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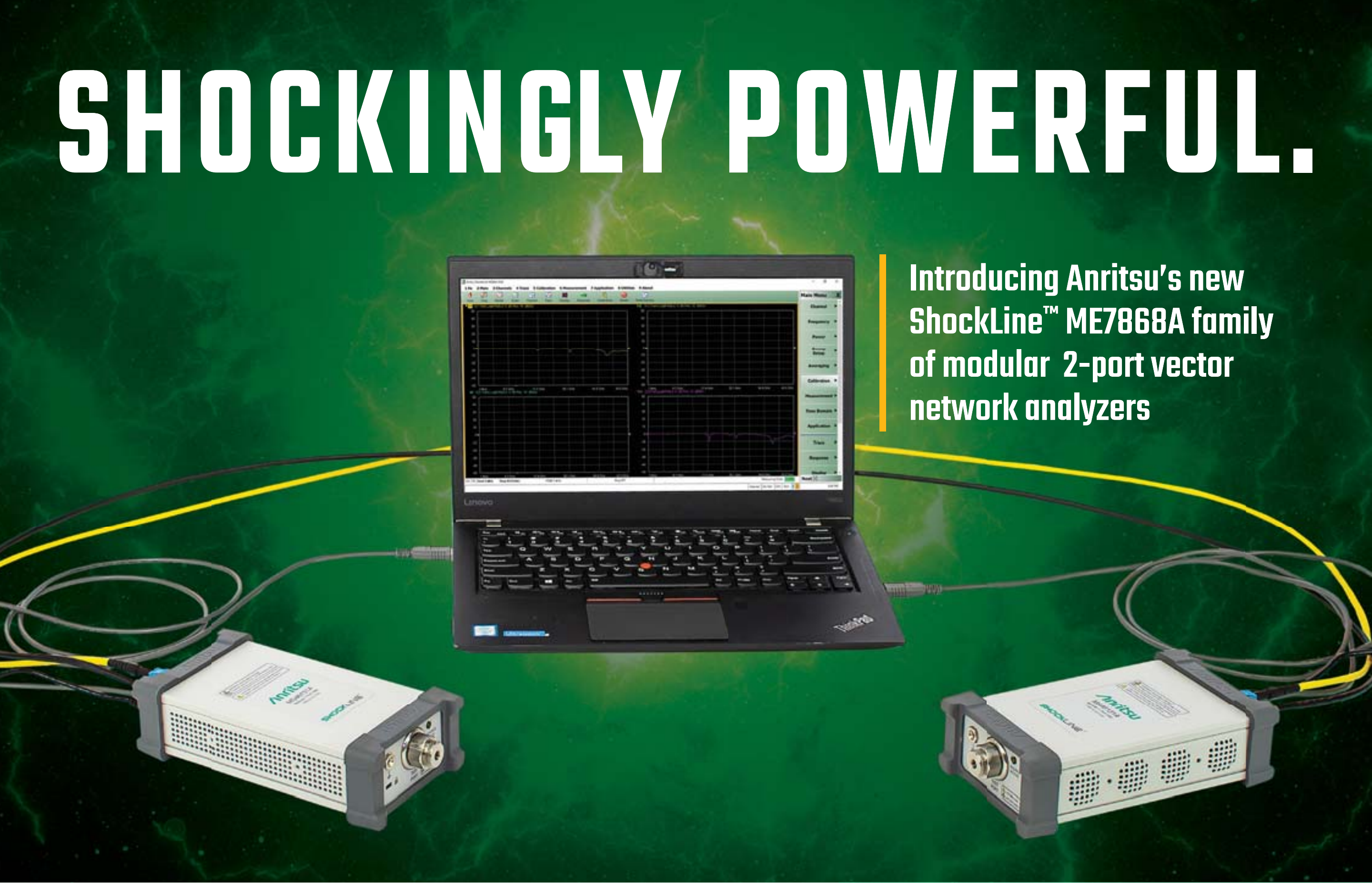

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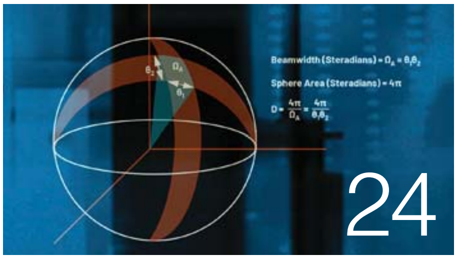

defense electronics

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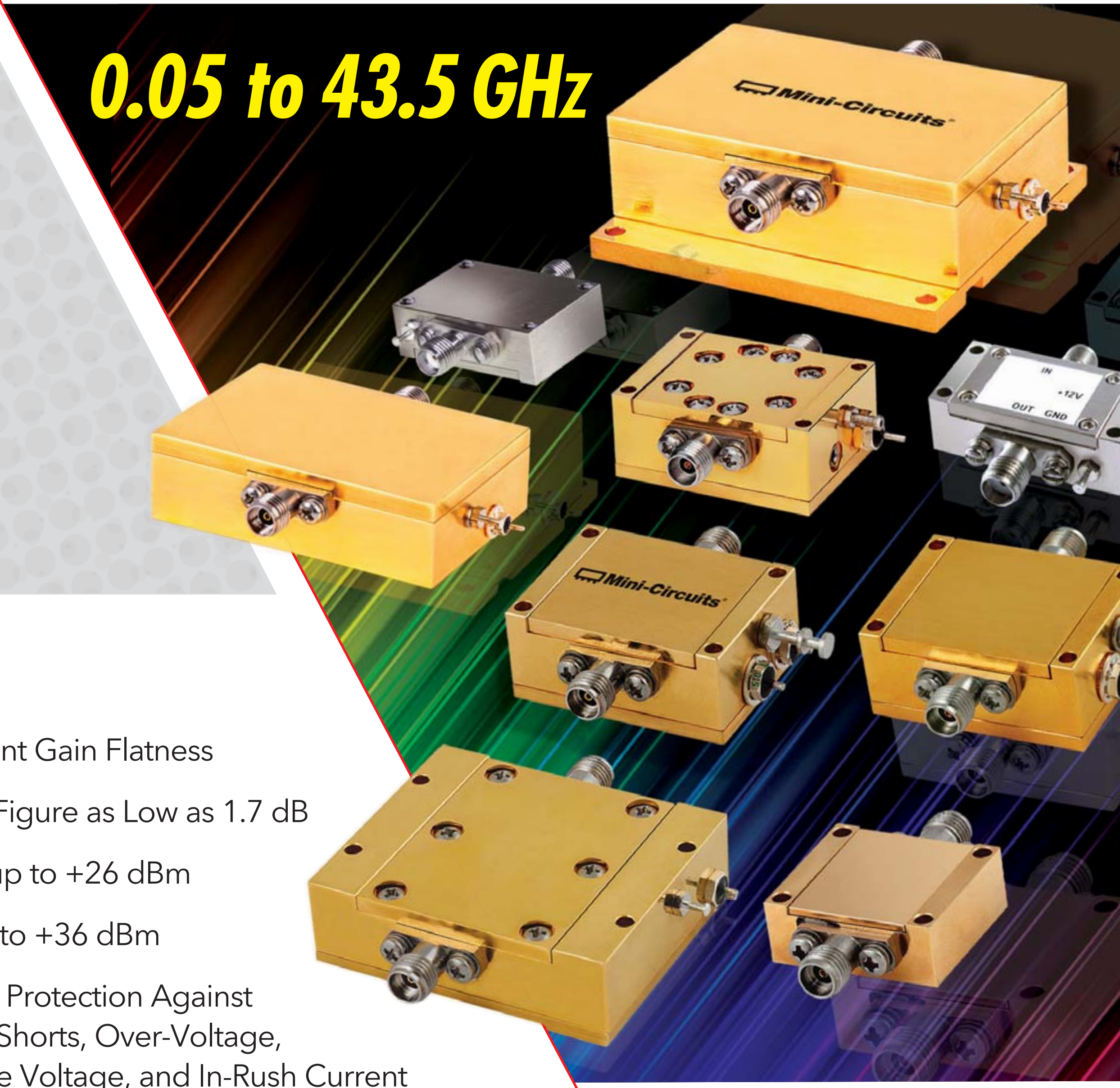

Editorial

DAVID MALINIAK | Editor
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How T&M Miscues Could Be Costing You

Results from a recent study expose how most businesses suffer from delays—leading to revenue loss—due to test equipment mishaps and failures.

Test and measurement (T&M) is a complex science, as most test engineers will tell you. Setups can be very finicky and calibration issues can doom your measurements from the start. Perhaps most importantly, the operator of the test setup needs to be well trained and highly knowledgeable. And, as shown in a recent study commissioned by Keysight, getting any of the above wrong is apt to cost you dearly.

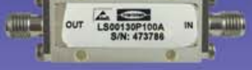
As was revealed in the third-party study conducted by Dimensional Research, nearly all companies that design and develop electronic products experience costly and preventable delays stemming from misconfiguration, maintenance, or training issues related to test equipment.

The survey of 305 R&D engineers across multiple industries found that 98% of respondents reported workflow issues related to calibration and setup, equipment misuse, or equipment failures. And 97% experienced delays that directly caused revenue loss to their business, with 53% reporting over $100,000 of waste per day while waiting to resolve critical technical support issues.

Other key findings from the survey of 305 R&D engineers across multiple industries, such as the technology and telecom sectors, include:

- *Test-equipment-related problems cause delays for almost all companies:* 97% of respondents said they experienced project delays stemming from test-equipment issues. Equipment failures requiring repair were the most common, cited by 63% of respondents, followed by equipment misconfigurations (56%) and equipment being out of calibration (50%).
- *Costs of lost days due to test equipment problems are high:* 53% said their companies lost over $100,000 per day when R&D teams could not make progress due to test-and-measurement equipment problems.
- *T&M equipment challenges are a regular problem:* In a typical month, 95% of respondents said they needed to contact their test equipment vendors' technical support team at least once.
- *The business impact of equipment problems:* 53% of survey respondents said product yield was negatively affected by test equipment failing to work properly. Furthermore, 47% said a product was rejected by a buyer and 45% said they had experienced increased product returns.
- *The value of expert test-related support services:* 90% of respondents said they would value access to technical support expertise from outside the organization. Assistance with troubleshooting an issue was the most desired service (cited by 54%), followed by answers to technical questions and discussion (53%), understanding how a particular test or equipment feature works (49%), and calibration services (46%).

To that last bullet, don't be afraid to lean on your equipment vendors for help. Application engineers at T&M vendors are paid to help customers solve their problems. Call them sooner rather than later before test issues overwhelm you and your team, impairing productivity and revenues. mw



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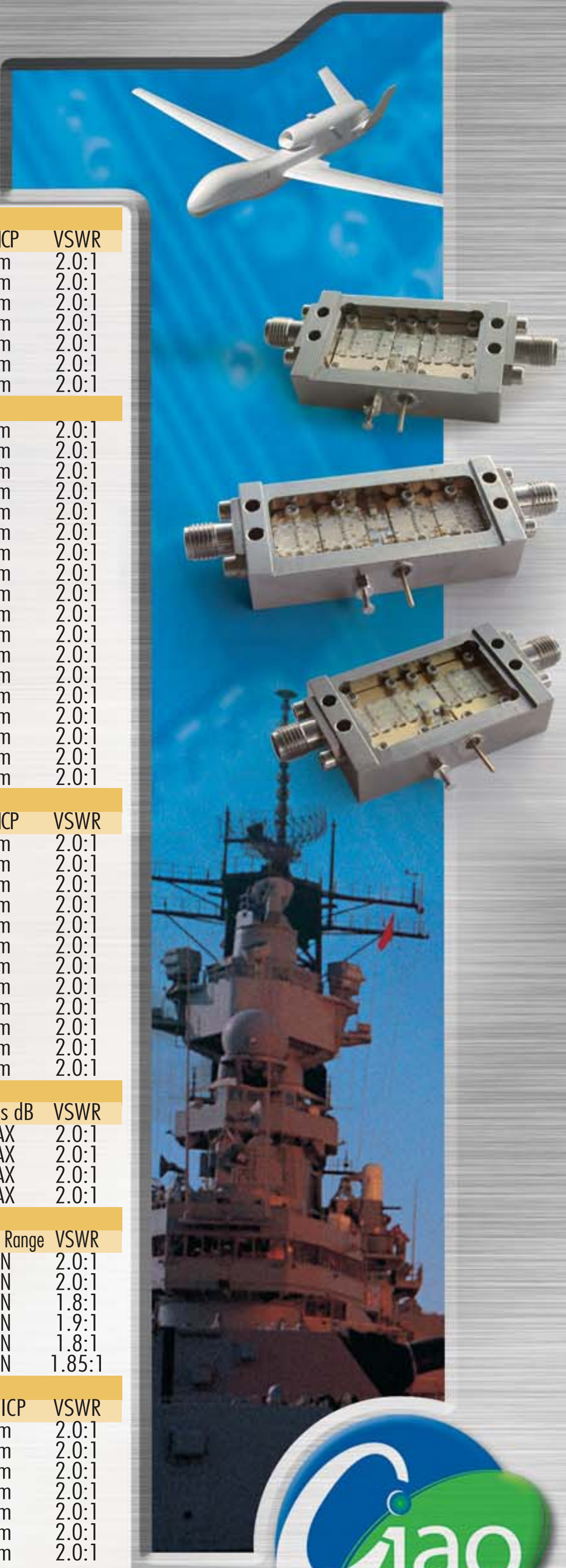

OCTAVE BAND LOW NOISE AMPLIFIERS

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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The International Microwave Symposium Goes Virtual (Part 1)

When it's time to railroad, you lay rail, and so the industry must adapt. That's why the International Microwave Symposium, the largest gathering of RF and microwave professionals, went virtual this year, due to COVID-19.

https://www.mwrf.com/events/article/21138638/the-international-microwave-symposium-goes-virtual-part-1

Millimeter Wave Goes Mainstream

After 30 years of toiling as a "niche" market, mmWave is about to hit the mainstream. Mobile Experts Founder Joe Madden explains why.

https://www.mwrf.com/technologies/systems/blog/21137436/millimeter-wave-goes-mainstream

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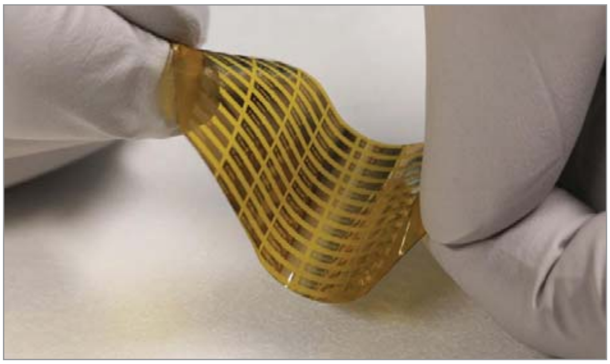


Picosecond Switching, Plasma Create All-Electronic Terahertz Pulses

Researchers developed relatively powerful terahertz pulses in a continuous stream by using large-magnitude picosecond pulses in a plasma-driven, chip-based arrangement.

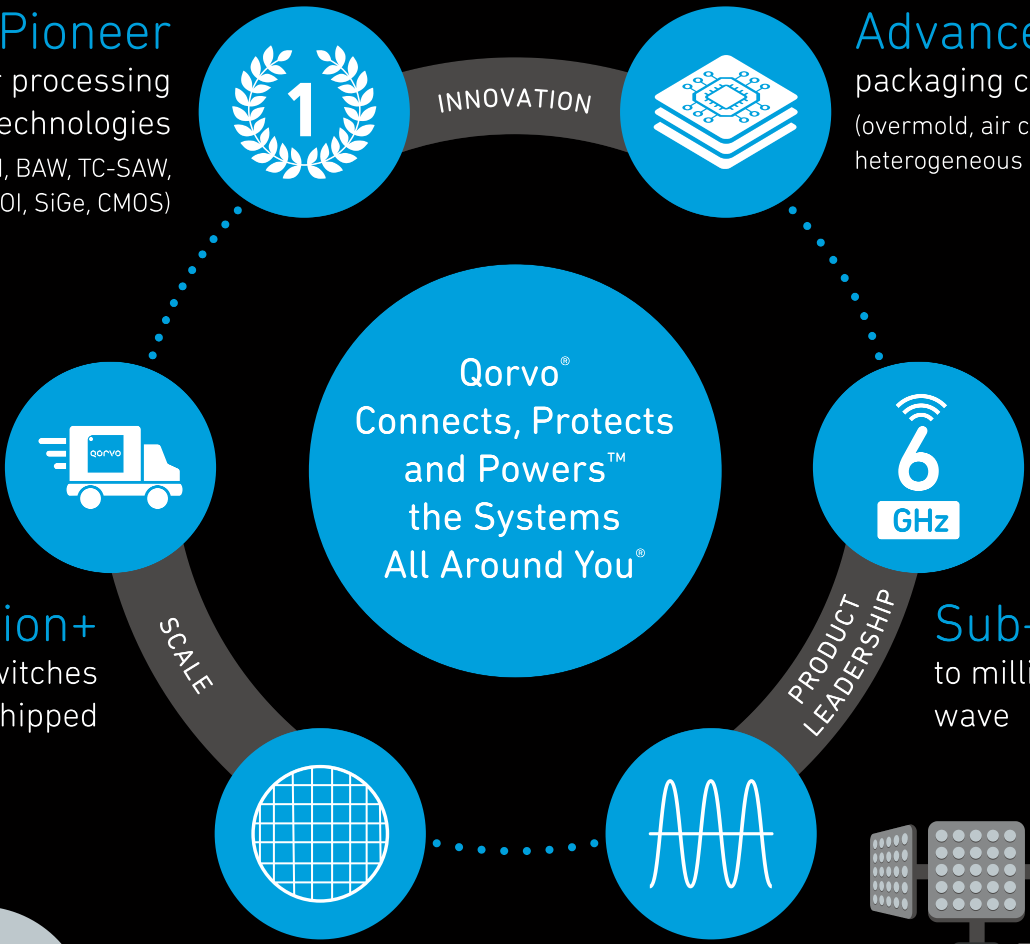
https://www.mwrf.com/technologies/semiconductors/article/21136026/picosecond-switching-plasma-create-allelectronic-terahertz-pulses

Develop and Test Algorithms on Commercial Radars—Moving from Simulation to Hardware

This installment of Algorithms to Antenna describes a workflow you can use to connect to software-defined radars in MATLAB.

https://www.mwrf.com/technologies/systems/article/21139510/algorithms-to-antennas-develop-and-test-algorithms-on-commercial-radarsmoving-from-simulation-to-hardware

ARE YOU WORKING WITH THE LEADER IN 5G?



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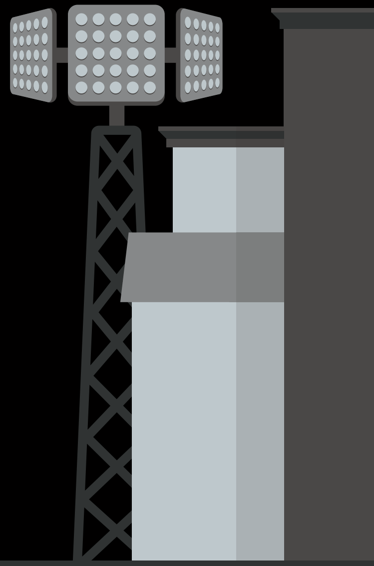

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News

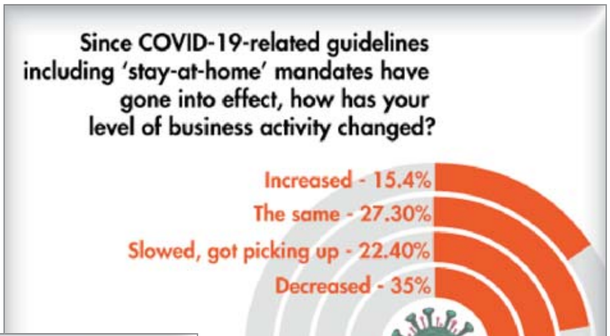
IN A SEA OF CHANGE, Engineers Retain Cautious Optimism

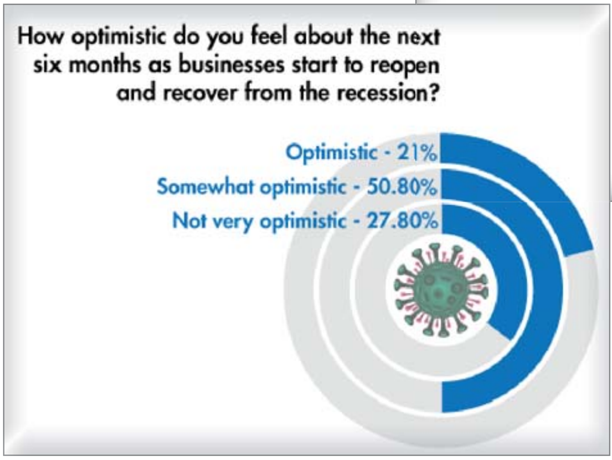
Post-COVID-19 recovery is expected, a Design Engineering group survey finds, but the workplace will be different for employees when they return.

The global COVID-19 pandemic has changed the way engineers have worked and the way their companies operate. And while there are strong expectations their own business will return to something close to normal in the next 12 months, their optimism for the rest of the economy is more tempered.

These are the key findings in a new study of the Design Engineering group of Endeavor Business Media. This group includes *Electronic Design*, *Electronic Sourcebook*, *Evaluation Engineering*, *Hydraulics & Pneumatics*, *Machine Design*, *Microwaves & RF*, and *Source Today*. The results were part of a larger study conducted across 78 Endeavor Business Media titles.

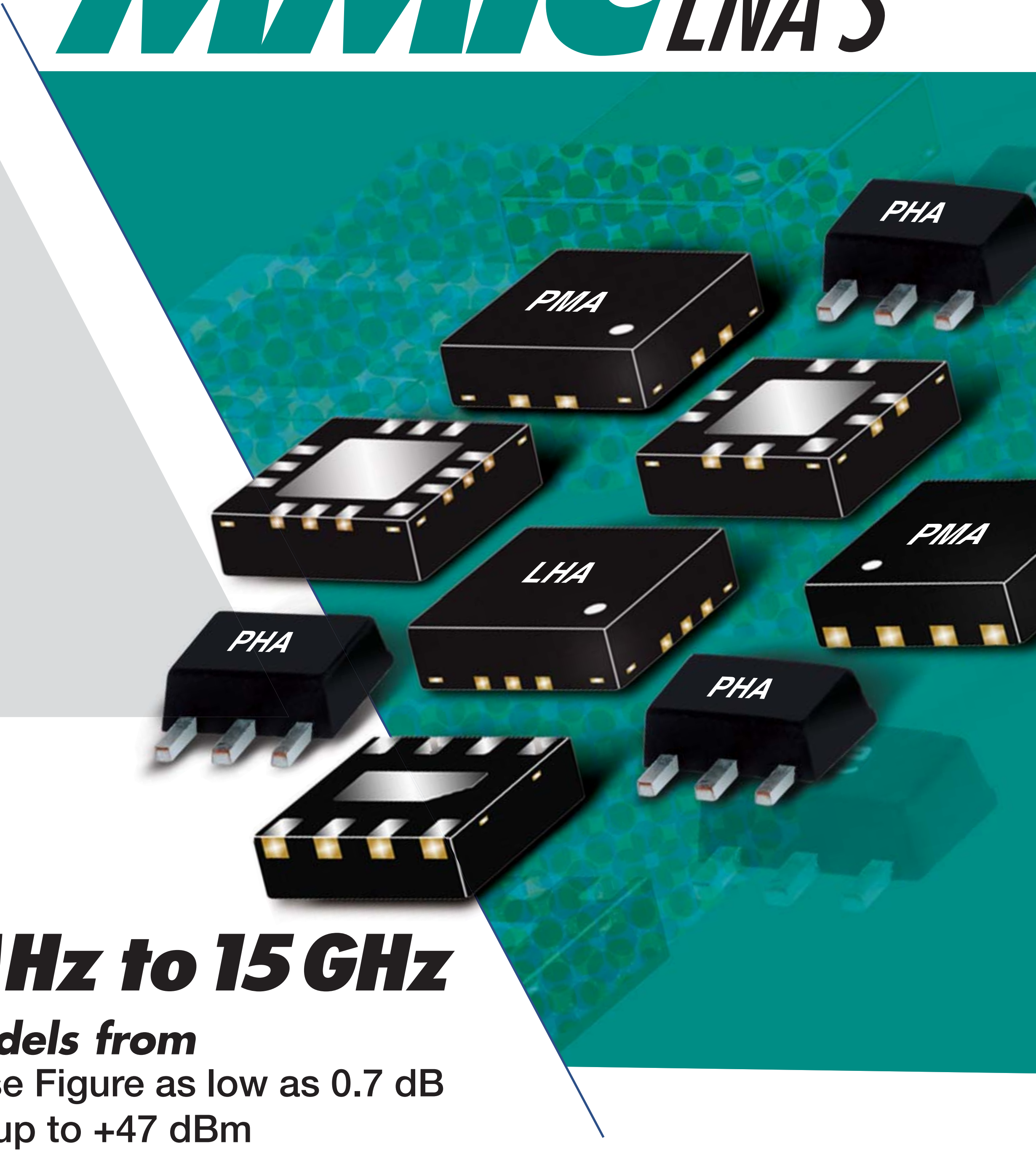
Engineering leaders expect recovery to start to take hold in 2021, with 32.2% seeing a rebound in the first half of the year and another 20% seeing recovery in the second half. Respondents are more optimistic that their own business will return to normal than for the economy as a whole. While 38.8% expect normal working conditions to resume on or shortly after the COVID-19 guidelines are lifted, 27.8% expect that normal business conditions could take a year to resume and 20% don't ever see a return to normal.





