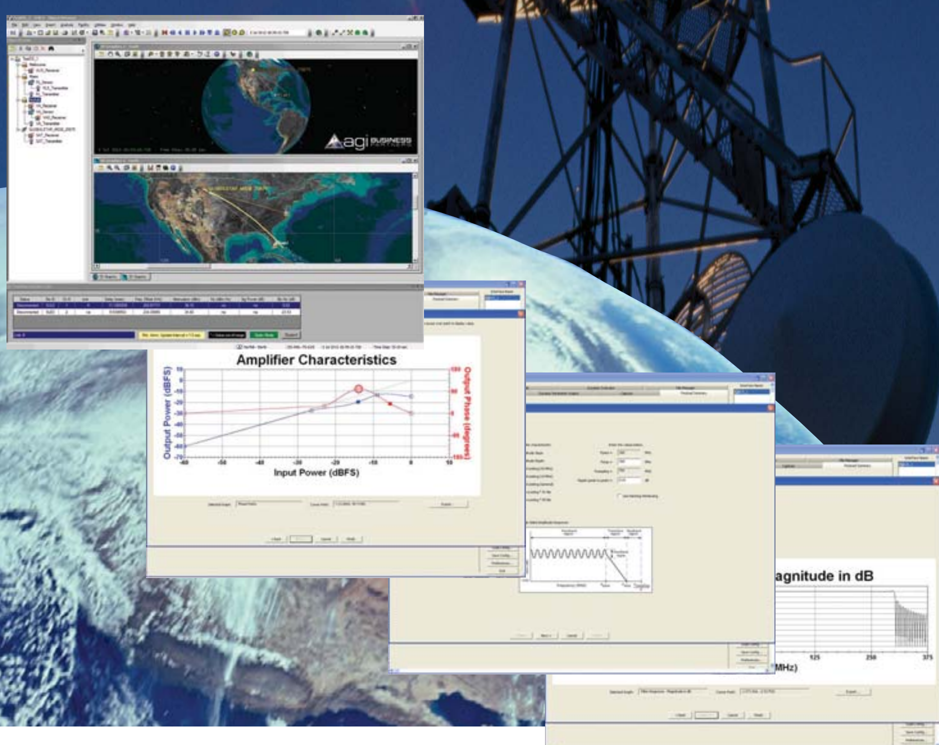

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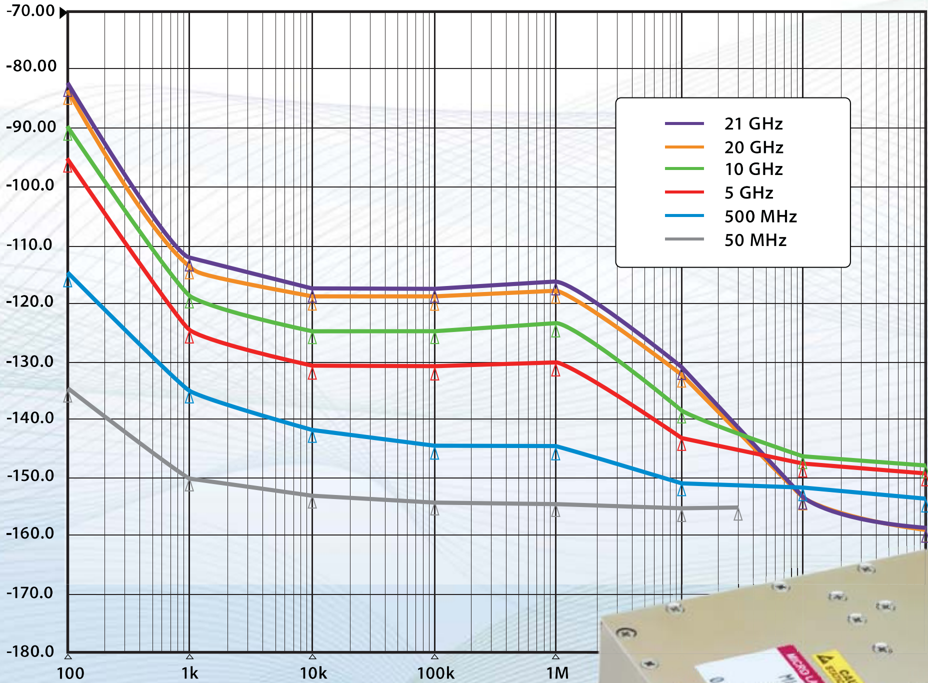

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