By comparison, while 34% of engineers think there could be an overall return to normal for all businesses, 38.3% said that could take more than a year and 22.8% said it would never return to normal.

When they do return to that new normal, engineers expect there to be changes in the way their business operates. These changes mainly concern sanitation, with 61.7% expecting an increased emphasis in that area, and social distancing, with 51.9% expecting continuing rules about maintaining worker spacing. And in one of the more surprising pieces of data, while 36% expect a re-evaluation of their supply chain and 19.1%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planning a virtual customer service model, just 15.3% expect a company investment in automation or Internet of Things technologies.

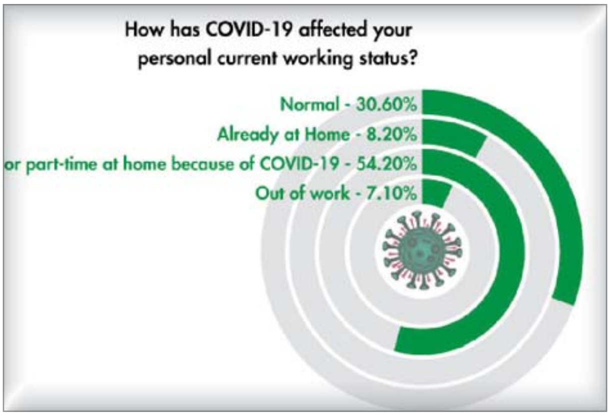
While about 35% of engineers said business activity has declined since "stay-at-home" guidelines were widely implemented, 27% have seen no change in business and 15.4% have seen an increase. Slightly more than half of respondents (50.8%) say they are optimistic about the next six months as businesses reopen, a higher level of optimism than expressed in the overall Endeavor survey (43.7%).

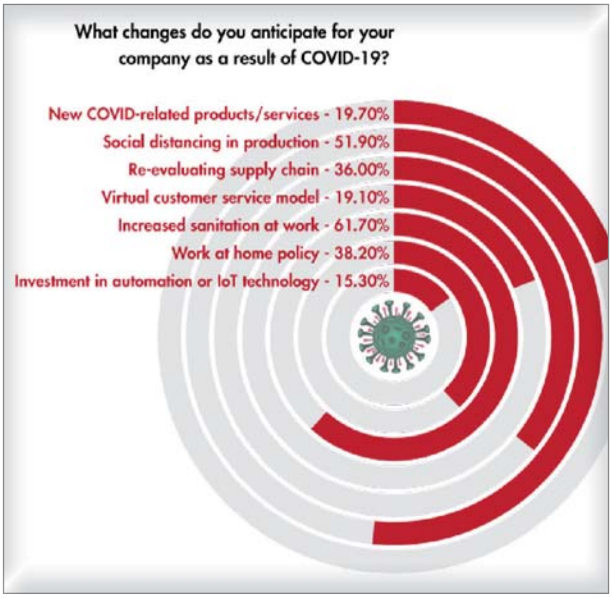
In many businesses, work-at-home guidelines have become a new normal, and 54.2% of engineering respondents said they now are working at home full-time or part-time as a direct result of COVID-19, while 30.6% are working normally, either in the office or in customer-facing roles in the field. Just 8.2% report they already were working from home full-time. The engineers said their company would be expanding the work-from-home policy for the future, with 38.2% expecting changes in that procedure even after restrictions are lifted.

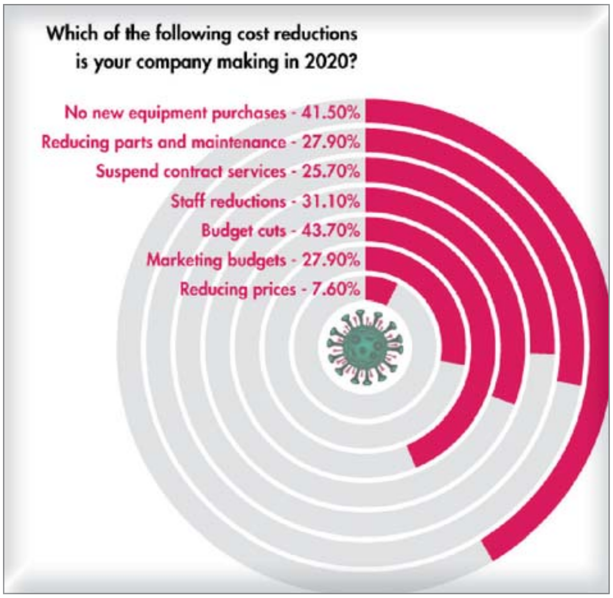
Company officials said they either were prepared for some sort of business disruption or were quickly able to adapt. A disaster plan was in place for 44.2% of businesses, although 37.1% needed to update the plan to deal with the specific impact of COVID-19. Another 19.1% quickly developed a response plan, and 10.9% are now implementing a plan.

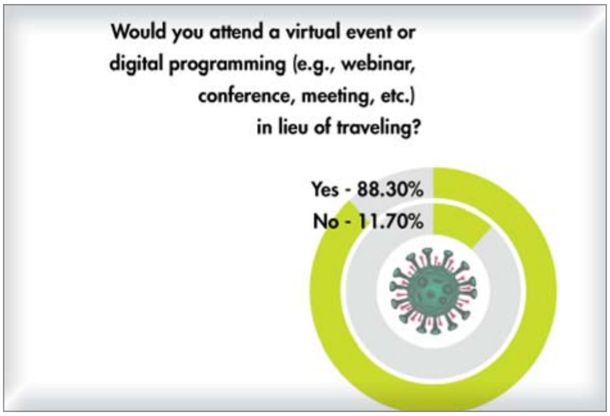
To meet the pandemic challenges, a number of businesses altered their purchasing, contract, employment and marketing plans. The two biggest areas of reductions were in overall budget cuts (43.7%) and eliminating new equipment purchases (41.5%). Companies also cut back on personnel, as 31.1% experienced either staff reductions or furloughs as a result of the pandemic.

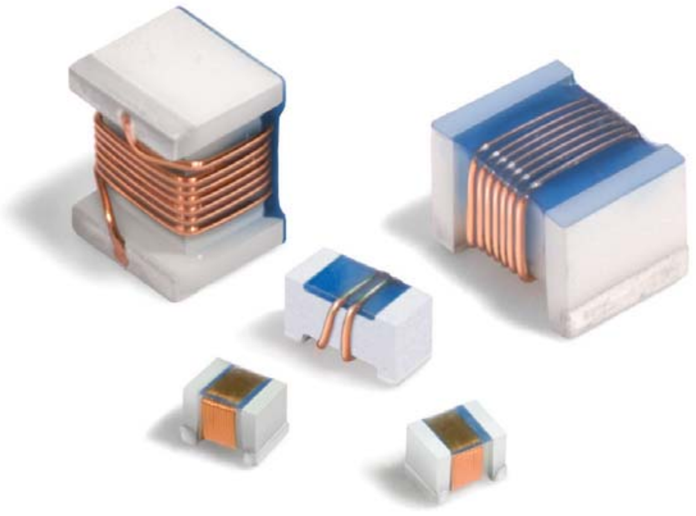
One big area of changes for the near future is the way engineers seek out and obtain information. While 62.8% said they have no travel planning in the next six months and just 8.9% are back to their pre-COVID-19s travel schedule, 88.3% of respondents said they would attend a digital webcast, conference or meeting instead of traveling. ■











MEMS CLOCK ICs AND OSCILLATORS

Arrive in Time for 5G

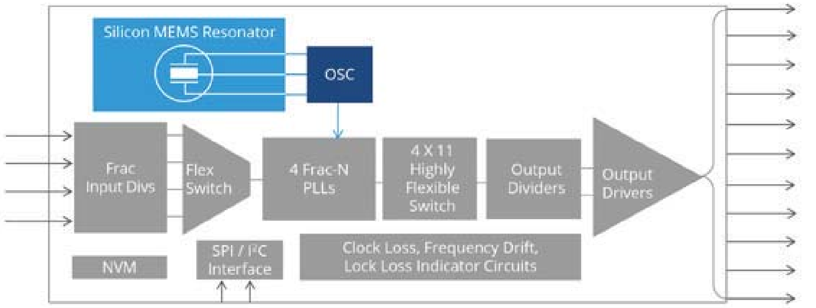
TIMING IS EVERYTHING in the fast-growing communications and enterprise markets, and SiTime recently made two announcements that further solidify its place in the realm of timing devices that are so critical to infrastructure. The company's Cascade SiT9514x family of MEMS clock ICs using its recently launched third-generation MEMS resonators deliver higher performance with lower power. Meanwhile, the SiT9501 differential MEMS oscillators deliver high performance for 100G to 800G optical modules in a package as much as 50% smaller than quartz-based oscillators.

CASCADE SIT9514X MEMS CLOCK ICs

Communications and enterprise electronics have previously used clock ICs with external quartz references to integrate multiple timing functions and to distribute clock signals. The all-silicon clock architecture in the SiT9514x devices provides more integration by integrating a MEMS resonator reference inside the package *(see figure)*. More importantly, with MEMS technology, the Cascade clock-system-on-a-chip delivers up to 10 times higher reliability and resilience, enabling the 5G vision of zero downtime. Either standalone or paired with the company's MEMS TCXOs and OCXOs, the SiT9514x delivers a complete timing solution for applications such as 5G RRUs, small cells, edge computers, switches, and routers.

The benefits of using SiTime's complete clock SoCs include:

- The devices' integrated MEMS resonator eliminates issues with quartz such as capacitive mismatch, activity dips, susceptibility to shock, vibration, and EMI.
- Four independent PLLs, with maximum flexibility to support time-synchronization applications where multiple independent clock domains are required.
- Up to 11 outputs with an operating frequency range of 8 kHz to 2.1 GHz, as well as a 1-pps (pulse per second) output, for maximum frequency agility.
- Programmable PLL loop bandwidth down to 1 millihertz for maximum filtering of wander or network noise in IEEE 1588 and synchronous Ethernet.
- Fail-safe operation in case of input clock failures through faster hitless switching between four independent inputs. In such a situation, the device automatically switches to different input clock sources with minimum phase transient at the output, allowing the downstream PLL to remain locked, and the system to continue to operate reliably.
- Excellent PSNR for highest performance in the presence of power-supply noise.
- Minimal external filtering circuits for simpler design, space savings, and BOM reduction.
- Rich programmable features and configuration options: (1) Blank ISP



1. SiTime's Cascade SiT9514x clock chips include integrated MEMS resonators, eliminating crystal matching and reliability issues.

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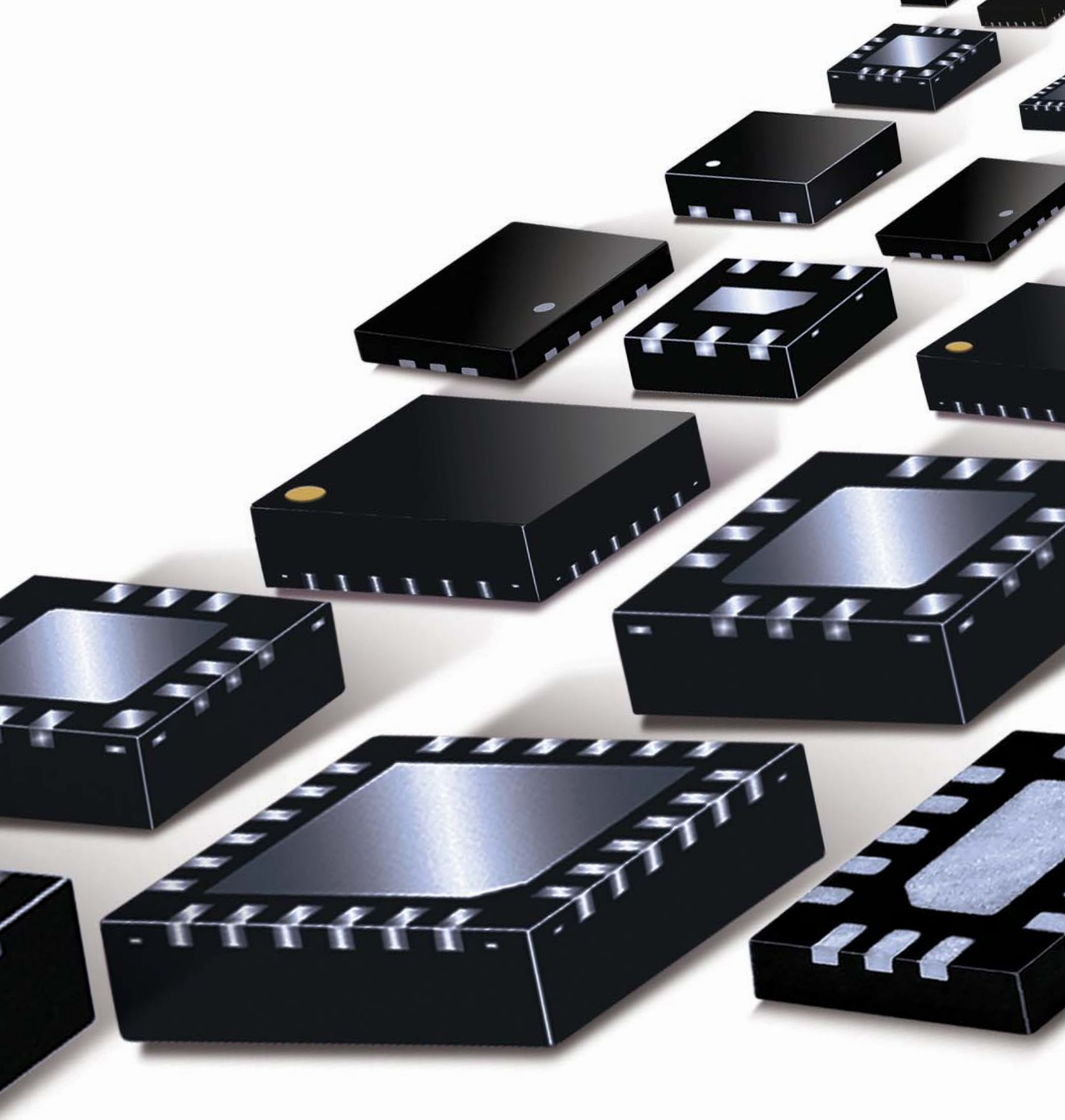

Available in Plastic SMT & Unpackaged Die (in-system programmable) devices provide maximum flexibility; (2) Pre-programmed devices enable system boot up without software configuration for maximum simplicity.

- EVBs and TimeMaster software enable users to map clock configurations and generate the scripts for software integration, which speeds development.

SIT9501 DIFFERENTIAL MEMS OSCILLATORS

SiT9501 differential MEMS oscillators offer a space savings of up to 50% compared with quartz oscillators, enabling them to integrate more features and reduce the development time for optical modules, data-center switches, telecom routers, edge servers, AI/graphics cards, and storage controllers.

In anticipation of massive Internet traffic growth, driven by 5G, AI, and cloud computing, data centers are increasing throughput. Optical modules and data-communications equipment need to deliver faster data rates. Outdoor 5G infrastructure is subject to environmental stressors such as high temperatures, vibration, and airflow that can degrade throughput. With the increased data rates and potential environmental stressors, timing margins shrink, requiring lower jitter oscillators to ensure the same quality of service.

In optical modules, a third of the PCB area is consumed by the optical sub-assembly, leaving little room for data-processing electronics, and making small size a critical factor in oscillator selection. The SiT9501 differential oscillator solves both key issues by offering the lowest jitter in the presence of environmental stressors, and the smallest size.

The SiT9501 is the industry's lowest-jitter programmable oscillator, and includes the following features:

- Popular networking frequencies from 25 MHz to 644.53125 MHz.
- 70 femtoseconds of RMS phase jitter.
- 2.0- x 1.6-mm package, as well as other industry-standard packages.
- Wide temperature range from -40 to +105°C.
- On-chip voltage regulators to filter power-supply noise, enhancing power integrity for module designs.
- FlexSwing driver reduces power consumption by 30% and integrates source-bias LVPECL resistors.

The SiT9514x clock system-on-a-chip family is sampling now. High-volume production quantities will be available in Q4 2020. The SiT9501 oscillator is sampling now. Production quantities are planned to be available in Q1 2021. Pricing is provided upon request, and a datasheet is available. ■


I50-A
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Infinity Probe™

Technology Report

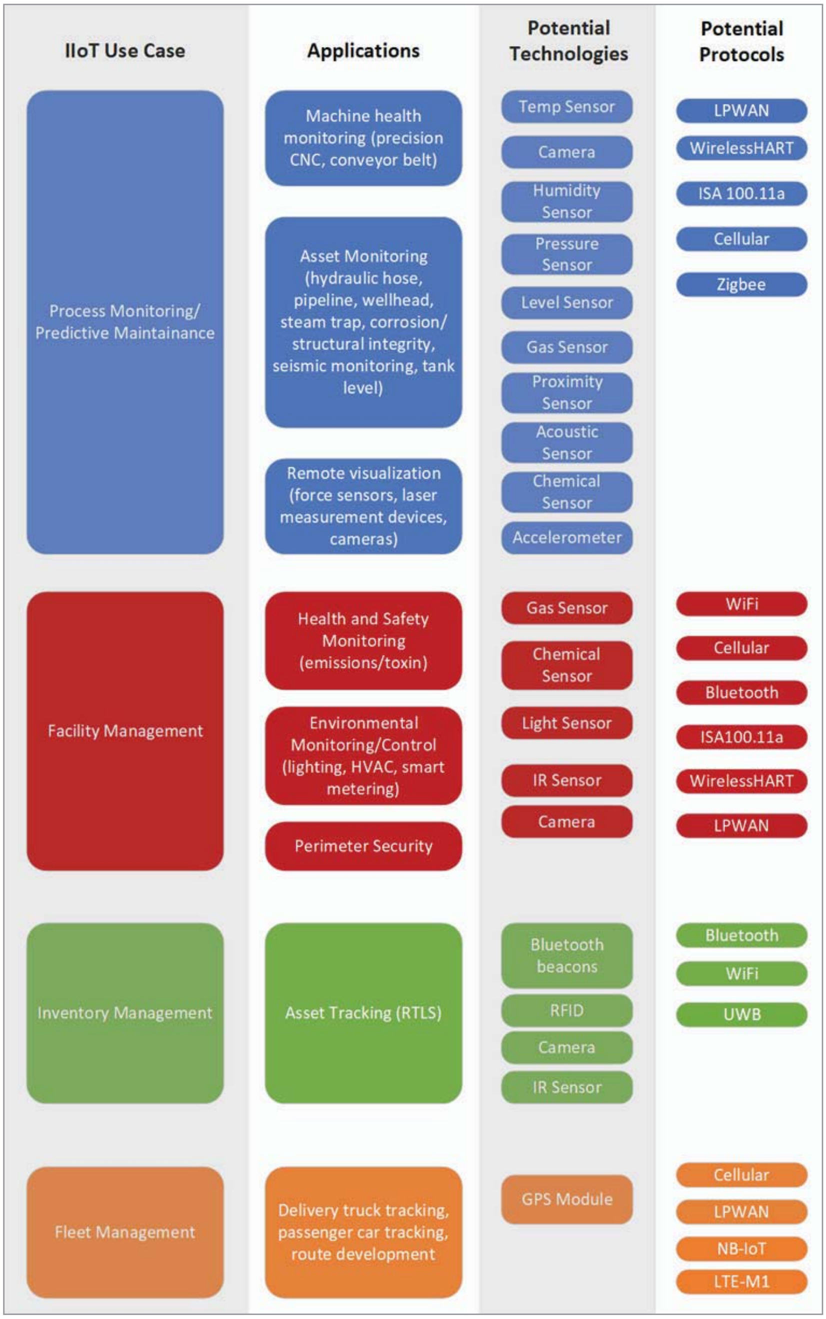
TINU OZA | IoT Product Manager, L-com

Understanding the Underlying Sensor and Wireless Technologies in IIoT Apps

This article details some of the more common industrial IoT applications that utilize wireless sensor technology to control, monitor, and report on critical processes and control functions.

From the connected home and smart wearables to Industry 4.0 and smart-city applications, wireless sensor networks (WSNs) permeate nearly every conceivable application. They bring automation to simple manual tasks with remotely controlled actuators and monitoring/tracking environments with evolving microelectromechanical-systems (MEMS) sensors. These relatively simple, energy-constrained devices reveal a massive potential in data collection and data analytics to better assess human, machine, and even plant systems.

In industrial IoT (IIoT), short-range wireless solutions, cellular, and low-power wide-area networks (LPWANs) can be leveraged to support the various sensor nodes. The choice of industrial communications depends on whether the process is time-critical with the need for real-time data or is non-time critical



IIoT Use Case	Applications	Potential Technologies	Potential Protocols
Process Monitoring/ Predictive Maintainance	Machine health monitoring (precision CNC, conveyor belt) Asset Monitoring (hydraulic hose, pipeline, wellhead, steam trap, corrosion/ structural integrity, seismic monitoring, tank level) Remote visualization (force sensors, laser measurement devices, cameras)	Temp Sensor Camera Humidity Sensor Pressure Sensor Level Sensor Gas Sensor Proximity Sensor Acoustic Sensor Chemical Sensor Accelerometer	LPWAN WirelessHART ISA 100.11a Cellular Zigbee
Facility Management	Health and Safety Monitoring (emissions/toxin) Environmental Monitoring/Control (lighting, HVAC, smart metering) Perimeter Security	Gas Sensor Chemical Sensor Light Sensor IR Sensor Camera	WiFi Cellular Bluetooth ISA100.11a WirelessHART LPWAN
Inventory Management	Asset Tracking (RTLS)	Bluetooth beacons RFID Camera IR Sensor	Bluetooth WiFi UWB
Fleet Management	Delivery truck tracking, passenger car tracking, route development	GPS Module	Cellular LPWAN NB-IoT LTE-M1

1. Depending on the industrial application at hand, there are numerous IIoT use cases in which many sensor technologies and/or communication protocols may be brought to bear.

with either frequent or infrequent transmissions. Depending on the industrial application at hand, there are numerous IIoT use cases in which many sensor technologies and/or communication protocols may be brought to bear *(Fig. 1)*.

PROCESS MONITORING

Process monitoring is likely to be the largest application for industrial WSNs (IWSNs) as it requires the placement and tracking of thousands to tens of thousands of sensor nodes over vast distances. This centralized method of tracking industry operations is what leads to realizing predictive maintenance strategies that systematically minimize factory downtime and save on operational overhead.

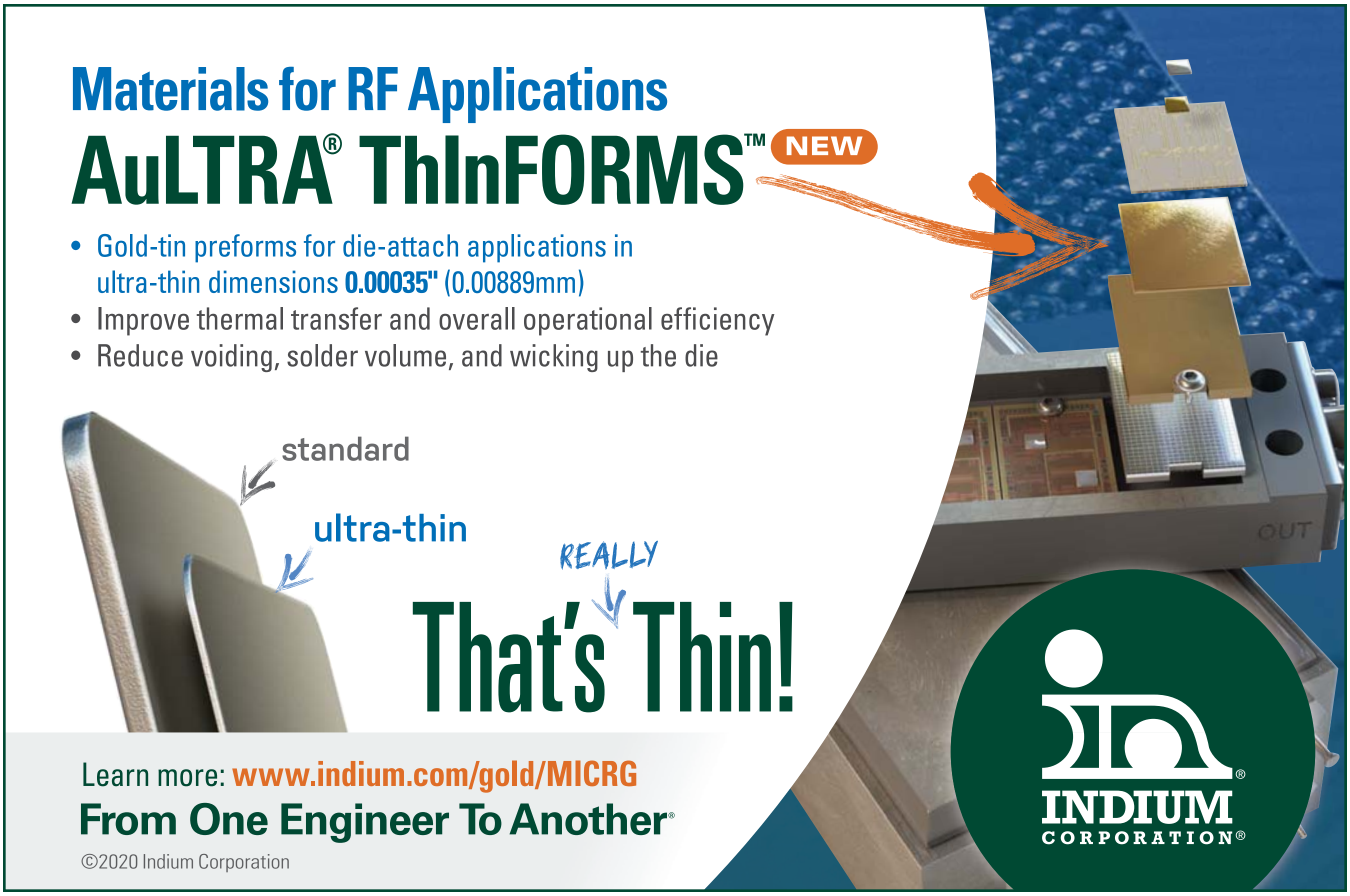
MACHINE-HEALTH USE CASES AND COMMON SENSOR TYPES

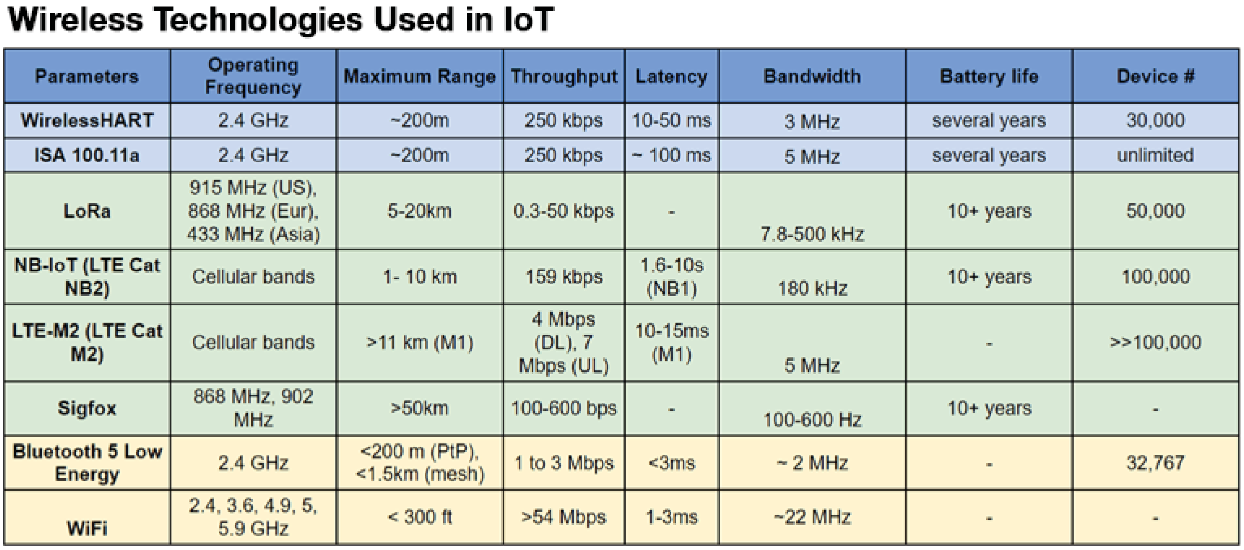
Hyper-specialized equipment is leveraged all over IIoT because monitoring common faults is critical to maintain optimal performance of machine equipment. For instance, while a high-end computer-numerical-control (CNC) system can perform precision machining on a massive scale, it can encounter the common faults of spindle unbalance.

Should such a fault occur, the mass unbalance in the spindle system can cause the machine tool to vibrate, ultimately degrading machine accuracy and potentially causing further machine damage if left unrepaired.[1] Typically, the bearings within the spindle are analyzed for vibrations as they allow the shaft to stay in place while rotation occurs—uncharacteristic vibrations would therefore be apparent with these components.

Accelerometers are able to monitor and detect such machine-tool failures by collecting vibration data. Ultrasonic and acoustic emission sensors can detect damage within the bearings of the spindle before any noticeable vibrations occur by discerning the ultrasonic acoustic emissions resulting from metal degradation. Armed with knowledge of the nominal thermal operation, temperature sensors can also note temperature anomalies in various critical components within the machine. An inductive current sensor would detect variations in the current consumed by the electrical motor, too, and similarly detect anomalies.

These same principles can be applied to any large machine that includes a large electric motor. Cranes, for instance, are often used in manufacturing facilities to move large, heavy equipment from passenger cars to airplanes. Pulleys and electric motors will be found in conveyor belts that are leveraged in a broad array of applications including coal mining, food processing, and chemical segregation. Accelerometers, temperature sensors, and inductive current sensors are all useful in adequate monitoring of such machines.[2]



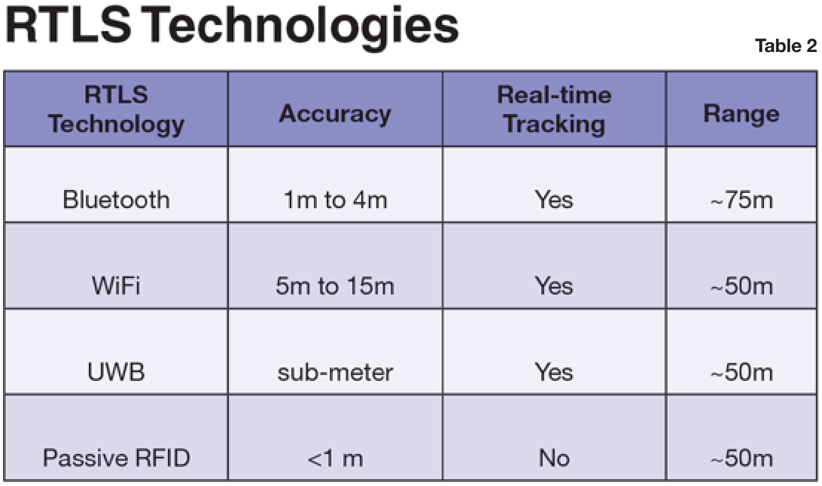


Wireless Technologies Used in IoT

Parameters	Operating Frequency	Maximum Range	Throughput	Latency	Bandwidth	Battery life	Device #
WirelessHART	2.4 GHz	~200m	250 kbps	10-50 ms	3 MHz	several years	30,000
ISA 100.11a	2.4 GHz	~200m	250 kbps	~ 100 ms	5 MHz	several years	unlimited
LoRa	915 MHz (US), 868 MHz (Eur), 433 MHz (Asia)	5-20km	0.3-50 kbps	-	7.8-500 kHz	10+ years	50,000
NB-IoT (LTE Cat NB2)	Cellular bands	1- 10 km	159 kbps	1.6-10s (NB1)	180 kHz	10+ years	100,000
LTE-M2 (LTE Cat M2)	Cellular bands	>11 km (M1)	4 Mbps (DL), 7 Mbps (UL)	10-15ms (M1)	5 MHz	-	>>100,000
Sigfox	868 MHz, 902 MHz	>50km	100-600 bps	-	100-600 Hz	10+ years	-
Bluetooth 5 Low Energy	2.4 GHz	<200 m (PtP), <1.5km (mesh)	1 to 3 Mbps	<3ms	~ 2 MHz	-	32,767
WiFi	2.4, 3.6, 4.9, 5, 5.9 GHz	< 300 ft	>54 Mbps	1-3ms	~22 MHz	-	-

802.15.4-based
LPWAN
Popular Protocols

Table 1



RTLS Technologies

RTLS Technology	Accuracy	Real-time Tracking	Range
Bluetooth	1m to 4m	Yes	~75m
WiFi	5m to 15m	Yes	~50m
UWB	sub-meter	Yes	~50m
Passive RFID	<1 m	No	~50m

Table 2

ASSET-MONITORING USE CASES AND COMMON SENSOR TYPES

Oil and gas manufacturers monitor assets such as pipelines over vast distances. In this application, leaks and ruptures are avoided at all costs to prevent the potential loss of life and damage to the environment. Pipelines have several significant failure modes, including construction/manufacturing defects; damage during installation; corrosion; and earth forces such as earthquakes, land slips, and extreme weather-related incidents.[3]

External accelerometers can monitor the pipeline's flow rate by tracking flow-induced vibrations. Crack monitoring can be accomplished through ultrasonic detection or transverse magnetic-flux leakage. Failures due to corrosion can be prevented through several sensors with technologies like RFID and fiber optics. Seismic sensors can provide a subsurface map for offshore drilling rigs, improving rig efficiency.

In chemical, food, and pharmaceutical processing facilities, mixing tanks rotate chemicals and ingredients that are added in precise values. Sensors placed at key locations on these tanks measure parameters such as temperature, humidity, pressure, pH value, and fill level, thus ensuring optimal plant operational procedures with little to no manual intervention.

IoT protocols for process monitoring vary greatly depending on the application. *Table 1* above lists some commonly used IoT protocols and some of their respective key parameters. Oftentimes, WSNs monitor machine health within a facility that, when compared to some asset-monitoring applications such as tracking pipeline health, is contained within a relatively small area.

In cases where small payloads of data are transmitted infrequently, LPWANs such as LoRa, Sigfox, and NB-IoT offer narrowband modulation schemes at sub-gigahertz frequencies—two qualities that increase signal range. The LPWANs are known not only for large transmission distances, but also for long battery lifetimes beyond 10 years and one-to-many architectures in which thousands of devices can be wirelessly connected to a gateway (when sensor nodes can be deployed on the scale of tens of thousands, energy-harvesting techniques and battery lifetime are critical considerations).

However, LPWAN protocols are often asynchronous with unscheduled transmissions. Thus, they're susceptible to data collisions at high network capacities. This would not be ideal for time-critical IIoT applications that require deterministic and reliable transmissions with a low bit error rate (BER). Industry-specific wireless networks such as WirelessHART and ISA100.11a are based on IEEE 802.15.4, low-rate wireless personal-area networks (LR-WPANs). With a maximum range of 200 meters, these offer up to a 250-kb/s throughput and latencies of 10 to 100 ms for more real-time communication on critical processes.

HEALTH AND SAFETY

Monitoring the environmental conditions with the respective intelligent alarm installations is essential in protecting industrial workers and maintaining smooth operations. This often involves the use of gas/chemical-based sensor nodes around areas of particular risk.

In the oil and gas industry, tracking highly combustible methane leaks is paramount in preventing any potential explosions around wellheads. Steam traps leverage a huge range of manufacturing facilities to filter out condensate from air without letting steam escape. A faulty steam trap would fail to remove water droplets from steam, causing water to accumulate and rupture steam lines, leading to expensive downtime and safety hazards.

Acoustic sensors and temperature sensors have been used to monitor the behavior of these critical components to prevent any costly failures. Underground mines are notorious for hazardous safety conditions; environmental parameters such as carbon-monoxide emissions, methane emissions, and airflow are actively monitored to ensure a safe working environment.

Reliable and deterministic protocols are necessary for these applications, often calling for WirelessHART or ISA100.11a communications within the facility. While these protocols may consume more power on sensor nodes than other WSN technologies such as Bluetooth Low Energy (BLE) or LPWANs, the ability to perform real-time analysis and control on data is critical to ensure adequate safety measures.

Both WirelessHART and ISA100.11a were specifically designed for industrial applications. WirelessHART is the wireless alternative to the existing HART technologies and ISA100.11a was developed by the International Society of Automation (ISA) to support multiple protocols already used in industrial applications, including HART, Modbus, Foundation Fieldbus, and ProfiBus. Both networks support star and mesh networking with bidirectional communication from the host to the sensor node.[4]

ASSET TRACKING WITH RTLS

Compared to outdoor tracking systems that rely on GPS and typically yield an accuracy around 10 m, indoor position systems (IPSs) such as real-time location systems (RTLSs) can achieve accuracies on par or lower without the major consideration of satellite signals penetrating factory walls. *Table 2 (on page 20)* lists some of the more commonly used RTLSs.

Such IPSs can be applied on the plant floor to actively track moving indoor equipment like forklifts and actively track inventory in transport within a facility. Outdoor environments, e.g. truck yards, can leverage RTLSs to monitor and manage truck movement by assigning docks and tracking loading/unloading of cargo.

Indoor positioning systems will employ either a trilateration or a fingerprinting localization method, depending on the wireless protocol in use. Trilateration uses estimated distances to calculate the likeliest coordinates of an object. The fingerprinting method compares current signal characteristics with a previously catalogued set of signal characteristics obtained from fingerprint locations—implementing this is often more technically involved. The movement of a sensor can then be obtained by comparing the online measurements with the "fingerprint." For brevity, this section will cover two popular RTLS protocols: Bluetooth and Ultra-wideband (UWB).

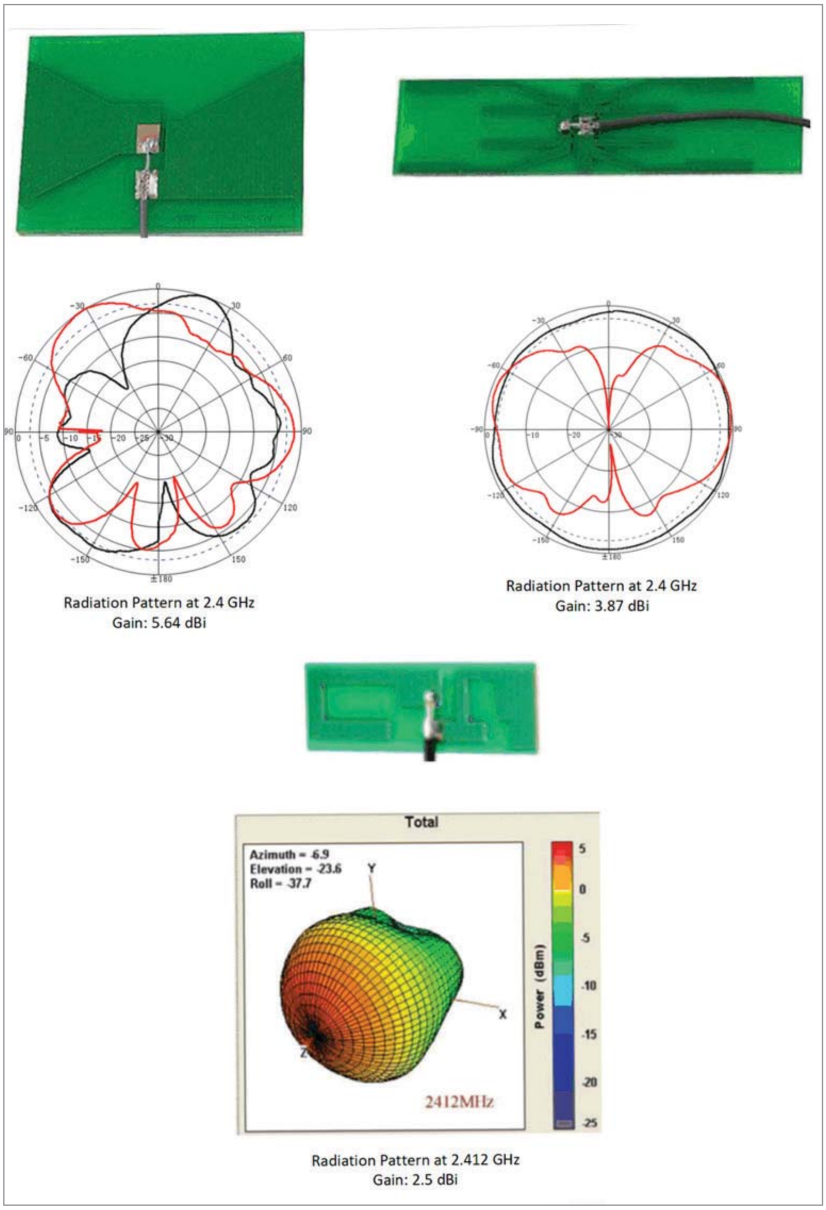
LEVERAGING A UWB SYSTEM FOR RTLS

Ultra-wideband (UWB) technology essentially sends a burst of energy of extremely short duration (< ns), resulting in a broadband signal. Sending out wideband bursts of energy would typically be a power-hungry process. However, a UWB system can be engineered to produce a low probability of detection (LPD) RF signature with a low energy density that doesn't interfere with neighboring equipment.

For RTLS applications, the short pulses in UWB modulation allow for precise delay estimates, ultimately yielding position/location data. Typically, UWB technology leverages time-of-arrival (ToA) and time-difference-of-arrival (TDoA) information generated by tags that emit low-power UWB pulses which are received by the sensors or UWB readers. Those pulses are used to determine the precise 3D location for a tag with centimeter accuracy. However, precise time synchronization is needed between the UWB readers within a network to successfully gain location data.

The UWB frequencies have frequency allocations between 3.1 and 10.6 GHz. Typically, a planar monopole antenna is employed in these applications due to their omnidirectional radiation pattern and ability to yield stable input impedance over the large frequency bandwidth. Because of their performance into the X-band and the fact that trace dimensions grow smaller at higher fre-

(Continued on page 41)


Radiation Pattern at 2.4 GHz
Gain: 5.64 dBi

Radiation Pattern at 2.4 GHz
Gain: 3.87 dBi

Radiation Pattern at 2.412 GHz
Gain: 2.5 dBi

2. Bluetooth PCB antennas with an omnidirectional radiation pattern are often suitable due to the 360-degree beam coverage over the factory floor.


4 dB
PASTERNACK
PE2204-6
IN
OUT

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Phased-Array Antenna Patterns (Part 2)—Linear-Array Beam Characteristics and Array Factor

Part 2 of this six-part series takes a look at antenna gain, directivity, and aperture, in addition to array factors.

Part 1 of the series covered beam direction and working with a uniformly spaced linear array of antennas. In part 2, we'll cover antenna gain, directivity, and aperture, as well as array factors.

ANTENNA GAIN, DIRECTIVITY, AND APERTURE

Before we go too far, it's helpful to define antenna gain, directivity, and aperture. Let's start with a clarification on gain vs. directivity, as the two are often interchanged. Antenna gain and directivity are in comparison to an isotropic antenna, which is an ideal antenna that radiates evenly in all directions. Directivity compares the maximum power measured, P_{max}, in a specific direction to the average power radiated across all directions. When no direction is defined, directivity is determined by Equation 1.

$$D = \frac{P_{max}}{P_{av}} \qquad (1)$$

Directivity is a useful metric when comparing antennas, because it defines the ability to focus radiated energy. Gain (Equation 2) has the same pattern of directivity, but gain includes the antenna losses:

$$\text{Gain} = G = kD, \text{ where } k = \frac{P_{rad}}{P_{in}} \qquad (2)$$

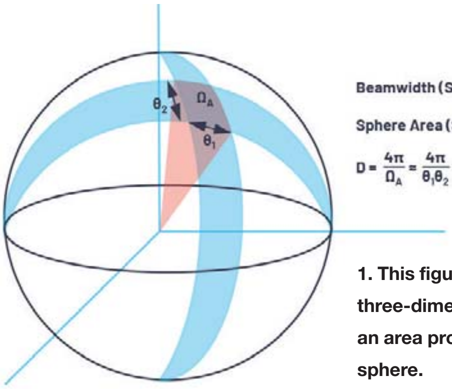
P_{rad} is the total power radiated, P_{in} is the input power to the antenna, and k accounts for losses in the antenna radiation process.

Next, let's consider an antenna pattern as a function of a 3D direction and directivity as a function of beamwidth *(Fig. 1)*.

The total surface area of a sphere is $4\pi^2$, and an area on a sphere is defined in units of steradians with 4π steradians in a sphere. Therefore, as shown in Equation 3, the power density from an isotropic radiator is:

$$\frac{P_{rad}}{4\pi r^2} \qquad (3)$$

and has units of (W/m^2).



1. This figure depicts a three-dimensional view of an area projected onto a sphere.

There are two angular directions for an area of a sphere. In radar systems, these are commonly referred to as azimuth and elevation. Beamwidths can be described as a function of each angular direction using the terms θ1 and θ2: the combination creates an area on the sphere of ΩA.

Ω is the beamwidth in steradians and can be approximated as $\Omega A \approx \theta 1 \times \theta 2$.

Recognizing ΩA as an area on the sphere, directivity (Equation 4) can then be expressed as:

$$D = \frac{4\pi}{\Omega_A} \approx \frac{4\pi}{\theta_1\theta_2} \qquad (4)$$

The third antenna term we'll consider is aperture. Antenna aperture represents an effective area for receiving electromagnetic waves and includes a function relative to wavelength. Referring to Equation 5, the aperture of an isotropic antenna is:

$$A\_isotropic = \frac{\lambda^2}{4\pi} \qquad (5)$$

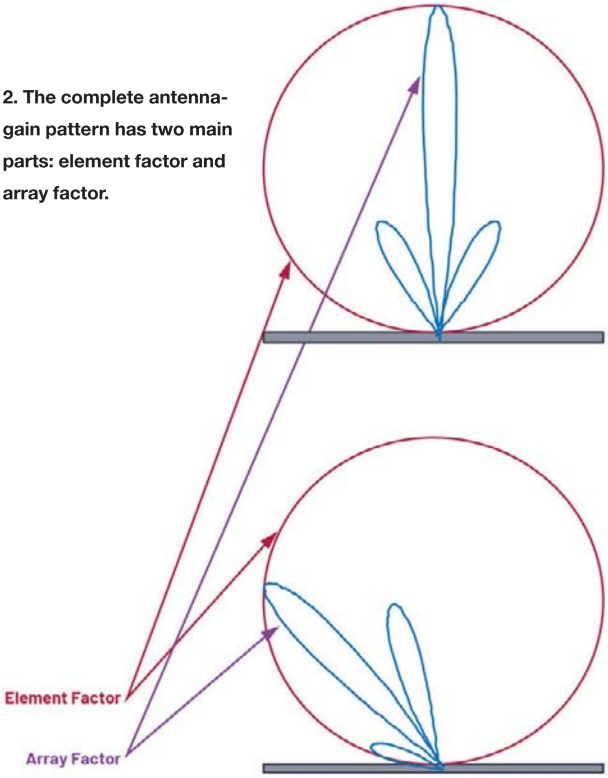
Gain is relative to isotropic radiation; as shown in Equation 6, the effective aperture of an antenna is:

$$A_e = \frac{G\lambda^2}{4\pi} \qquad (6)$$

Pulling these three terms together, we can see that gain can be considered a function of angle that defines a radiation pattern and accounts for efficiency (or losses) in the antenna.

ARRAY FACTOR FOR A LINEAR ARRAY

At this point, we're able to predict the optimal time (or phase) delta between elements to achieve maximum antenna directivity. But we'd really like to understand and manipulate the complete antenna-gain pattern. There are two main parts to this pattern *(Fig. 2)*. First, there's the gain of each individual element of our array (perhaps one patch), called the element factor (GE). Secondly, there's the impact that we can exert through beamforming the array, called the array factor (GA). The full antenna-gain pattern of the array is the combination of the two factors, as shown in Equation 7:



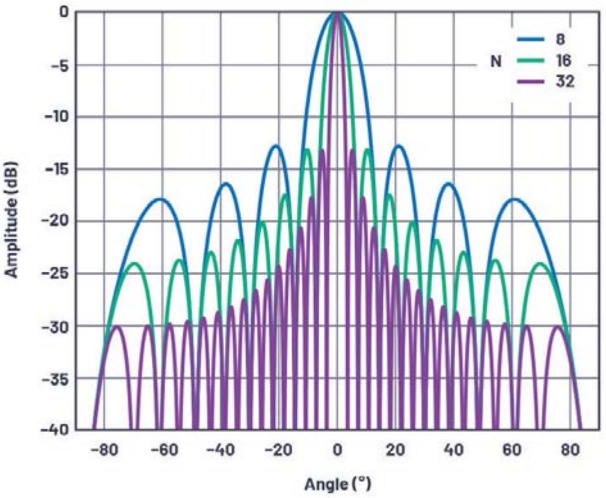
2. The complete antenna-gain pattern has two main parts: element factor and array factor.

$$G(\theta) = G_E(\theta) + G_A(\theta), \text{ in dB} \qquad (7)$$

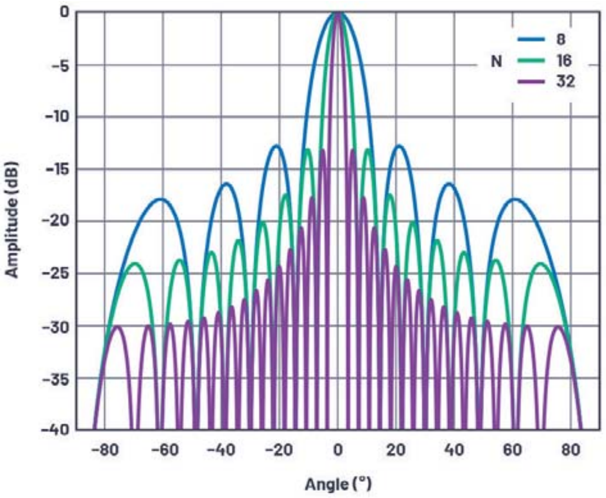
The GE is the radiating pattern of a single element in the array. This is defined by the geometry and construction of the antenna, and not something that's varied in operation. It's important to know because it will limit the gain of our total array—particularly near the horizon. But since we can't control it electrically, we'll leave it as a fixed influencer to our total phased-array gain equation. For this article, we'll assume that all of the individual elements have the same element factor.

The focus then turns to the array factor, GA. The array factor is calculated based on array geometry (d for our uniform linear array) and beam weights (amplitude and phase). Deriving the array factor for a uniform linear array is straightforward, but the details are best covered in the references cited at the end of this article.

There are some variations in equations used across literature depending on how parameters were defined in the linear array. We use the equations from this article, which results in consistency with our definitions in Figures 2 and 3 in Part 1 of this series. Because our primary concern is how the gain changes, it's often more instructive to plot the normalized array factor relative to unity gain. That normalized array factor can be derived using Equation 8:



3. Shown is a plot of normalized array factor at boresight of a linear array with an element spacing of d = λ/2 and an element count of 8, 16, and 32.



4. This plot depicts the normalized array factor of a 32-element linear array at several beam angles with an element spacing of d = λ/2.

$$AF[\theta] = \frac{\sin\left(\frac{N\pi d}{\lambda}\left[\sin(\theta) - \sin(\theta_0)\right]\right)}{N\sin\left(\frac{\pi d}{\lambda}\left[\sin(\theta) - \sin(\theta_0)\right]\right)} \qquad (8)$$

where θ_0 = beam angle.

We've already defined beam angle θ_0 as a function of phase shift between elements $\Delta\Phi$; therefore, we can also express the normalized antenna factor using Equation 9:

$$AF[\theta, \Delta\Phi] = \frac{\sin\left(N\left[\frac{\pi d}{\lambda}\sin(\theta) - \frac{\Delta\Phi}{2}\right]\right)}{N\sin\left(\frac{\pi d}{\lambda}\sin(\theta) - \frac{\Delta\Phi}{2}\right)} \qquad (9)$$

The conditions assumed in the array-factor equation include:

- The elements are equally spaced.
- There's an equal phase shift between elements.
- The elements are all at equal amplitude.

Next, using these equations, we plot the array factor for several array sizes *(Figures 3 and 4)*.

Some observations from these figures include:

- The first sidelobe is at –13 dBc regardless of the element count. This is due to the sinc function in the array-factor equation. The sidelobes can be improved by tapering the gain across elements and will be the subject of an upcoming section in this series.
- The beamwidth narrows with the number of elements.
- The beamwidth widens as the beam is scanned away from boresight.
- The number of nulls increases as the number of elements increases. **mw**

AUTHORS' NOTE: This series of articles is not intended to create antenna design engineers, but rather to help the engineer working on a subsystem or component used in a phased array to visualize how their effort may impact a phased-array antenna pattern.

PETER DELOS is Technical Lead and BOB BROUGHTON is Director of Engineering for Analog Devices' Aerospace and Defense Group, and JON KRAFT is Senior Staff Field Applications Engineer at Analog Devices.

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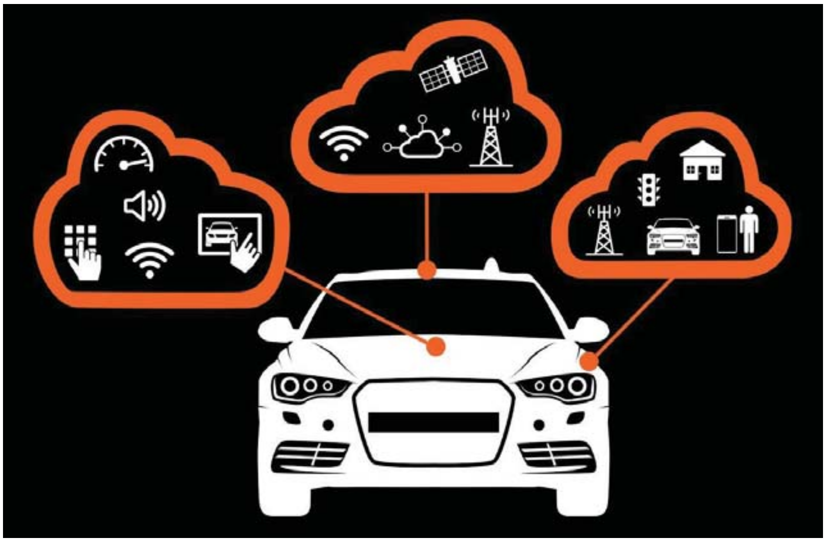
ALI BAWANGAONWALA | Head of Marketing, V2X, Qorvo Inc.

Mitigating Spectrum Coexistence of V2X Systems with High-Performance Filters

Before we can fully realize the safety and efficiency benefits promised by a shift to autonomous vehicles, designers must first overcome spectrum challenges associated with V2X systems.

Wi-Fi and 5G will both be necessary in realizing a future with autonomous vehicles. The challenge lies in how these wireless connectivity technologies will coexist. Spectrum interference between them and other in-vehicle radio systems can inhibit operation and potentially put passengers at risk. This article highlights how high-selectivity filter solutions enable coexistence of V2X with Wi-Fi and electronic toll collection (ETC) in future self-driving cars.



THE FOUNDATION FOR VEHICULAR CONNECTIVITY

The next generation of autonomous vehicles will continuously capture and interpret real-time data from the surrounding environment for automotive safety and autonomous driving. To navigate without human intervention, data of all types must be shared in real time with vehicles and the surrounding infrastructure. This communication will happen over vehicle-to-everything (V2X) radio systems. A constant stream of information is exchanged between everything from other cars to traffic lights to pedestrians. Cars will have all of the data needed to brake and accelerate safely without driver assistance.

V2X encompasses vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P) communications. These systems will not only reduce traffic accidents and injuries, they will also improve global transportation efficiency and dramatically reduce harmful CO^2 emissions. Taken together, the positive impact on public health and private safety will be significant.

V2X technology is based on a 5.9-GHz, dedicated short-range communications (DSRC) standard that's designed for fast-moving objects. It makes establishing a reliable radio link possible in non-line-of-sight conditions. Anything that interferes with this V2X link will limit an autonomous car's ability to perceive and react to road hazards. This critical element is complicated by the fact that V2X can be either C-V2X (cellular vehicle-to-everything), which uses cellular technology to create direct communication links; or DSRC, which is based on the IEEE 802.11p standard and was, at one time, the only V2X technology available.

Despite different auto manufacturers and countries supporting one standard over another, both utilize the same spectrum to solve the same problem and they can coexist. This means that both standards need high-performance filtering to mitigate the spectrum interference adversely impacting vehicle operation and passenger safety.

UNDERSTANDING CONNECTIVITY TECHNOLOGIES

To better address these coexistence challenges, it’s helpful to understand the different technologies involved in vehicular connectivity and how they interact. Besides V2X, as many as four different types radios may reside in an autonomous vehicle:

4G/5G Cloud Connectivity

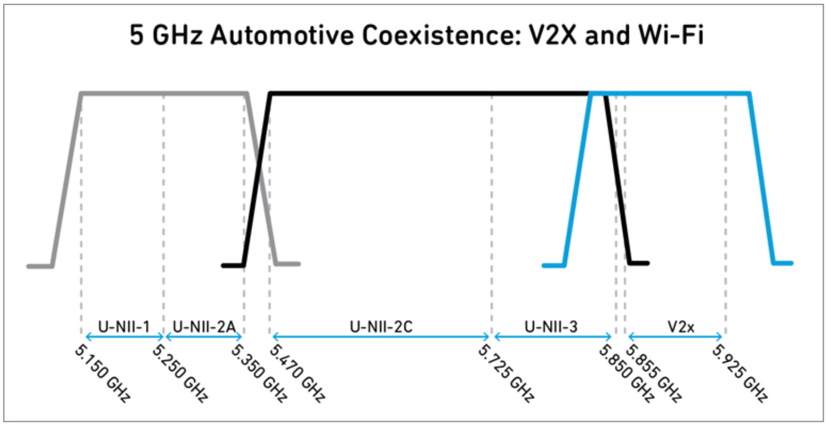
- *Vehicle OEM services:* Applications would include remotely diagnosing and monitoring car operations, making over-the-air software updates, performing teleoperation, and operating a fleet of shared, autonomous vehicles.
- *In-vehicle experiences:* Drivers and passengers would use this type of connectivity to enjoy new in-vehicle experiences, from augmented-reality-based navigation to rear-seat entertainment and music streaming services.

Wi-Fi

- *In-vehicle experiences:* Drivers and passengers would use in-car Wi-Fi for ultra-high-definition (ultra-HD) video streaming to multiple displays and screen mirroring from compatible devices and wireless back-up cameras.
- *Automotive dealer services:* Wi-Fi would support enabling automatic check-in, diagnostic data transfer, and software updates.

Bluetooth

- Drivers and passengers could stream high-fidelity music via



1. The 5-GHz Wi-Fi beats the 2.4-GHz band on data rates, but wreaks havoc with V2X when a vehicle’s passenger uses a 5.6-GHz in-car or mobile hotspot.

Bluetooth, as well as benefit from practical services such as using a smartphone as a key fob.

Satellite Digital Audio Radio Services (SDARS)

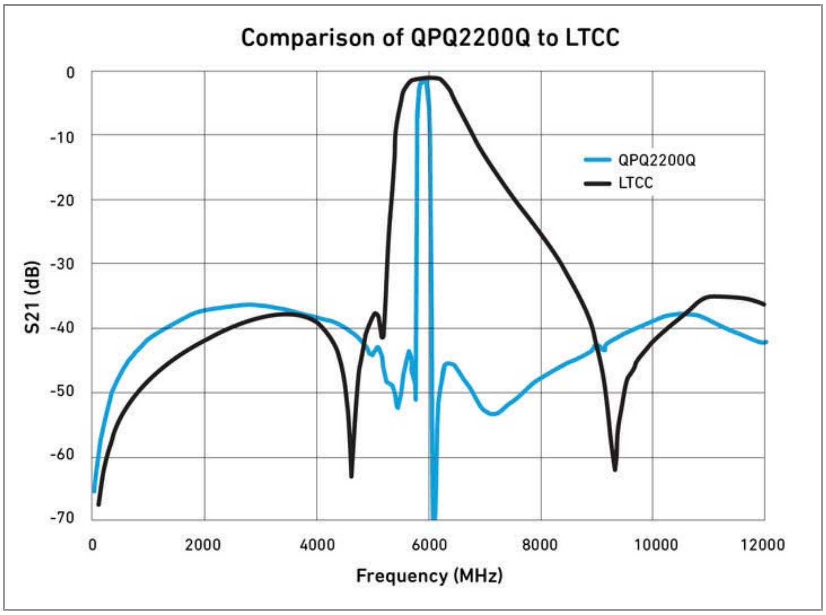
- With connectivity to satellite-based radio services, vehicle occupants can connect to their favorite radio broadcasts anywhere.

In some cases, these radio technologies will use adjacent frequency bands, creating coexistence issues.

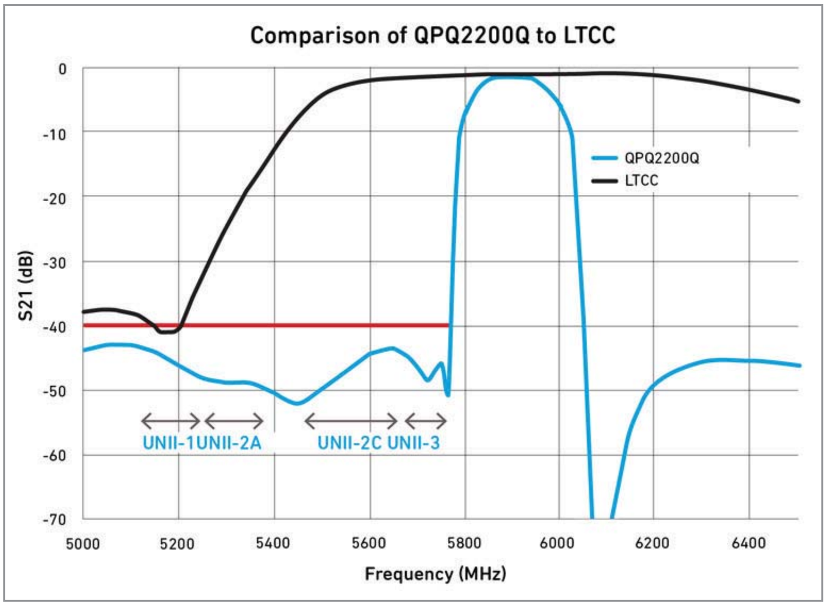
As an example, Wi-Fi operates in the 2.4-, 5.2-, and 5.6-GHz spectrums. This means that 2.4-GHz Wi-Fi operates between the LTE B40 and B41 bands. The 5-GHz Wi-Fi delivers higher data rates than 2.4 GHz because more channels can be bundled together due to larger bandwidth. However, this interacts with V2X *(Fig. 1)* when a passenger uses a 5.6-GHz in-car or mobile hotspot. This means radio designers must use the correct filter products—ones that have enough attenuation in adjacent bands to deliver good receiver sensitivity—to ensure relatively low desense to the receiver.

HIGH-PERFORMANCE FILTERING—WHY LTCC ISN'T ENOUGH

These different wireless technologies all contribute to an improved in-car experience, but they require multiple radio transceivers operating in close proximity to one another. If the transmit power of one RF chain exceeds the power level of the signal reaching a nearby receiver, it significantly degrades system performance. The resulting receiver sensitivity issues can prevent vehicles from achieving regulatory compliance for safe operation.



2. This plot compares the performance of a B47 bulk acoustic-wave (BAW) filter with a low-temperature co-fired ceramic (LTCC) broadband filter.



3. Compared with a B47 BAW filter (QPQ2200Q), the LTCC filter provides no rejection of the 5-GHz UNII 1-3 band.

Coexistence filters reduce interference issues from these "aggressor signals," but not all filters that claim coexistence capabilities work in the unique automotive environment. For example, the plot in *Figure 2* compares the performance of a B47 bulk acoustic-wave (BAW) filter with a low-temperature co-fired ceramic (LTCC) broadband filter.

The graph shows that the LTCC is only filtering broadband frequencies. The B47 BAW filter offers similar insertion loss as the LTCC filter, but also provides high rejection of the 5-GHz UNII 1-3 bands. The B47 BAW filter can replace the LTCC filter on the Tx/Rx path or be placed on the Rx side to enable V2X coexistence with 5-GHz Wi-Fi. *Figure 3* illustrates how the LTCC filter provides no rejection of the UNII 1-3 band.

It's also worthwhile to compare LTCC and B47 V2X coexistence filters from a systems and implementation standpoint. *Figure 4 (shown on page 63)* compares the V2X and Wi-Fi antenna isolation needed to achieve a 1-km V2X link. The plot to the left shows that a V2X system (TCU and active antenna) with only an LTCC filter on the Tx path requires more than 80 dB of antenna isolation. This is difficult to achieve in practice, let alone in a real-world scenario.

The plot to the right in *Figure 4* shows a V2X system with a B47 V2X coexist filter in the TCU; the active antenna requires just 15 dB of antenna isolation to achieve a 1-km V2X link. If systems engineers can achieve >20-dB antenna isolation, they may need only one V2X coexist filter in the active antenna. Even if the vehicle doesn't feature built-in Wi-Fi capabilities, there are other use cases to consider when deciding on filtering solutions. For example, one might be passengers using Wi-Fi hotspots from their mobile devices.

Some optimized filter products on the market use BAW technology to address complex selectivity requirements, from 1.5 GHz up to 6 GHz in standard footprints. These filters also offer a smaller footprint than ceramic filters, which gives systems engineers greater design flexibility.

COEXISTENCE MITIGATION WITH NOTCH FILTERS

Yet, even BAW bandpass filters aren't a complete solution to coexistence issues in the V2X environment. It's important to also consider the essential role played by notch filters. While the bandpass filter discussed above provides adequate out-of-band rejection to UNII bands, a notch filter will be needed to "notch out" Rx band noise in the V2X band on the 5-GHz Wi-Fi path, thus preventing Rx band noise from coupling back into the V2X system and causing desense issues.

Figure 5 (on page 63) shows the placement of this filter on the 5-GHz Wi-Fi path, and *Figure 6 (on page 63)* illustrates that there will be up to 18-dB desense in the V2X receiver if the notch filter is not used on the 5-GHz Wi-Fi path. On the same system, there's almost zero desense when using a well-designed notch filter to leverage the benefits of BAW technology.

Another critical challenge that needs careful attention is the coexistence issues between V2X systems and ETC due to the narrow spacing between V2X and ETC spectrums across North America, Europe, and China.

(Continued on page 63)

MIKE EDDY | Senior Marketing Advisor, Resonant

Resonators Fuel High-Performance RF Filters for 5G

To address coexistence issues for the adjacent Wi-Fi and 5G portions of the spectrum, rethink the resonators that make up bandpass filters in 5G mobile devices.

The proliferation of 4G LTE networks, the deployment of new 5G networks, and the pervasive nature of Wi-Fi are driving a dramatic increase in the number of RF bands that smartphones and other mobile devices must support *(Fig. 1)*. Each band must be isolated using filters to avoid interference that will drain battery life, reduce data speeds, and cause dropped calls.

Filters are constructed by coupling basic building blocks, or resonators, to pass the desired frequency while rejecting interfering frequencies.

So, what is a resonator? Various potential resonating structures are utilized to generate filters for different applications *(Table 1)*.

Discrete inductor-capacitor (LC) filters are passive circuits in which the inductor blocks high-frequency signals and conducts low-frequency signals while the capacitor does the opposite. In the case of integrated passive devices (IPDs), which integrate the functions into the printed-circuit board's laminate, they're very compact. Although such filter implementations have low passband loss, they don't reject potential interfering signals in close frequency proximity.

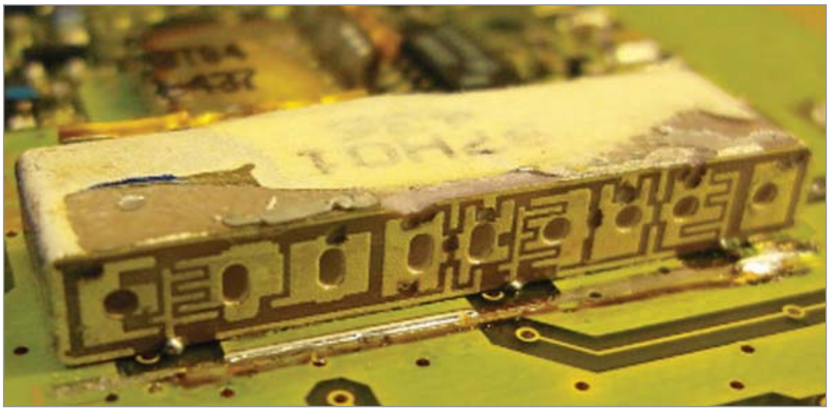
Cavity resonators are expensive and bulky. However, for high-power cellular base stations, these are the filters of choice because of their ability to handle very high-power signals (tens of watts).

Multilayer ceramic filters feature a very low insertion loss, but again, attenuation of potential interfering signals is poor. In addition, relative to IPDs, these devices are large, especially with regards to their height, which limits usage in modules. Such filters are proposed for very high millimeter-wave frequency bands.

Table 1: Resonator Structure Types

	Cost	Performance	Size
Discrete inductor-capacitor (LC)	◔	◐	◔ (IPD)
Multilayer ceramic	◐	◐	◐ (thickness)
Monoblock ceramic	◕	◔	◕
Cavity	●	◔	●
Acoustic	◔	◔	◔

◔ = GOOD ; ● = BAD



2. Shown is an example of a monoblock filter used in a 1994 Motorola handset.

1. The highlighted segment within the U.S. radio frequency spectrum of 300 MHz to 3 GHz is the 2-GHz band for mobile devices.


9-16 VDC
+20 dBm MAX
GPS Antenn
10 MHz ou
Trigger
10 MHz in
USB 2.0
10 GbE SFP+
Signal Hound SM200C
Spectrum Analyzer / 100 kHz to 20 GHz
CE
Made in USA
RF In - 50 Ω
Status
GPIO

FROM MONOBLOCK FILTERS TO ACOUSTIC-WAVE RESONATORS

Early mobile phones used monoblock ceramic-based filters, which provided the required performance characteristics *(Fig. 2)*. But these phones needed comparatively few filters compared to today's phones, which can require as many as 40 to 50 filters. Ceramic monoblock filters are now in limited use in modern phones because of their large size and high cost.

Modern mobile-phone RF architectures and the explosion in smartphone usage has been enabled by the development of acoustic-wave resonators. These devices combine low cost, small size, and performance characteristics suitable for the frequency ranges and signal power ranges of current smartphones up to 4G.

Acoustic-wave resonators based on the piezoelectric effect are very attractive for mobile-phone applications because of their compact size, related to the wavelength of frequencies of interest in a variety of media *(Table 2)*.

Table 2: Velocity and Wavelength for Waves in Different Media

	Wave velocity	Wavelength at 2 GHz
Electromagnetic wave in air	300,000,000 m/s	150 mm
Electromagnetic wave in dielectric ($\varepsilon = 100$)	30,000,000 m/s	15 mm
Acoustic wave in solid material (piezoelectric)	4,000-12,000 m/s	2-6 µm

The *piezoelectric effect* exists in certain crystals due to an asymmetry within the structure. For example, in the lithium-niobate ($LiNbO_3$) lattice shown in *Figure 3*, the lithium and niobium ions are displaced from the center of the oxygen octahedron.

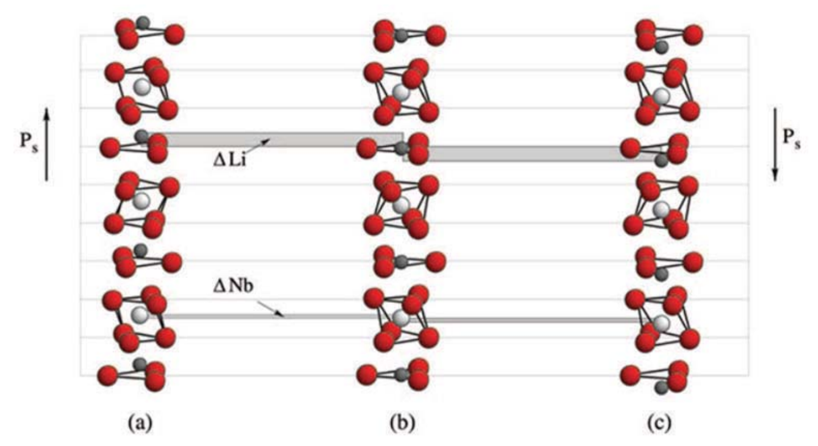
Consequently, when voltage is applied to this crystal, it will deform mechanically, converting electrical energy into mechanical energy. The opposite occurs when mechanically compressing or expanding such a crystal. Charges form on opposite faces of the crystalline structure, causing a current to flow in the terminals.

An alternating mechanical deformation creates acoustic waves that travel at velocities of 4,000 to 12,000 meters

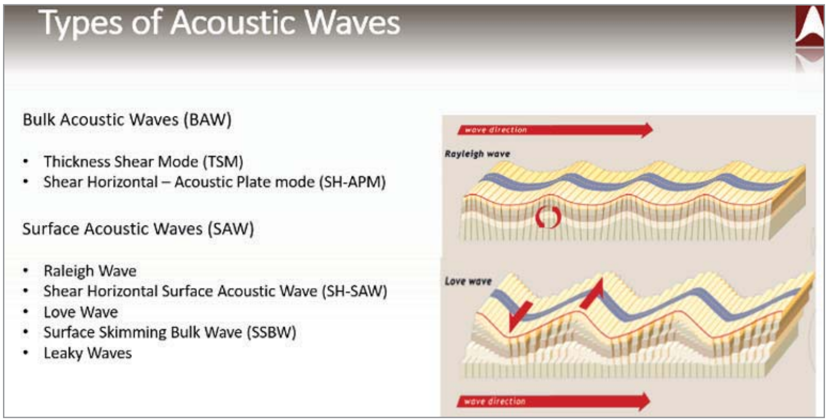
per second. Depending on the details of the metal-piezoelectric structure, acoustic waves can be initiated to flow on the surface or through the bulk of the piezoelectric. In fact, even within the surface-acoustic-wave (SAW) and bulk-acoustic-wave (BAW) categories, there's a family of acoustic waves with differing properties *(Fig. 4)*.

To design a filter, multiple resonators are coupled together to form a passband, often in the form of a "ladder" configuration that alternates series and shunt resonators. Key characteristics of the filter include:

- *Bandwidth* is often described as the fractional bandwidth because the width of the filter passband/center frequency is expressed as a percentage of the band's frequency. This is related to a key parameter of the acoustic wave resonator—the coupling coefficient, or k^2.
- *Frequencies* at the lower end of the spectrum require larger resonators. At higher frequencies, dimensions become smaller, which limits achievable yields.
- *Loss* refers to the reduction in the signal's strength as it passes through the filter. Low loss maximizes the signal efficiency, which enables reduction of signal power for the transmitted signal. This in turn extends battery life.
- *Power levels* of mobile signals continue to rise because higher-frequency signals have lower propagation and need more power for coverage and higher speeds. This puts improved reliability demands on filters.



3. The lines in this illustration show the asymmetry within the lithium-niobate lattice that leads to a piezoelectric effect.



Types of Acoustic Waves

Bulk Acoustic Waves (BAW)

- Thickness Shear Mode (TSM)
- Shear Horizontal – Acoustic Plate mode (SH-APM)

Surface Acoustic Waves (SAW)

- Raleigh Wave
- Shear Horizontal Surface Acoustic Wave (SH-SAW)
- Love Wave
- Surface Skimming Bulk Wave (SSBW)
- Leaky Waves

4. This image summarizes the differences between BAW and SAW acoustic waves.

Many of these parameters are a function of design, materials selection, and manufacturing process. However, bandwidth is a fundamental property of the acoustic resonator. In the case of acoustic-wave resonators, each individual resonator has two “resonances”—both resonance and anti-resonance. The frequency separation of these two resonances (characterized as the coupling coefficient, or k^2) determines the optimal filter bandwidth.

Below are equations that illustrate key acoustic-wave principles:

$$\lambda = \frac{v}{f}$$

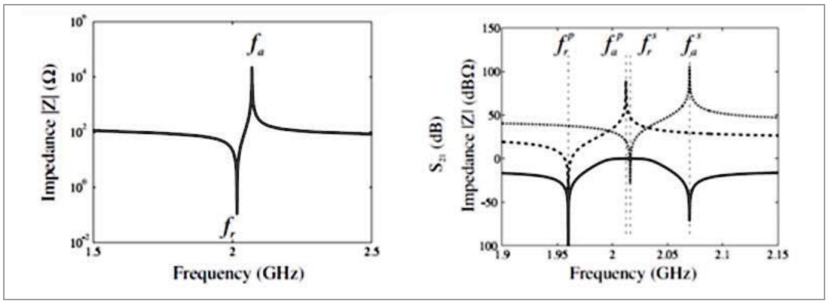
where λ is the acoustic wavelength, v is the wave velocity, and f is the resonant frequency.

$$k^2 = \frac{\pi^2}{4}\left(\frac{f_r}{f_a}\right)\left(\frac{f_a - f_r}{f_a}\right)$$

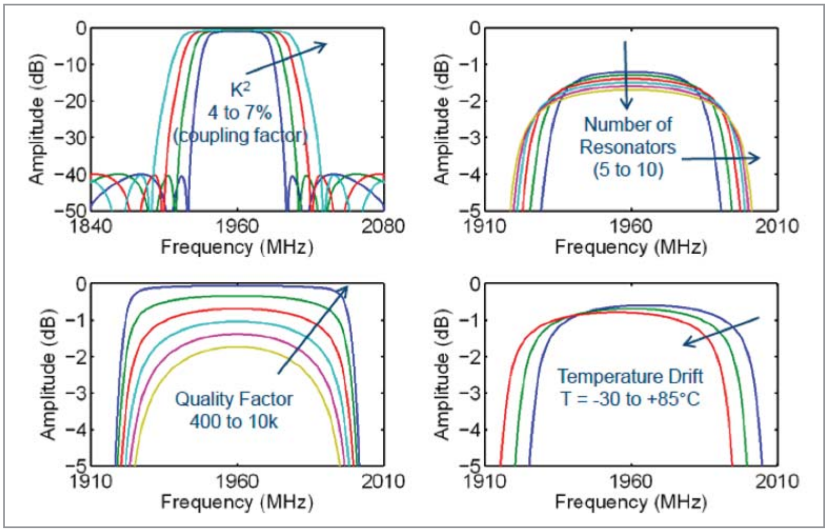
where k^2 is the coupling coefficient, f_r is the frequency of the resonance, and f_a is the frequency of the anti-resonance.

Going from resonator to filter, the maximum achievable bandwidth of an acoustic-wave ladder-type filter is limited by the resonance-anti-resonance frequency separation, which is related to k^2 *(Fig. 5)*.

Filter performance is affected by the coupling coefficient (higher coupling increases bandwidth); number of resonators (more resonators increases bandwidth at the expense of loss); quality factor (higher quality factor lowers loss, especially at the band edge); and temperature stability *(Fig. 6)*.



5. An impedance vs. frequency model shows the resonance and anti-resonance for an acoustic-wave resonator (a); by cascading multiple resonators, one may generate a passband filter (solid line, b).



6. Filter performance is affected by coupling coefficient (higher coupling increases bandwidth; upper left), number of resonators (increasing number of resonators increases bandwidth at the expense of loss; upper right), quality factor (higher quality factor lowers loss, especially at the band edge; lower left), and temperature stability (lower right).

FILTERS FOR 5G

The key application for 5G mobile phones involves increased streaming video and related streaming services such as gaming or AR/VR—all of which depend on high bandwidth to the device. To dramatically grow wireless broadband capacity and speed, much wider swathes of spectrum, and aggregation of available spectrum, is required. Hence, 5G has new allocations of spectrum that are much wider and at higher frequencies than 4G.

Wide bandwidth is critical to realizing high data rates. In terms of instantaneous bandwidth, this is only available above 3 GHz. Hence, the filter requirements for these new bands are quite different from 4G. 5G requires hundreds of megahertz of spectrum and frequencies above 3 GHz—rather than the tens of megahertz of spectrum at around 2 GHz—as well as filters to protect this bandwidth.

The acoustic-wave resonator used for 3G and 4G can be modified (through doping of the piezoelectric effect and adding external inductors) to increase the achievable bandwidth. However, this comes at the expense of other performance parameters.

Traditional acoustic-wave resonators were developed for previous generations of wireless technology (2G, 3G, and 4G) and the much narrower associated bandwidths. Today’s wireless technology requires new resonating structures optimized from the beginning for the current requirements.

XBAR is a type of BAW acoustic resonator that’s not appropriate for narrower bandwidth filters, yet it’s perfectly matched for 5G *(Fig. 7)*. We’re still in the early days of 5G; high-performance filtering will not yet be needed due to the

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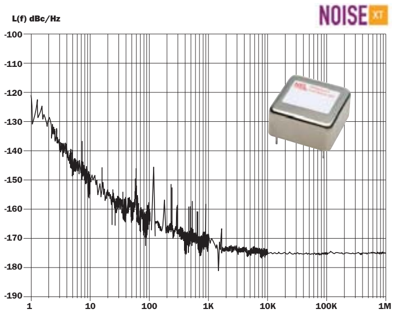
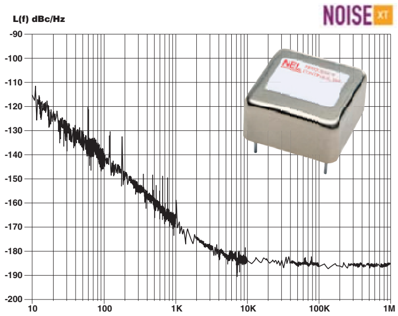
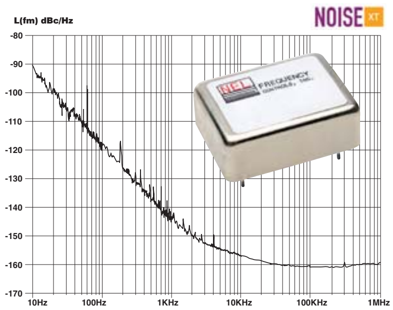
10 MHz Output Frequency



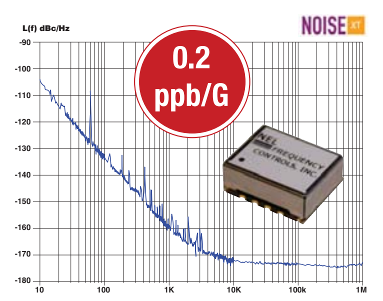
100 MHz Output Frequency



1 GHz Output Frequency

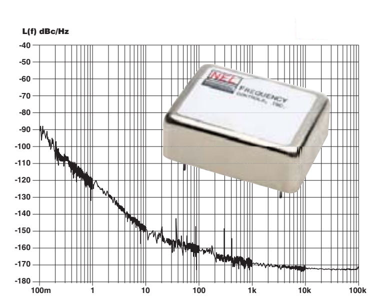


ULPN TCXO @ 100 MHz with Low G Sensitivity



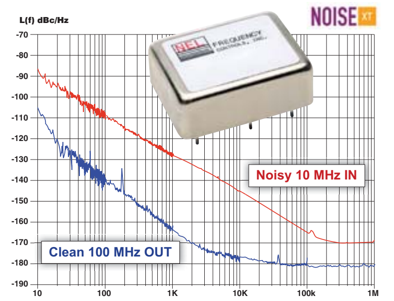
0.2 ppb/G

Precision Europack ULPN OCXO @ 10 MHz

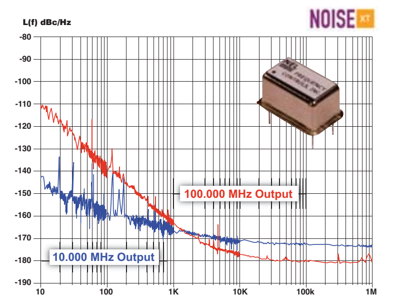


Extraordinary Low Phase Noise close to the carrier

Clean Up OCXO

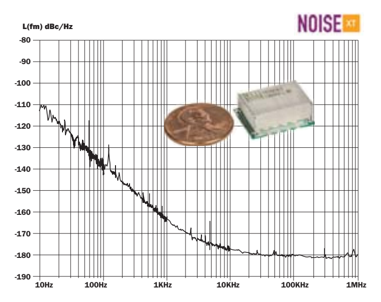


DIP 14 OCXO— 10 MHz or 100 MHz



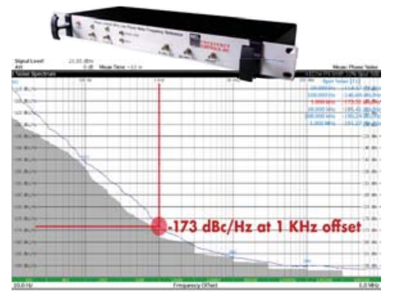
Ultra low phase noise, low power consumption (250 – 350mW)

ULPN Surface Mount OCXO



Miniature 14 x 21 x 7.5 mm package

ULPN Mixed Signal Reference



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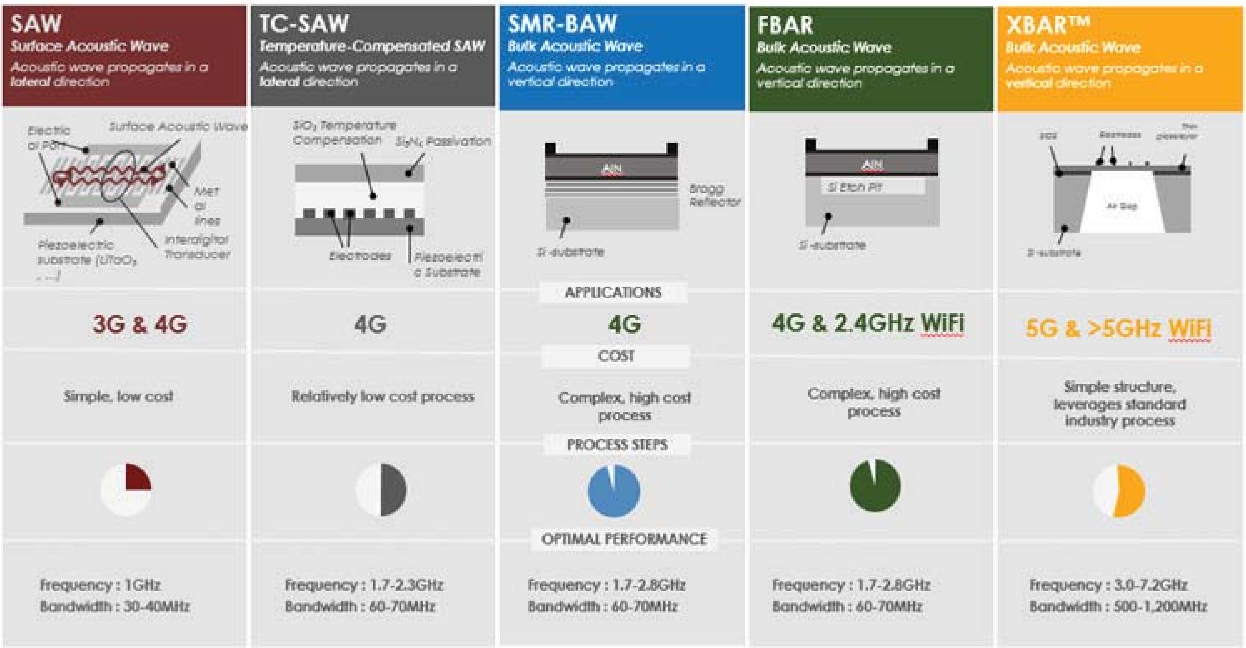
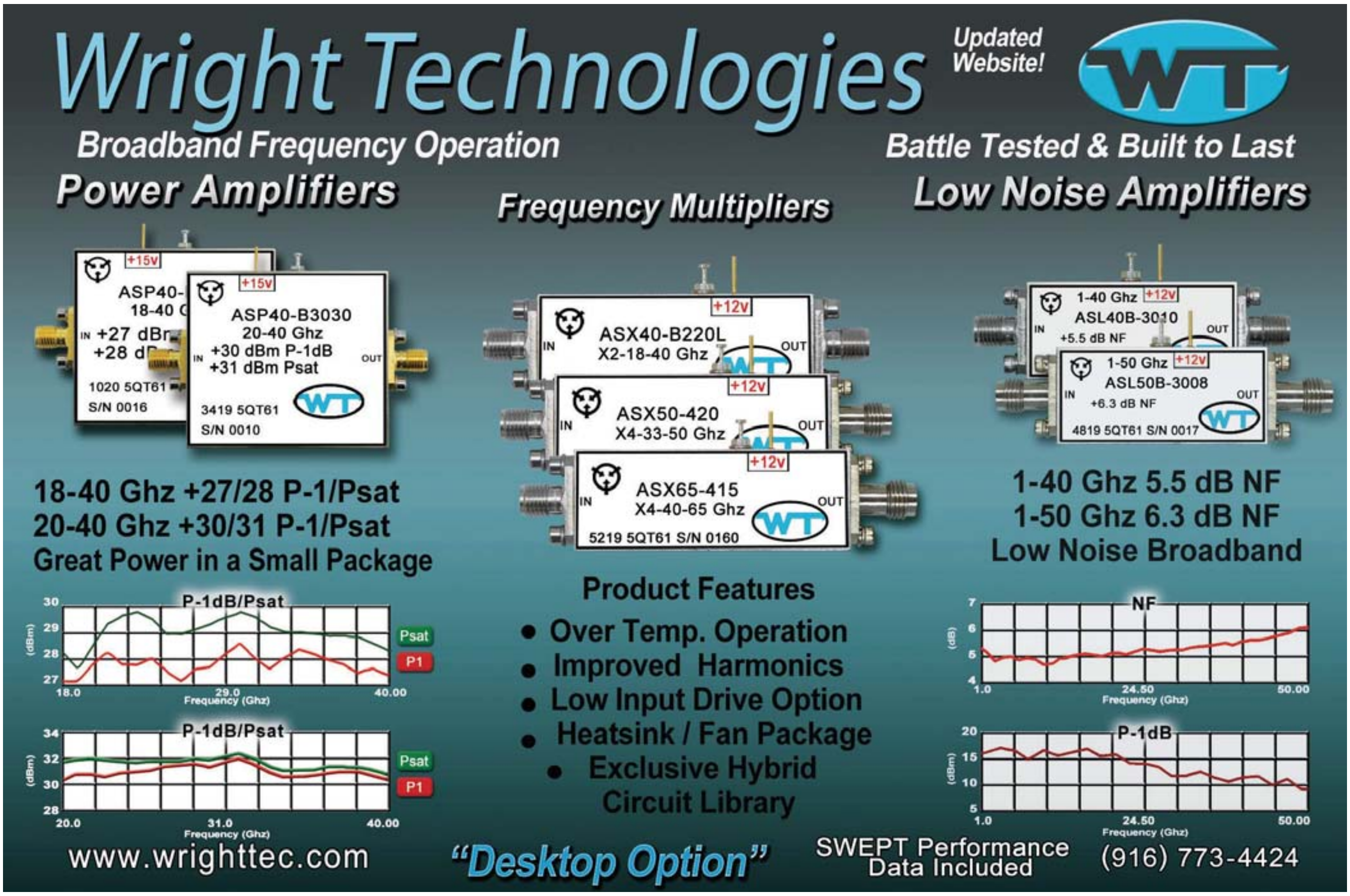


7. Different acoustic-wave resonating structures show the applicability to different generations of wireless networks with relative cost and performance.



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SDLVA-1G20G-58-12-SFF

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PMI Model No.	Frequency Range (GHz)	TSS (dBm)	Log Slope (mV/dB)	Rise / Fall Time (ns)	Recovery (ns)	Dynamic Range Log (dBm)	Size (Inches) Connectors
SDLVA-0120-70-100M2G-10DBM https://www.pmi-rf.com/product-details/sdlva-0120-70-100m2g-10dbm	0.1- 2	-65	25	25 / 30	40	-65 to +5	3.75” x 1.5” x 0.5” SMA (F)
SDLVA-07103-70-LA3 https://www.pmi-rf.com/product-details/sdlva-07103-70-la3	0.75- 1.25	-70	30 ± 5%	25 / 30	50	-65 to +5	1.3” x 0.95” x 0.27” GPO (Full Detent)
SDLVA-0R71R3-75-MEC https://www.pmi-rf.com/product-details/sdlva-0r71r3-75-mec	0.75- 1.3	-70	40	15 / 15	40	-70 to +5	3.75” x 1.5” x 0.5” SMA (F)
SDLVA-1G20G-55-12-SFF https://www.pmi-rf.com/product-details/sdlva-1g20g-55-12-sff SDLVA-1G20G-58-12-SFF https://www.pmi-rf.com/product-details/sdlva-1g20g-58-12-sff	1 - 20	-58 -60	50 14	5 / 20	28	-55 to +5 -54 to +5	PE2 Housing 1.08” x 0.71” x 0,29” Removable SMA (F)
SDLVA-2G6G-70-CD-1 https://www.pmi-rf.com/product-details/sdlva-2g6g-70-cd-1	2 - 6	-70	40	15 / 25	50	-65 to +5	3.75” x 1.5” x 0.5” SMA (F)
SDLVA-212-65-16MV-12DBM https://www.pmi-rf.com/product-details/sdlva-212-65-16mv-12dbm	2 - 12.5	-64	16.7 ± 1.3	10 / 12	30	-55 to +10	4.24” x 0.994” x 0.38” SMA (F)
SDLVA-218-65-16MV-12DBM https://www.pmi-rf.com/product-details/sdlva-218-65-16mv-12dbm SDLVA-218-75-16MV-12DBM https://www.pmi-rf.com/product-details/sdlva-218-75-16mv-12dbm	2 - 18	-64	16 ± 2	10 / 15	30 25	-55 to +10 -60 to +15	4.24” x 0.994” x 0.38” SMA (F)
SDLVA-6G18G-CD-2-OPT218 https://www.pmi-rf.com/product-details/sdlva-6g18g-cd-2-opt218	2 - 18	-70	25 ± 10% 50 Ohms	10 / 30	60	-70 to +5	3.2” x 1.8” x 0.4” SMA (F)
SDLVA-6G18G-CD-2 https://www.pmi-rf.com/product-details/sdlva-6g18g-cd-2	6 - 18	-70	25 ± 10% 50 Ohms 48 ± 10% No Load	10 / 30	60	-70 to +5	3.2” x 1.8” x 0.4” SMA (F)
PLVA-6G18G-40-1 https://www.pmi-rf.com/product-details/plva-6g18g-40-1	6 - 18	-42	50 ± 4%	20 / 45	150	-40 to 0	2.2” x 1.5” x 0.4” SMA (F)
SDLVA-18G40G-65-CD-292FF https://www.pmi-rf.com/product-details/sdlva-18g40g-65-cd-292ff	18 - 40	-65	25	11 / 30	60	-63 to +2	2.37” x 1.8” x 0.42” 2.92mm (F)

SDLVA-212-65-16MV-12DBM

SDLVA-218-65-16MV-12DBM
SDLVA-218-75-16MV-12DBM

SDLVA-6G18G-CD-2
SDLVA-6G18G-CD-2-OPT218

PLVA-6G18G-40-1

SDLVA-18G40G-65-CD-292FF

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Frequency Multiplier Delivers Clean 12- to 20-GHz Output

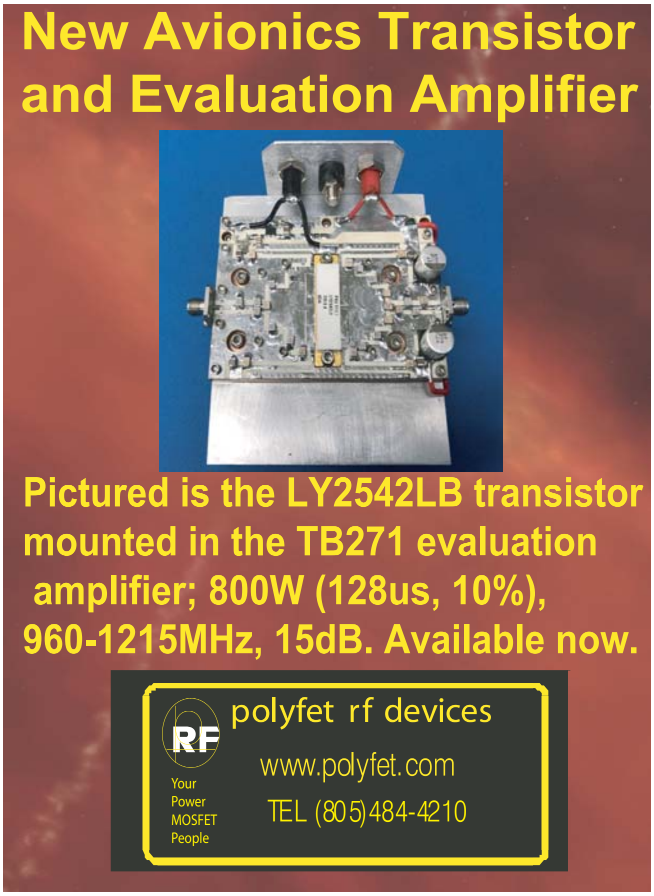
Mini-Circuits' model ZXF90-2-24-K+ is a X2 frequency multiplier that transforms inputs of 6 to 10 GHz to clean output signals of 12 to 20 GHz. It accepts input signals at power levels from +16 to +22 dBm and delivers multiplied output signals at approximately -1 to +5 dBm (due to 17-dB typical conversion loss). The frequency multiplier is a cost-effective source for a wide range of systems, including terrestrial and satellite communications and radar systems. The 50-Ω, RoHS-compliant frequency multiplier provides strong spurious suppression, with typical fundamental signal suppression of -35 dBc and third-harmonic suppression of -38 dBc. It measures 0.68 × 0.73 × 0.36 in. (17.27 × 18.54 × 9.27 mm) with female 2.92-mm coaxial connectors and has an operating temperature range of -55 to +100°C.

MINI-CIRCUITS, https://www.minicircuits.com/WebStore/dashboard.html?model=ZXF90-2-24-K%2B

Multiport Network Analyzer Checks MIMO/5G Antennas and Applications

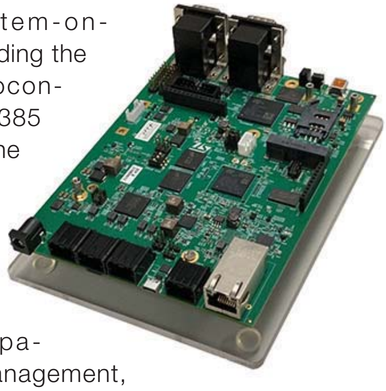
Copper Mountain Technologies has released its RNVNA Multiport Testing network analysis testing solution for MIMO antennas and 5G applications. The testing platform can link up to 16 analyzers together, creating a multiport network testbed that allows users to measure vector reflection and scalar transmission parameters. The RNVNA is compatible with Copper Mountain's 1-Port USB VNAs with frequencies that range up to 6 GHz (R60), 14 GHz (R140), and 18 GHz (R180). The platform also provides shelving for each VNA and is designed to fit 19-inch rack-mounted systems, incorporating up to eight VNAs.

COPPER MOUNTAIN TECHNOLOGIES, www.coppermountaintech.com



Smart-Gateway Platform Serves Automotive-Gateway and Domain-Controller Apps

STMicroelectronics recently unveiled its SGP-TC-EVK smart-gateway platform designed for automotive-gateway and domain-controller applications. The gateway platform packs ST's secure automotive system-on-chips (SoCs), including the SPC58NHx microcontroller and a STA1385 microprocessor. The SGP features high-level processing and security capabilities along with enhanced performance capabilities for OTA management, Ethernet packet inspection, fast wake-up response, and secure data routing for CAN-to-CAN and CAN-to-Ethernet. It also offers M.2 and Mini PCIe expansion connectors for Wi-Fi and LTE modules, which brings cloud connectivity options as well.



STMICROELECTRONICS, www.st.com

(Continued from page 22)

quencies, these antennas offer a small form-factor solution that can be printed on the same PCB holding the transmitter/receiver.[5]

BLUETOOTH BEACONS

While already a prolific short-range protocol, BLE modules are utilized in RTLS applications by delivering Bluetooth beacons to disseminate localized content. These beacons can act as proximity sensors by broadcasting low-energy signals with packets of data at predetermined intervals of time (>100 ms).

Distances are calculated with received signal-strength indicator (RSSI) readings, ultimately extrapolating distances between nodes based on the mathematical relationship between the strength of the received signal and the propagation of an RF signal through space.[6] This creates a live map of inventory outfitted with unique IDs and BLE tags with actively updated location data. Because most smart devices are Bluetooth-enabled (i.e., smartphone, tablet, laptop), this can potentially eliminate the need for custom hardware, leading to dramatic cost savings.

While BLE does support mesh topologies with bidirectional communications, BLE beacons generally support one-way communications and are therefore limited to star topologies. In such configurations, beacons connect to a Bluetooth-enabled device/router and relay information to the cloud, typically via cellular or Wi-Fi.

As alluded to earlier, many of these beacons can include multi-protocol SoCs with a sub-gigahertz, long-range wireless network to control/monitor factory environments with smart lighting or HVAC control. The large window for the advertising packet can allow for the sub-gigahertz radio to be in a receiving state, obtaining non-frequent and unpredictable packets of information from distant locations within the facility.

Typically, BLE beacon designs will involve a 2.4-GHz PCB antenna combined with a vendor-specific Bluetooth chip. In some cases, the Bluetooth chip will have an integrated chip antenna. If the board employed a sub-gigahertz frequency protocol, a PCB antenna would not be viable as it would be too large.

As stated earlier, BLE typically uses trilateration (RSSI) to determine location areas. In this case, an omnidirectional radiation pattern is often suitable due to the 360-degree beam coverage over the factory floor, so long as the antenna matches the transmitter's impedance for maximum signal transfer and range *(Fig. 2 on page 22)*. However, a TDoA algorithm can be implemented, calculating either two angles from a singular beacon signal, or three angles from two beacon signals. In this case, a 3D map can potentially be created with the use of the complex mapping and placement of BLE beacons outfitted with more sophisticated antenna arrays.[7]

FLEET MANAGEMENT

Industrial fleet management can vary with passenger cars, tractor trailers, railways, airplanes, ships, and heavy equipment. Trucks alone account for 70% of the goods transported in the United States, making tracking logistics such as repairs, replacements, and scheduled maintenance all the more important to prevent poor fleet operation. Typically, the cellular infrastructure is used for applications that transcend plant-wide boundaries. However, in the case of localized equipment such as heavy equipment operation within a mine, LPWANs can be considered.

Fleet telematics can communicate with 2G, 3G, and 4G infrastructures or IoT-specific cellular alternatives such as NB-IoT or LTE-M1. Sensor nodes can consist of GPS modules, gyroscopes, level sensors, and accelerometers. Where the GPS provides location data, the accelerometer offers the orientation of the vehicle, and the level sensor measures fuel in real time. More complex systems are also utilized for fleet management; autonomous mining trucks have been in operation since 2008, outfitted with over 200 sensors, a GPS receiver, and radar guidance system.[2]

SUMMARY

An array of sensors and communication protocols can serve industrial networks depending on the required level of reliability, latency, and flexibility. Process monitoring and health and safety applications often require real-time communications with IEEE 802.15.4-based protocols (e.g. ISA100.11a, WirelessHART), while some asset-monitoring applications can benefit from the long range offered by LPWAN applications.

Indoor asset-tracking applications have specific localization systems with ToA- or RSSI-based algorithms for accuracy. Fleet-management systems, on the other hand, can rely on GPS for location data but must transfer all sensor data to a centralized point via either cellular backhaul. They can even benefit from LPWAN if the fleet is based in a restrictive geographic location.

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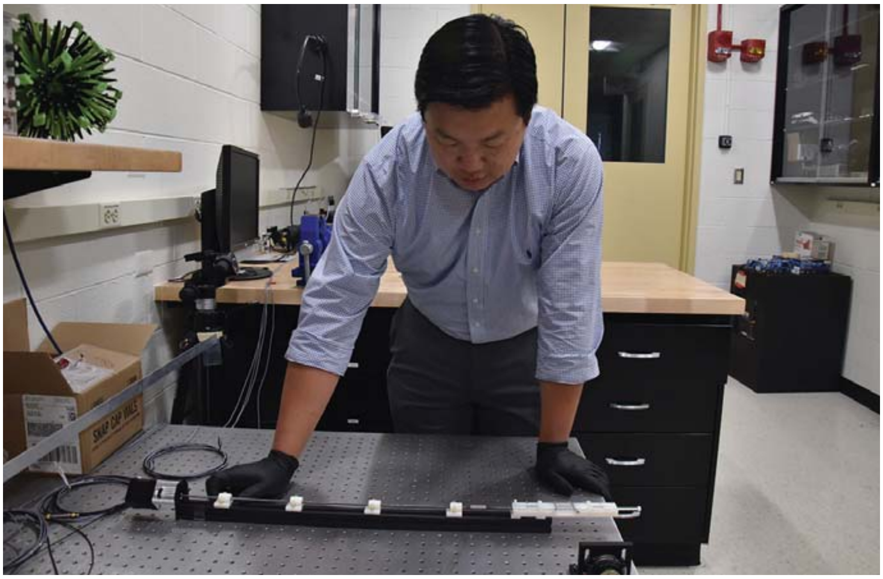


AFRL, UW Study Shape-Shifting Materials

Composite materials that change shape when subjected to a magnetic field offer promise for use as tunable filters and vibration-reducing components in military vehicles.

JACK BROWNE | Technical Contributor

MATERIALS THAT CAN change shape under magnetic fields might sound like something out of a science fiction story, but the Air Force Research Laboratory (AFRL) is exploring the potential use of such materials in tunable components that might help with vibration absorption and suppression in vehicles. Working with academic colleagues at the University of Wisconsin (UW), the AFRL is studying a family of soft magneto-active composites that can reversibly change form, enabling them to switch between multiple shapes.

The elastomer composites exhibit an increase in stiffness and change in shape in response to an applied magnetic field so that they can be actively tuned. By tuning the materials with magnetic fields, they may be suitable for such applications as filters and vibration dampers that can be adjusted with noncontact tuning. In the *figure* above, Dr. Vincent Chen, an AFRL scientist, is applying a magnetic field to

(Continued on page 44)

Can Coronavirus Stand the Heat?

THE U.S. AIR FORCE RESEARCH LABORATORY (AFRL) is investigating the role of higher temperatures in the interiors of military planes to minimize the threat of the COVID-19 coronavirus and other biological contaminants. Researchers from the AFRL 711th Human Performance Wing are exploring the use of standard ground heaters to boost the interior temperature of a C-17 aircraft enough to kill viral agents such as the COVID-19 coronavirus that has fueled the recent pandemic.

"Our goal with this test was to demonstrate the ability for any Air Force base to assist with aircraft disinfection utilizing only commonly available equipment and materials," said Doug Lewis, 711th Human Performance Wing Protection Systems Team Lead, who is heading the anti-viral aircraft heating efforts. "We knew that if we could prove the ability of this equipment to heat aircraft interiors to temperatures in the +120°F range, we were potentially demonstrating an Air Force-wide disinfection capability, pending further laboratory results."

As part of two separate measurement experiments conducted at Wright-Patterson Air Force Base, Ohio, Lewis and his research team placed sensors and test equipment inside a C-17 aircraft and sealed the aircraft using materials common to military installations. Hoses from the heaters were directed inside the air-

(Continued on page 44)

AFRL, UW Study Shape-Shifting Materials

(Continued from page 43)

change the shapes of various magneto-active composite materials.

Details on these novel magneto-active materials were recently published in the physics journal, *Physical Review Letters* (April 14, 2020 issue). The research examines the interactions between different mechanical instabilities and magnetic fields and how they can be applied as practical solutions for vehicles, such as for vibration suppression and dampening.

Contributors to the research include Dr. Stephen Rudykh from the University of Wisconsin, who noted that the AFRL and the University plan to build on the basic ideas of the study to develop reconfigurable forms for new function. He said, “The design space for architected elastomers is very rich, with additional mechanisms for magneto-mechanical interactions to be discovered and harnessed for applications.” Co-author D. Abigail Juhl from the Materials and Manufacturing Directorate of AFRL added, “We are excited about the potential for magnetic tuning to improve vibration sensing and control in aircraft and other vehicle environments.” ■

Can Coronavirus Stand the Heat?

(Continued from page 43)

craft and the temperature was raised over a period of six hours to as much as 50°F above the ambient temperature *(see figure)*. In working with the Battelle Memorial Institute (Columbus, Ohio), preliminary results indicate that the temperatures were high enough to disable the coronavirus on the surfaces of a variety of materials, including aluminum, silicon, and nylon webbing. Lewis and his team will continue to work with Battelle in the hopes of learning more about the effects of heating on COVID-19 and how different temperatures and exposure times may be applied. ■

U.S. Air Force Research Laboratories

Electronic Belt Helps Dutch Soldiers Navigate On Foot

This electronic belt uses small vibrating motors and GPS to provide foot soldiers with silent navigational cues on land and when walking through water bodies.


Elitac Wearables

THE ROYAL NETHERLANDS ARMY can now "feel their way around," thanks to the delivery of the first order of Mission Navigation Belts (MNBs) by Elitac Wearables B. V. The lightweight belt, which is worn around the waist, uses Global Positioning System (GPS) guidance and small vibrating motors to signal waypoint navigation directions to a soldier. The order of belts is part of a wider initiative by the Netherlands Ministry of Defense to improve situational awareness and survivability using new technologies.

The electronic belt conveys navigation cues to soldiers using haptic feedback in contrast to traditional navigation methods checking maps or display screens on computers or audio guidance on communications devices. These traditional techniques can distract a soldier from the mission at hand whereas the MNB allows a soldier to use their sense of touch for navigational guidance and their remaining senses to focus on their surroundings.

Elitac Wearables developed the MNB by working closely with the Netherlands Ministry of Defense. Major Van Veen, of the Royal Netherlands Army Defence Centre of Expertise for Soldier and Equipment, explains: "Modern soldiers have access to incredible, hi-tech navigation systems, but these all require soldiers to keep checking their screens constantly. This makes an already dangerous job even more dangerous because it reduces situational awareness." He added: "It has proved its value convincingly during field tests: Soldiers reported that they were more aware of their surroundings and found the navigational cues very intuitive. And because it plugs into our own soldier system, there is no learning curve or need for an additional battery. We look forward to implementing this order of belts and investigating other possible applications of the MNB."

The belt can be used effectively by foot soldiers on land and in water. Merijn Klarenbeek, chief executive officer (CEO) and co-founder of Elitac Wearables, noted: "Its design really pushes the boundaries when it comes to integrating electronics and textiles, as the belt had to be robust, comfortable, and, most importantly, reliable." de

RFSoC PCIe Board Serves Broad Array of Wireless Applications

Pentek

BRINGING RFSoC PERFORMANCE to PC platforms with a complete system on a board, Pentek's new Quartz 7050 is an 8-channel DAC and ADC on a PCIe double-wide board. The model 7050 is based on the Xilinx Zynq UltraScale+ RFSoC, a single-chip, adaptable radio platform, making it very popular for 5G and LTE wireless, SIGINT and COMINT, EW countermeasures, radar-on-a-chip, test and measurement, satellite communications, and LiDAR applications.

The Model 7050 design places the RFSoC as the cornerstone of the architecture. All control and data paths are accessible by the RFSoC's programmable logic and processing system. A full suite of Pentek-developed IP and software functions utilize this architecture to provide data capture, timing, and interface solutions for many of the most common application requirements.

Pentek's Quartz architecture embodies a streamlined approach to FPGA boards, simplifying the design to reduce power and cost, while still providing some of the highest performance FPGA resources available today. Designed to work with Pentek's Navigator Design Suite tools, the combination of Quartz and Navigator offers users an efficient path to developing and deploying software and FPGA IP for data and signal processing.

Xilinx's Zynq UltraScale+ RFSoC Processor integrates eight RF-class DACs and ADCs into the Zynq FPGA fabric and quad Arm Cortex-A53 and dual Arm Cortex-R5 processors, creating a multichannel data-conversion and processing solution on a single chip. Complementing the RFSoC's on-chip resources, the Quartz board architecture adds:

- 16 GB of DDR4 SDRAM
- Sophisticated clocking for single-board and multi-board synchronization
- High-signal integrity connectors for RF inputs and outputs
- x8 PCIe Gen 3 interface
- An 8-lane, 28-Gb/s optical interface with industry-standard MPO connectors for supporting Gigabit serial protocols
- 12 LVDS general-purpose I/O pairs for specialized interfaces
- On-board GPS receiver
- Speeds development and deployment for QuartzXM eXpress Module designs
- Factory-installed application IP

The Model 7050 is pre-loaded with a suite of Pentek IP modules to provide data capture and processing solutions for many common applications. Modules include DMA engines, DDR4 memory controllers, test signal and metadata generators, data packing, and flow control. The board comes pre-installed with IP for a triggered radar chirp generator, triggered radar range gate engine, wideband real-time transient capture, flexible multi-mode data acquisition and extended decimation. The Model 7050 can be used out-of-the-box with the built-in functions requiring no FPGA development.

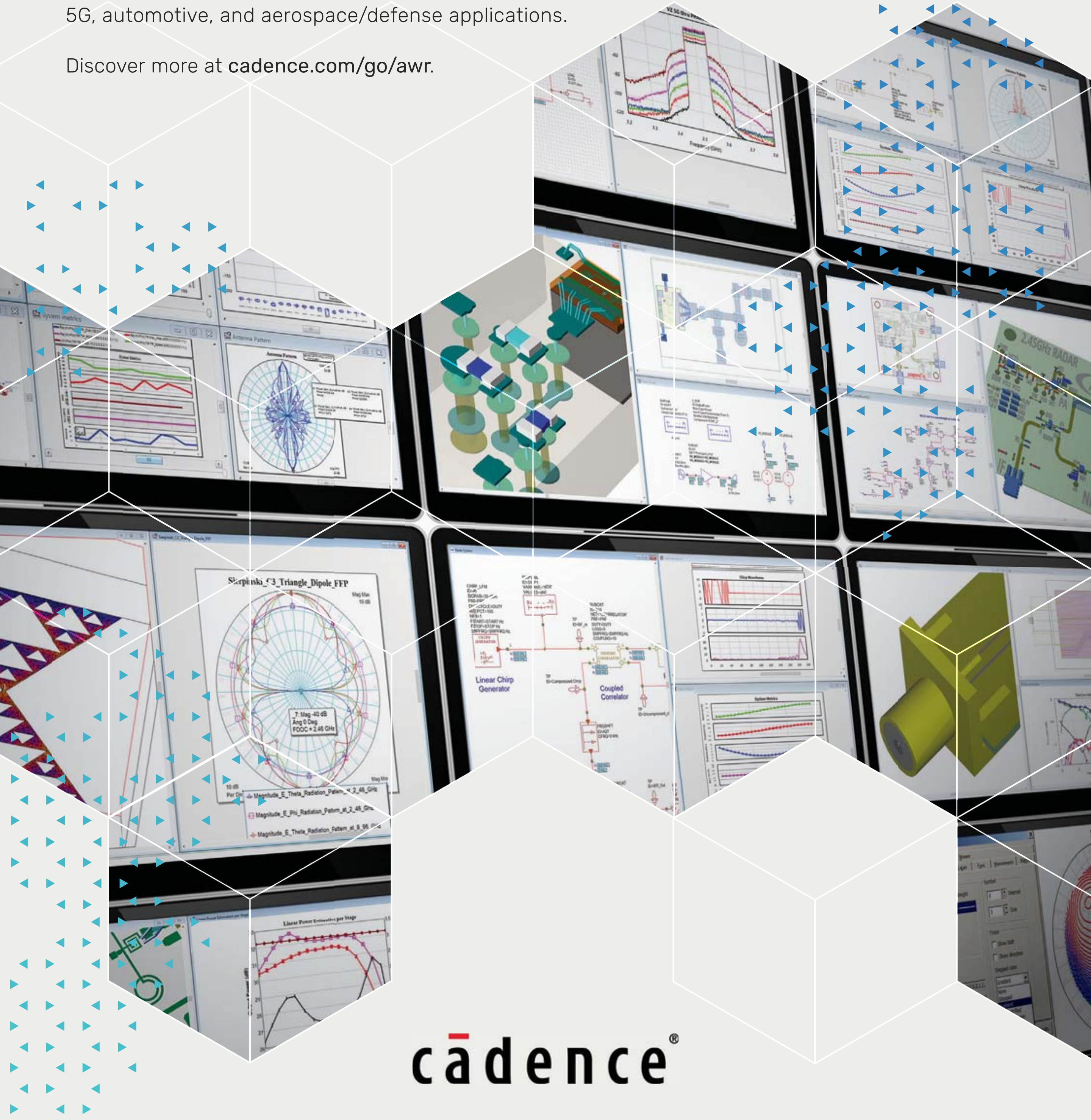
The front end accepts analog IF or RF inputs on eight panel-mounted MMCX connectors with transformer-coupling to eight 4-Gsample/s, 12-bit ADCs delivering either real or complex DDC samples. With additional IP-based decimation filters, the overall DDC decimation is programmable from 2 to 128. The eight DACs accept baseband real or complex data streams from the FPGA's programmable logic. Each 6.4-Gsample/s, 14-bit DAC includes a digital upconverter with independent tuning and interpolations of 1x, 2x, 4x, and 8x. Each DAC output is transformer-coupled to an MMCX connector.

Pentek's Navigator Design Suite includes the Navigator FDK (FPGA Design Kit) for custom IP and the Navigator BSP (Board Support Package) for creating host software applications. The former includes the board's entire FPGA design as a block diagram that can be graphically edited in Xilinx's Vivado tool suite, with full source code and complete documentation included. Developers can integrate their IP along with the factory-installed functions or use the Navigator kit to replace the IP with their own. The Navigator FDK Library is AXI-4 compliant, providing a well-defined interface for developing custom IP or integrating IP from other sources.

The Navigator BSP supports Xilinx's PetaLinux on the ARM processors. Users work efficiently using high-level API functions or gain full access to the underlying libraries including source code. Pentek provides numerous examples to assist in the development of new applications.

The PCIe SPARK development systems are ready for immediate operation with software and hardware installed. In many applications, the SPARK development PC can become the final deployed application platform.

Designed for air-cooled environments, the Model 7050 board starts at $28,495. Options for optical interface, GPS support, and memory are available. The Navigator BSP is $2,500 and the Navigator FDK is $3,500 and includes free lifetime support.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Linear Chirp Generator
Coupled Correlator
2.45GHz RADAR
System metrics
Antenna Pattern
Linear Power Estimation per Stage

JACK BROWNE | Technical Editor

Digital Techniques Train Cognitive EW Systems

In cognitive electronic-warfare systems, designers are recruiting artificial intelligence and machine learning for intelligent, automated responses to detected threats.

ELECTRONIC-WARFARE (EW) systems are often considered the most stable and dependable portions of a military electronics suite. But efforts to "modernize" defense electronics systems apply very much to EW technology. They're drawing from advances not just in spectrum extending to millimeter-wave (mmWave) frequencies, but also in the improved capabilities of more powerful microprocessors, faster data converters, and expanded artificial intelligence (AI). In terms of global EW technology, the U.S. hopes to close the gaps between the EW technologies employed by its own troops and the advanced EW systems being developed by Russian and Chinese researchers for their troops.

By applying AI and machine-learning (ML) techniques to EW systems, threats can be identified by machines and computers rather than human pilots and system operators. Subsequently, the process of selecting an electronic-countermeasures (ECM) response to a threat can be automated.

While that may sound like taking the human element out of warfare, it's following current trends for the growing use of robotics, unmanned ground vehicles (UGVs), and unmanned aerial vehicles (UAVs) in defensive warfare strategies. EW systems are leveraging the benefits of smarter electronic devices and circuits that meet reduced size, weight, and power (SWaP) requirements to provide increased signal-processing capabilities within smaller equipment enclosures.

1. The U. S. Army Combat Capabilities Development Command's Army Research Laboratory (ARL) is investing heavily in future EW capabilities through its Foundational Research for Electronic Warfare in Multi-Domain Operations (FREEDOM) program. *(Courtesy of ARL)*

MORE ROBUST CYBER SYSTEMS

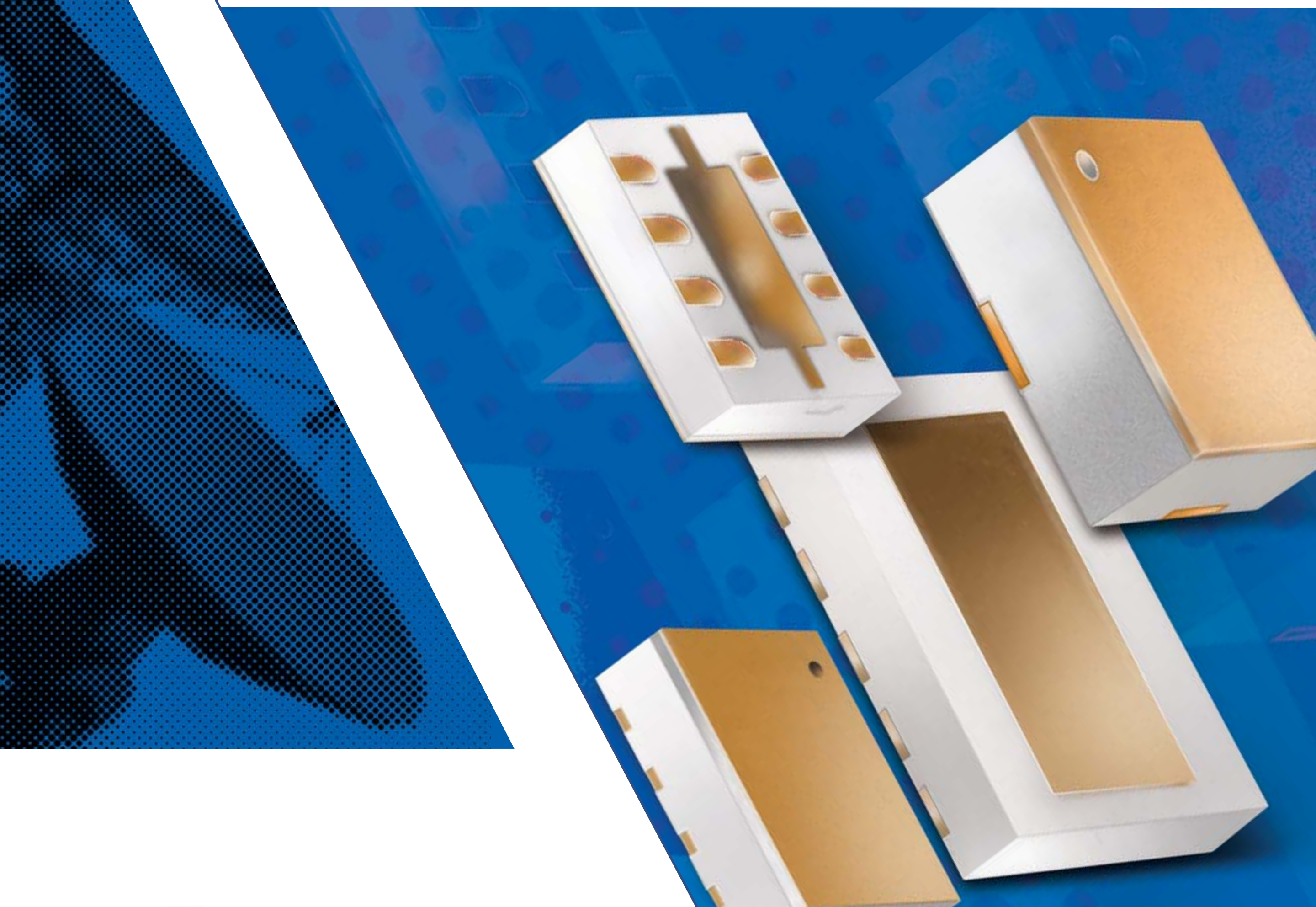
Military campaigns are typically fought within a few domains at once, such as on land, at sea, in the air, or in space. Cyberspace is becoming yet another domain for warfare, with computers linked via the internet and attempting to manage the electromagnetic spectrum (EMS) so vital for radar and secure communications. Increasingly, "smarter" or cognitive EW systems provide many of the functions needed for control or some level of comfort when operating in the EMS.

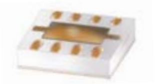
Newer EW system designs are more fully adopting digital EW system (DEWS) architectures promoted by each branch of the U.S. armed forces, such as the Army. DEWS approaches shift from traditional broadband analog radar warning receivers (RWRs) and signal-intelligence (SIGINT) subsystems to more thoroughly digital electronic subsystems.

For example, one program funded by the U.S. Army Combat Capabilities Development Command's Army Research Laboratory (ARL) in support of DEWS research, the Foundational Research for Electronic Warfare in Multi-Domain Operations (FREEDOM) research effort, is a starting point for much of the work in digitizing EW equipment suites. The EW enhancements include improving secure communications among allied troops and creation of techniques to measure the effectiveness of electronic attack (EA) and electronic protection (EP) techniques *(Fig. 1)*.

As part of FREEDOM, Army researchers are also hoping for greater integration of cyber electronics with EW systems as part of an initiative called cyber electromagnetic activities (CEMA), resulting in increased mobility of electronic systems within the battlefield and cyberspace.

Dr. Matthew Higgins, FREEDOM Program Manager, explains, "Electronic warfare is increasingly vital to Army preparations to defeat any potential threat. The Army's focus on large-scale combat operations highlights the need for a robust ground electronic warfare force to support multi-domain opera-





2. The Silent Crow EW pod can fit under the wing of the MQ-1C Grey Eagle UAV. *(Courtesy of Lockheed Martin)*

tions and enable the Army to fight and win in a complex world.

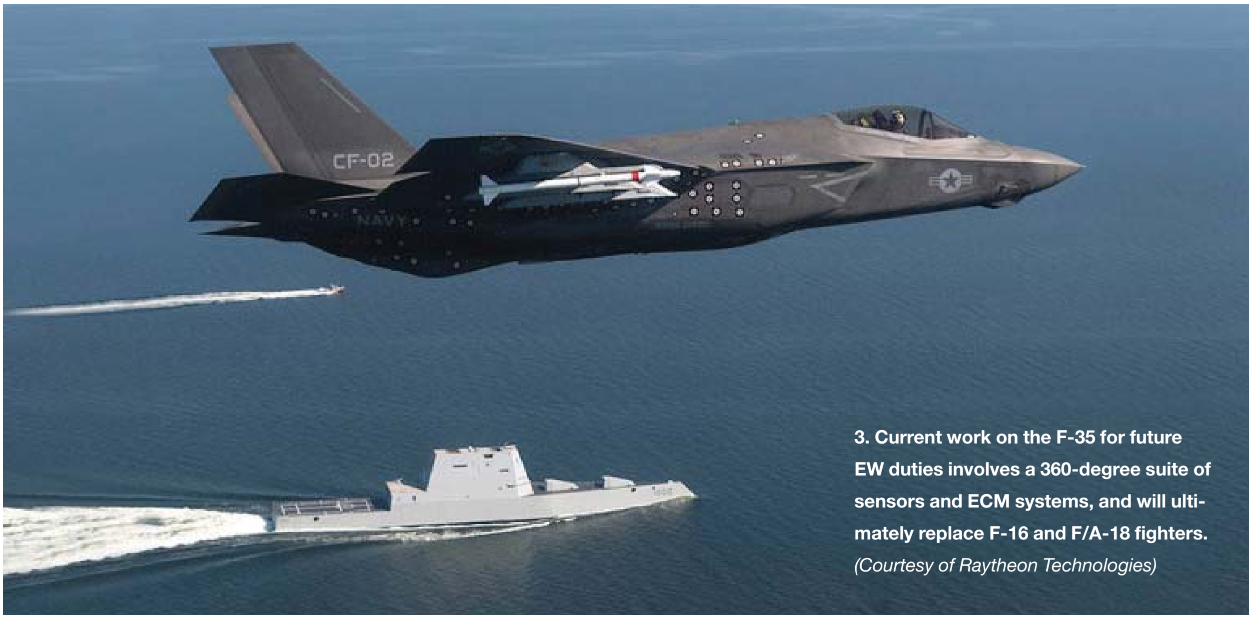
"In the long term, we are looking at multi-function RF capabilities from distributed platforms with research focused on adaptive filters, wideband amplifiers, and adaptive manufacturing-enabled antenna technology. The soldier will have freedom to maneuver on the battlefield and to dynamically access the congested and contested electromagnetic spectrum."

Newer cognitive EW systems are being designed with advanced digital hardware, even to the extent of exploring different approaches to computer processing, such as quantum computing (which may be a few years away). Although development of these EW systems follows SWaP requirements for UGVs as well as UAVs, they're also taking advantage of the large capacities of solid-state memories. Extended memories are needed in cognitive EW systems in companion with threat-recognition algorithms to locate known or anticipated threat emitters and respond with an ECM such as a jammer.

By building a library of transmitters, such as for radars and other threats, for a particular nation or adversary, a cognitive EW system can be programmed to quickly detect and identify a known emitter. This would avoid spending long hours scouring through bandwidth for every emitter on the planet that might be a threat. As additional data is collected, these threat libraries can be expanded, and the cognitive capabilities of the EW system extended, as part of an electronic order of battle (EOB) that includes optimum ECM responses for each type of threat.

SPEEDING THE EW EVOLUTION

Acknowledging the need for more modern EW systems, the U.S. Army is working with Lockheed Martin among others on several cognitive EW strategies. For Lockheed Martin, one approach involves a prototype tactical



3. Current work on the F-35 for future EW duties involves a 360-degree suite of sensors and ECM systems, and will ultimately replace F-16 and F/A-18 fighters. *(Courtesy of Raytheon Technologies)*

electronic warfare system (TEWS). The terrestrial layer system (TLS) is intended for ground-based vehicles, such as the Humvee. And long-range airborne and ground-based jammers currently in process at the company will work their way into ECM response systems. The Army has encouraged a modular open architecture for the TEWS's C4ISR/EW suite of standards.

Lockheed Martin has quietly and secretly worked on a next-generation EW pod for attachment to ground vehicles and aircraft, even small UAVs. Called the Silent Crow EW pod *(Fig. 2),* it can fly under the wing of the MQ-1C Grey Eagle UAV. Smaller versions of the EW pod are being developed for the Army's multifunction EW Air Large (MFEW-AL) unmanned aircraft, such as the RQ-7 Shadow and the Future Tactical UAS. The Army recently awarded the company $74.85 million for further development of the EW pods used in the Silent Crow, seeking modernization of EW technologies beyond simply 2 to 18 GHz, RWRs, and jammers.

The prime contractor has been working on a set of ML algorithms to feed the cognitive EW pod's AI capabilities. It has even employed the latest 3D-printing technologies to shrink the size of some components, such as antennas.

Silent Crow is an example of how a newer EW system can process available sensor data with high-speed processors, AI, and ML techniques to provide a pilot with more detailed information about a received signal source and a possible threat. The DEWS pods come in relatively compact housings per SWaP design guidelines and can be miniaturized for use on smaller UASs. Lockheed Martin also developed a version of the Silent Crow EW technology for ground-based vehicles, called ground RF intelligence node (GRFIN), to supply ground troops with an optimized EW system.

The Surface Electronic Warfare Improvement Program (SEWIP) Block 3 involves adding advanced electronic counterattack capability to an EW system. The U.S. Navy is working closely with Northrop Grumman so that maritime AN/SLQ-32(V) systems can outmaneuver emerging long-range missile threats. The block upgrade will provide EA capability to surface users with growth for EW using information-operations (IO) capability.

The upgraded EW system will be able to detect and disrupt inbound threats, such as guided missiles, and operate against an adversary's radar and communications systems. It employs active electronically scanned array (AESA) technology to detect and identify multiple threats, using narrow EM beams to

avoid detection. It can also operate in a "silent" mode—no beams are transmitted, but it can still detect threat signals. The system's initial installation design targets Navy DDG-51 Class Destroyers.

FUTURISTIC FLIGHT

BAE Systems is doing its part to make the F-35 the EW fighter of the future for the U. S. Navy and Air Force in terms of air-to-air and air-to-ground combat *(Figure 3 on page 50)*. It's being groomed, for example, as a replacement for the Air Force's F-16 and the Air Force and Marine Corps' F/A-18s. The aircraft features a 360° array of sensors and display units built into the visor of a pilot's helmet so that the detected information moves with the pilot.

The Air Force is also looking to BAE Systems for its AN/ALQ-250 Eagle Passive Active Warning Survivability System (EPAWSS) EW system to modernize upgraded F-15 fighter aircraft, such as the F-15E and the F-15EX from Boeing. The modular DEWSs provide many advanced capabilities to counter new and emerging threats.

The ALQ-239 platform features fully integrated radar warning, geolocation, situational-awareness, and self-protection capabilities for detecting and defeating both airborne and surface-based threats, even in dense signal environments. It includes an advanced ECM subsystem with rapid response capabilities and features multispectral RF and infrared (IR) countermeasures subsystems, a digital RWR, digital RF memory jamming, and integrated ECM dispenser to speed responses to detected threats.

In response to growing use of EW technologies, L3Harris is working on adaptive EW systems, such as its HalcyonLink equipment. These systems employ interference cancellation techniques to maintain critical tactical communications even during an adversary's efforts at jamming. In some cases, it may even be a pilot's own equipment that's doing the jamming, since an aircraft's EW suite has been known to block the same aircraft's communications equipment.

Such interference cancellation techniques allow troops to simultaneously perform EW, cyber operations, and tactical communications effectively within the small space of an in-flight fighter aircraft. For example, the interference cancellation system (INCANS) on the EA-18G Growler airborne electronic attack (AEA) carrier-based aircraft enables tactical communications even when the on-board ALQ-99 tactical jammer system is operating.


5G


USB / TTL Attenuator

PAUL COOK | Director of Missile Systems, Curtiss-Wright Defense Solutions

Transitioning to C-Band for Flight-Test Telemetry

The U.S. Government's auction of flight-test telemetry bands has resulted in crowded frequencies in the remaining spectrum. But the transition to the C-band has been slow. Here's how tri-band transmitters can help in adopting the new requirements.

THE U.S. GOVERNMENT auctioning off telemetry frequency bands has drastically affected the day-to-day operation of the flight-test community—the increased frequency crowding is reducing operational availability. The government responded with new standards for bandwidth-efficient modulation schemes to "pack" more data bandwidth in the remaining telemetry workspace, allowing the private sector to develop hardware in the new C-band allocations for telemetry.

Telemetry vendors responded first with the spectrum-efficient hardware for both air and ground applications, while the requirements for C-band applications evolved from initial experiments to actual orders.

The ground segment in the U.S. has upgraded to be C-band-capable across the country. Of interest, the commercial occupation of their new ownership of the L- and S-bands (D- and E-bands) is regional, with local test ranges still using the L- and S-bands due to the current availability. In areas of the country where frequency crowding occurs, C-band is widely used with equal activity in L-band as well. The wide variation in frequency-band availability has now put the focus on tri-band transmitters for flight-test operations *(Fig. 1)*.

1. A tri-band transmitter can support S-, L-, and C-bands.

DEVELOPING A TRI-BAND TRANSMITTER

Curtiss-Wright developed a tri-band transmitter to provide a multiband solution in a single unit. Thus, engineers can avoid having to replace units to change bands between test flights or when flying from range to range. The transmitter provides lower and upper L-(D)-band, full S-(E)-band, and C-band in a form factor designed to replace many existing field units.

The unit also includes the latest technology as defined in the IRIG-106-19 standard for advanced range telemetry (ARTM)-compliant modulation, forward error correction (FEC), and space-time compensation (STC), as well as providing independently controlled dual RF outputs. The unit went through a full series of in-house testing as a design-verification step. In addition, the U.S. government has conducted many tests to both validate the hardware performance and become familiar with the new features in a real telemetry environment.

As a result of these tests, there were several modifications and enhancements that included customization, as many of the flight-test ranges didn't agree on the list of useful features based on their test objectives. Consequently, four variants of the tri-band transmitter now address the desired feature list.

During the test campaigns, several undesirable performance issues were observed and corrected using active compensation. The linearity response of the IQ modulator device (where I is the in-phase component and Q is the 90-degree phase difference) across the three frequency bands didn't match the manufacturer's performance data. Unfortunately, the selected IQ modulator had the highest performance currently available amongst the leading suppliers.

The corrective action was to incorporate active band-linearization compensation using a microcontroller to actively monitor temperature and apply compensation factors across the three frequency bands. Another challenge, the RF-power leveling across the three bands, was enhanced with a second microcontroller-based compensation circuit. Control of the transmitter's overall temperature was also implemented to prevent overheating and component damage.

INTEROPERABILITY TESTING

Much of the funding gained by the sell-off of the telemetry bands was spent on a modern upgrade to receiver offerings for flight-test ranges, with DSP-based receiver designs from several manufacturers addressing the multi-band, the STC, and the IRIG 106 Chapter 7 standards. Unfortunately, these efforts by the vendor community were a failure from the standpoint of interoperability testing.

The community assembled for an operability test session at the 2019 International Telemetry Conference in Las Vegas, where the transmitter vendors could test their products against receivers from multiple vendors, allowing them to record the waveforms for future development. Curtiss-Wright was the only transmitter vendor with an IRIG-106-19-compatible transmitter.

As a testament to the accuracy of the IRIG-106-19 standard, the tri-band transmitter performed well, given that receivers from many vendors were able to demodulate the tri-band waveforms at various data rates and using different modulation schemes. This test confirms the stated modulation formulas, the LDPC, and STC coding schema in the IRIG-106-19 standard.

SPACE-TIME PROCESSING PERFORMANCE

Space-time processing (STP) in transmitters is a method of eliminating intersymbol interference (ISI) between upper and lower antennas in an antenna array. Time delays between the upper and lower antennas is usually caused by differences in cable lengths. Typical propagation delay in coaxial cables can vary from 1.2 to 1.6 ns/foot, depending on the material.

For short cables, the impact of propagation delays is minimal. However, due to the typical scenario of telemetry equipment being added to aircraft after they're built, long cable(s) are often routed through the vehicle, resulting in differences in the propagation delays.

In the author's experience, most implementations measure and match the cable delays to minimize the effects of propagation delays. The tri-band transmitter is equipped to delay the STC data pattern from zero to one clock period in increments of 1,024 steps, independently of the two RF outputs, to match the delay of each RF path.

Tests performed with a STC-enabled receiver (STC-ER) have determined that with a timing mismatch of one clock period or less, the STC-ER performs as expected. Mismatches of greater than one clock period result in a significant loss of lock and no data. The vendor of the STC-ER provided a metered representation of the mismatch that provides the user with a visual indication of the balanced time delay with the air system, which makes adjustment of the tri-band transmitter delay feature simple and repeatable.

FORWARD ERROR CORRECTION

Today, with the adoption of low-density parity-check (LDPC) code FEC, the IRIG-106-19 standard specifies six varying LDPC coding schemes for improved link margin. However, the improved noise performance isn't without cost: It increases the bandwidth with the FEC data overhead.

The bandwidth expansion factor (EF) as described in the IRIG-106-19 standard states that regardless of the information block length, or IBL (whether 1024 or 4096 bits), the EF is 33/16 for a channel data rate of 1/2, 25/16 for a 2/3-channel data rate, and 21/16 for a 4/5-channel data rate. This includes the FEC as well as the attached synchronization marker (ASM). The six coding schemes, and their IBLs, are as follows:

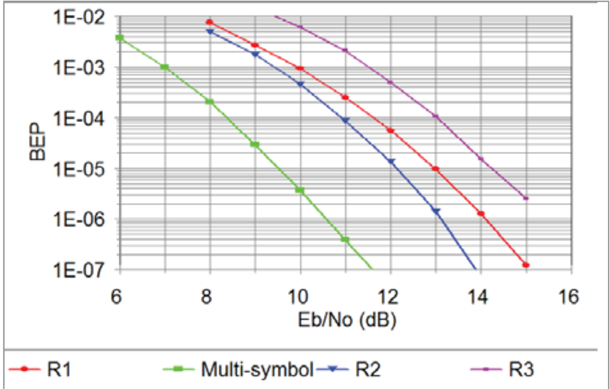
1 = Code Rate 1/2, IBL 1024
2 = Code Rate 1/2, IBL 4096
3 = Code Rate 2/3, IBL 1024
4 = Code Rate 2/3, IBL 4096
5 = Code Rate 4/5, IBL 1024
6 = Code Rate 4/5, IBL 4096

As an example, the EF for a 4-Mb/s, NRZ-L stream with LDPC 4 (2/3 rate; block 4096) would result in a data rate of 6.25 Mb/s. The same 4-Mb/s, NRZ-L stream when encoded with LDPC 5 would result in a 5.25-Mb/s data rate; and at the LDPC 1 code rate, the 4-Mb/s stream would result in a data rate of 8.25 Mb/s. The equation is as follows, where R is rate and F is factor:

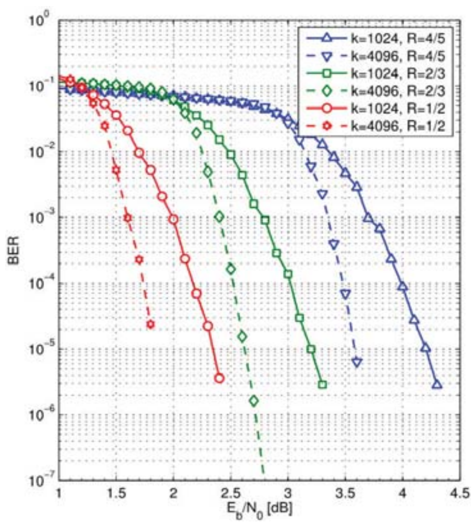
$$R_{Transmitter} = R_{NRZ-L} \times F_{code\ rate\ expansion}$$

Lab experiments with this FEC determined that the encoding performance is well-behaved. The algorithm performs as described in the IRIG standard. Bit-error-rate (BER) performance without and with FEC are shown in *Figures 2 and 3*.

Be advised that the operational region for repeatable performance narrows as the coding gain increases. When applying maximum gain with the 1/2 coding rate, the operation region is somewhat limited down to several decibels.



2. This plot illustrates BER performance with no FEC applied by the transmitter.



3. Shown is a graph of BER performance with FEC applied by the transmitter.

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Part Number	Frequency Range (GHz)	P_{OUT} (dBm)	PAE (%)	Gain (dB)
CMD242K4	DC-40	20	–	10.5
CMD304	DC-67	14	–	10
QPA2213D	2-20	34	23	16
QPA1022D	8.5-11	36.5	45	24
CMD299K4	18-40	9	–	16
TGA2222	32-38	40	22	16
TGA2224	32-38	37	20	16

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FEC isn't useful for all applications, and special consideration should be made before deciding to use this tool to obtain your telemetry data. From the tri-band transmitter perspective, switching the LDPC on and off is easily accomplished by sending a transmitter command of "FE1" to "FE6" to enable a desired code rate, or "FE0" to disable it.

Depending on the ground-state receiver of choice, the changeover from no FEC to FEC being enabled may take several seconds to reconfigure. Planning when to change over in flight will take scheduling to avoid longer loss of data. Certainly, though, FEC works and has been the method of improving link margins for many years.

THERMAL MANAGEMENT

With the initial prototype of the tri-band transmitter, deploying it as a "drop-in replacement" resulted in thermal-management issues.

The primary heat-sink path for transmitters is the bottom mounting surface. With the thermal dissipation equally distributed, modules that are farther away from the bottom mounting surface have a higher temperature rise compared to the lower modules. We measured a temperature differential of 20°C between the bottom baseplate and the internal temperature of the top-most module.

MITIGATION OF THE THERMAL RISE

Decreasing the thermal resistance between the module sections with overlapping mechanical joints, combined with increased wall thickness on the center power-supply module, reduced the thermal rise from 20°C to 15°C. This increased the RF efficiency with optimized RF tuning through the RF chain, resulting in reduced current draw and an additional 3°C decrease in the temperature differential between the bottom mounting surface and the top-most module's internal temperature.

We implemented thermal protection with a microcontroller that monitors key areas in the transmitter, controlling thermal dissipation by regulating the output RF power. This control, when activated, throttles back the RF output power when temperature rises above a preset value (typically 75°C). This eliminates the risk of exposing the devices in the top module to excessive temperatures.

Thermal protection is enabled by the end user. To reduce the risk of damage, the user sets the desired temperature threshold and then enables the control through the transmitter communication port. This feature was found to work well and is an easy safeguard against hardware damage when in the field.

SUMMARY

Every development includes new features, problem resolution, manufacturing maturity, as well as surprising results. Development of the tri-band transmitter was no different.

The complete control over the RF output power with independent control of the RF power going to the upper and lower antennas was evidently a useful tool for lab testing. No longer does the test engineer need to carry the variety of RF attenuators to match the RF levels driving the test equipment to perform BER tests.

A simple commanded adjustment of the RF power allows for a smooth RF-level adjustment rather than the manual step attenuator, which eases performance testing. The author historically has not favored the 1-dB step adjustment in RF power. However, after completing this development, the advantage of such a feature is obvious, and the credit goes to the telemetry community for this advance.

The ease of responding to both the 106-15 programming protocol and the 106-19 command protocol was a surprise. From a transmitter vendor's perspective, the transmitter command listing across the various versions of the IRIG standard has evolved to include well over 60 commands. For the user, having to remember the appropriate protocol for a given transmitter causes delays and inappropriate programming. The tri-band transmitter acknowledges the previous command structure as well as the latest IRIG standard command structure, which saves time and increases typing accuracy for the test engineer.

Throttling back the RF power to limit temperatures in the tri-band transmitter helps avoid hardware damage. In some applications, it's desirable for the transmitter to "die trying" and continue to transmit through high-temperature events. This isn't true for flight tests, though, when there are long pre-flight and flight times during which the temperature-limiting function will save the hardware from damage. This is certainly an advanced feature and welcomed by the flight-test community not to have to turn the transmitter off to cool down.

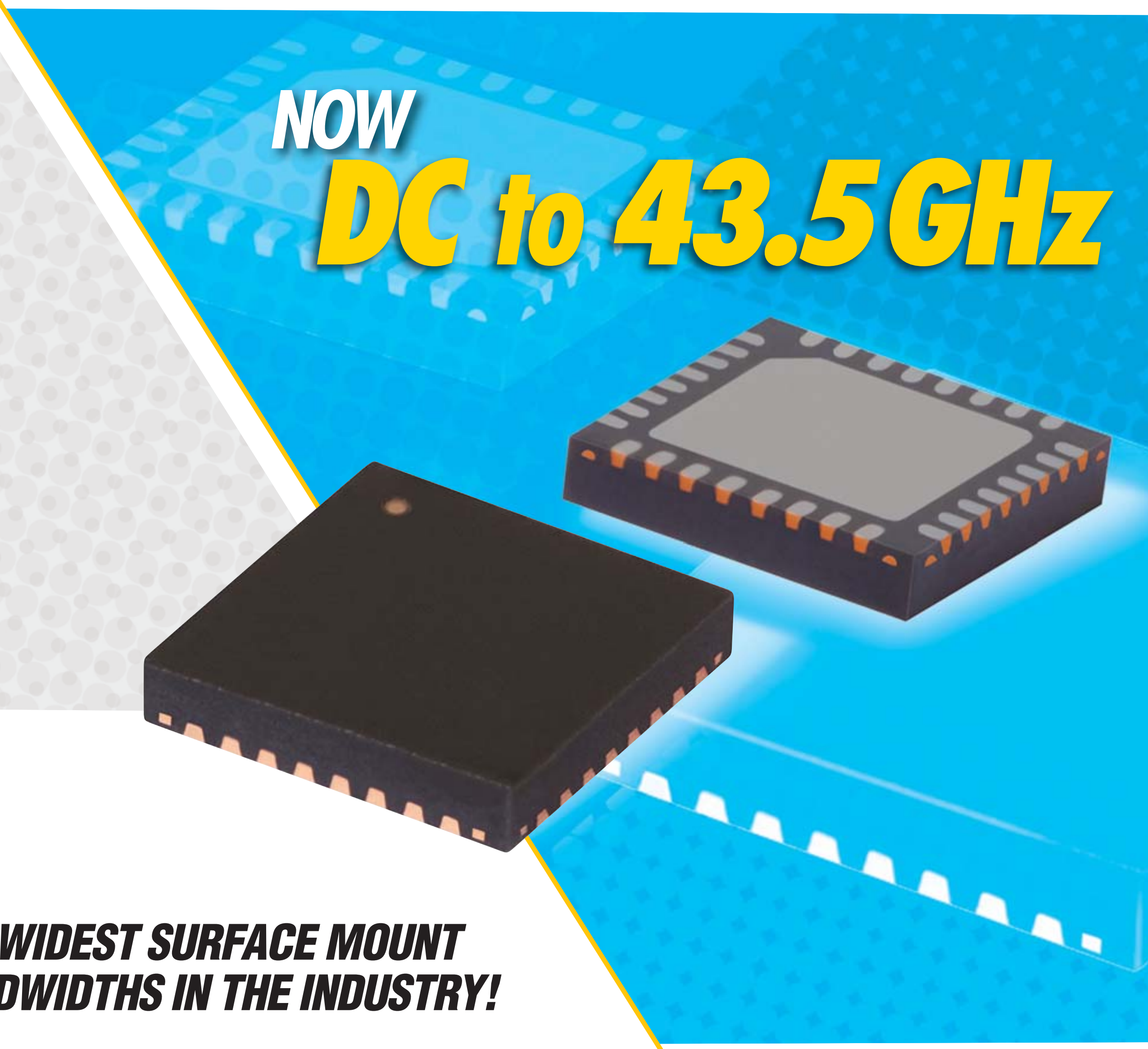
Thumbwheel and serial-port programming is still required for these flight-test transmitters. The author found those features to be easy to use, presenting very few difficulties in communicating with the tri-band transmitter. The takeaway here is "the simpler, the better," and it all works. A friendly element of this type of interface is the "?" command, with which the test engineer can print out the many command structures for guidance in choosing the correct one.

Cable-delay matching between the upper and lower antennas is quite easy using the STC balance displays on some of the vendor's receivers. The delay matching to within 1-bit time is required for STC demodulation performance as the interoperability testing results provided.

As users gain experience using tri-band transmitters, requirements will continually evolve to assure successful reception of data in the current and future frequency bands. de

REFERENCE

Range Commanders' Council IRIG-106-19 Telemetry Standard, Chapter 2, and Appendix (performance data provided from the standard for clarity)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7-in. Touchscreen Mission Display Serves in Rugged Vehicular Environments

CURTISS-WRIGHT HAS ANNOUNCED a new addition to its family of rugged displays: the SVDU-M 7-in. touchscreen mission display, which packs new technologies including optically bonded glass; dual-mode, NVIS-compatible LED backlighting (MIL-STD-3009); and full touchscreen operation. The display brings PCAP (Projected CAPacitive) multipoint touchscreen technology to a compact, single DVI-input unit that is optimized for size, weight, and power (SWaP). The SVDU-M display, which features a resolution of up to 1920 x 1080 pixels and is responsive even while wet or wearing gloves, can be integrated into any airborne, naval, civilian, or law enforcement vehicle platform.

CURTISS-WRIGHT DEFENSE SOLUTIONS

www.curtisswrightds.com

OpenVPX Chassis Keeps Up to 16 Slots Cool

PIXUS TECHNOLOGIES recently announced the company's new RiCool chassis configurations for 9-slot and 16-slot OpenVPX backplanes in the 6U height. The RiCool OpenVPX series pulls air from an intake area located on the bottom of the chassis and pushes the hot air 90 degrees out of the rear of the enclosures. The enclosures are outfitted with hot-swappable dual fans that provide up to 191 CFM of cooling, which, in a full 16-slot OpenVPX system (at 1.0-in. pitch), translates to 125 W per slot. The 9-slot backplane features a BKP6-CEN09-11.2.13 profile per VITA 65 specifications, allowing it to handle rugged environments. It's also designed for PCIe Gen3 (8 Gbaud/s) speeds, but higher-speed options are available upon request. The 16-slot 6U backplanes can also be configured in multiple routing configurations if required. Pixus offers standard modular power supplies for VPX voltages for the RiCool OpenVPX chassis series, with pluggable VITA 62 or other ac or dc power-supply options depending on customer's needs.

PIXUS TECHNOLOGIES

www.pixustechnologies.com

System-on Module Powers AI Applications in Defense Systems

AITECH GROUP has added Nvidia's Jetson AGX Xavier SoM (system on module) to its GPGPU (general-purpose GPU) family of rugged systems designed for defense systems. The A178 Thunder GPGPU allows Aitech to increase the level of AI applications via 512 CUDA cores and 64 Tensor cores. The ultra-SFF AI supercomputer boasts an eight-core ARM v8.2 64-bit CPU, H.264/H.265 hardware encoder, NVMe SSD, and 16 GB of LPDDR4x. Video is simultaneously captured on up to four channels via SDI (SD/HD) or over eight channels at full frame rates using Composite (RS-170A [NTSC]/PAL) interfaces. The SoM can handle up to 22 TOPS to provide local processing of high volumes of data harvested from system sensors.

AITECH GROUP

www.aitechsystems.com

Channelized Receiver Spans 1 to 18 GHz

PLANAR MONOLITHIC INDUSTRIES' (PMI's) PRX-20-1G18G-850M-SFF channelized receiver covers 1 to 18 GHz instantaneously in 20 channels, with IF frequencies between 1 and 4.4 GHz (output), which are ready for digitization. The receiver is designed to cover a 60-dB dynamic spread using an internal 10-MHz reference, which locks the internal LOs used in downconverting the signal into the required frequency bands. The receiver features a gold-anodized MIL-A-8625 Type II, Class 2 dyed gold finish, has an RF input power of -55 to +5 dBm, and an RF input VSWR of 2.0:1 maximum. It also offers an RF output frequency of 5.0 GHz maximum/4.4 GHz typical, an RF output gain of 0 dB ± 3 dB typical, an RF output passband of 870 MHz typical, and an RF output stopband of 1.4 GHz maximum.

PLANAR MONOLITHIC INDUSTRIES

www.pmi-rf.com

Single-Board Computer/RTOS Pairing Soars in Avionics Applications

DDC-I HAS TEAMED UP with Abaco Systems to provide the Deos RTOS for Abaco's SBC314 3U VPX single-board computer (SBC) for avionics applications. DDC-I's Deos D0-178C Design Assurance Level A (DAL A) RTOS for avionics offers support for ARINC 653 APEX, Rate Monotonic Scheduling (RMS), and is targeted at the FACE Safety Base Profile. Abaco Systems' SBC314 3U VPX SBC features a QorIQ T2081 (1.8-GHz) or T1042 (1.4-GHz) processor; 4 GB of DDR3L ECC RAM; and a host of ports, including COM, Gigabit Ethernet, GPIO, SATA, and USB. It's also available in 5X air and conduction-cooled ruggedization levels and offers VITA 48 formats for 2-level maintenance (2LM) requirements.

ABACO SYSTEMS

www.abaco.com

SOSA-Aligned Dual Upconverter Operates From 6 to 18 GHz

MERCURY SYSTEMS recently unveiled its industry-first SOSA-aligned, ultra-wideband, dual microwave upconverter for demanding electronic-warfare environments. The RFM3103s offers a dynamic range and performance operation of 6 to 18 GHz with low phase noise and an internal local oscillator (LO). The upconverter has also been optimized for future upgradability and is packaged in a low-swap 3U module that's ideal for electronic attack, ELINT, and beamforming systems. In a standard configuration, the RFM3103s features a pair of transmitting modules installed on two OpenRFM module sites and offers adjustable parameters for instantaneous bandwidth, frequency range, and output power.

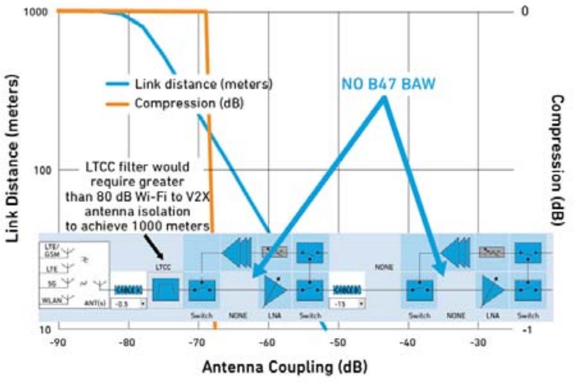
MERCURY SYSTEMS

www.mrcy.com

(Continued from page 31)

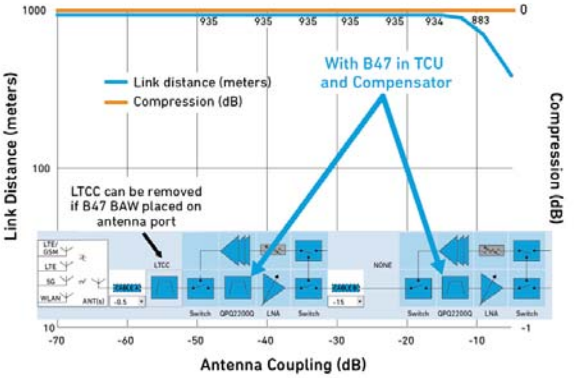
Without BAW, Wi-Fi Creates IM3 and Compression

Estimated Link Distance with Rx IMD3 and Compression



With Two BAW, Link Distance is Maximized

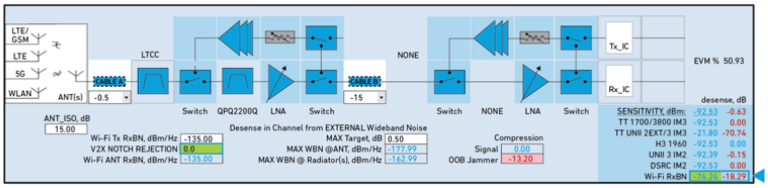
Estimated Link Distance with Rx IMD3 and Compression



4. These plots compare the V2X and Wi-Fi antenna isolation needed to achieve a 1-km V2X link.

Rx Band Noise and Desense

No Notch Filter



CABLE A -0.5

CABLE B -15

EVM % 50.93

ANT_ISO, dB 15.00

Wi-Fi Tx RxBN, dBm/Hz -135.00

V2X NOTCH REJECTION 0.0

Wi-Fi ANT RxBN, dBm/Hz -135.00

Desense in Channel from EXTERNAL Wideband Noise

MAX Target, dB 0.50

MAX WBN @ANT, dBm/Hz -177.99

MAX WBN @ Radiator(s), dBm/Hz -162.99

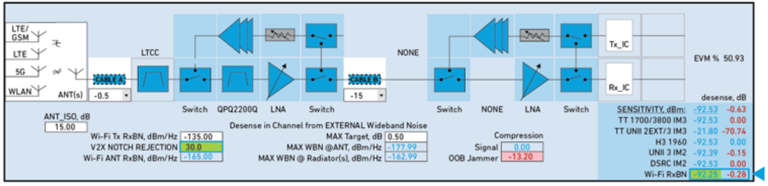
Compression

Signal 0.00

OOB Jammer -13.20

		desense, dB
SENSITIVITY, dBm:	-92.53	-0.63
TT 1700/3800 IM3	-92.53	0.00
TT UNII 2EXT/3 IM3	-21.80	-70.74
H3 1960	-92.53	0.00
UNII 3 IM2	-92.39	-0.15
DSRC IM2	-92.53	0.00
Wi-Fi RxBN	-74.24	-18.29

Notch Filter with 30 dB Rejection



CABLE A -0.5

CABLE B -15

EVM % 50.93

ANT_ISO, dB 15.00

Wi-Fi Tx RxBN, dBm/Hz -135.00

V2X NOTCH REJECTION 30.0

Wi-Fi ANT RxBN, dBm/Hz -165.00

Desense in Channel from EXTERNAL Wideband Noise

MAX Target, dB 0.50

MAX WBN @ANT, dBm/Hz -177.99

MAX WBN @ Radiator(s), dBm/Hz -162.99

Compression

Signal 0.00

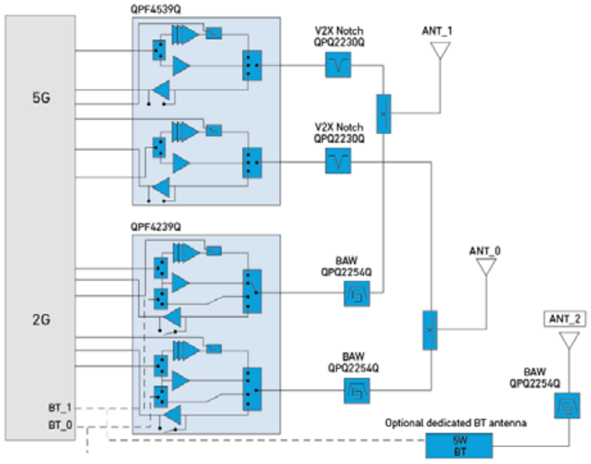
OOB Jammer -13.20

		desense, dB
SENSITIVITY, dBm:	-92.53	-0.63
TT 1700/3800 IM3	-92.53	0.00
TT UNII 2EXT/3 IM3	-21.80	-70.74
H3 1960	-92.53	0.00
UNII 3 IM2	-92.39	-0.15
DSRC IM2	-92.53	0.00
Wi-Fi RxBN	-92.25	-0.28

6. At top, we see that there will be up to 18-dB desense in the V2X receiver if the notch filter isn't used on the 5-GHz Wi-Fi path. On the same system, there's almost zero desense when using a well-designed notch filter.

One way to address this issue is by notching out the ETC spectrum with a properly designed filter on the V2X path. A notch filter at the input of V2X front-end module (FEM) will limit spectrum emissions from the output of the V2X system, thus allowing it to pass the ETC spec of –65 dBm/MHz.

Wi-Fi Front-End With a V2X Notch (QPQ2230Q) on the 5 GHz Path



5. While a bandpass filter provides out-of-band rejection to UNII bands, a notch filter on the 5-GHz Wi-Fi path prevents Rx band noise from coupling back into the V2X system.

CHOOSING THE RIGHT FILTERING SOLUTION

When design engineers choose a filter for their system, the most important parameters to consider are the two that characterize the resonator qualities: quality factor (Q) and coupling factor (k2). A high Q is necessary to achieve the lowest insertion loss, while a high k2 enables wider bandwidth. Technology advances at the resonator level have helped improve insertion loss and high-selectivity performance with wider-bandwidth filter products at frequencies up to 6 GHz to address the industry's most complex spectrum challenges.

A combination of high-Q bandpass and notch filters offers the most complete solution to coexistence challenges in the design of autonomous vehicles. The seamless coexistence of all technologies on the connected-car spectrum, enabled by advanced BAW bandpass and notch-filtering solutions, will ensure that our increasingly mobile world is safer, more reliable, and more enjoyable. mw

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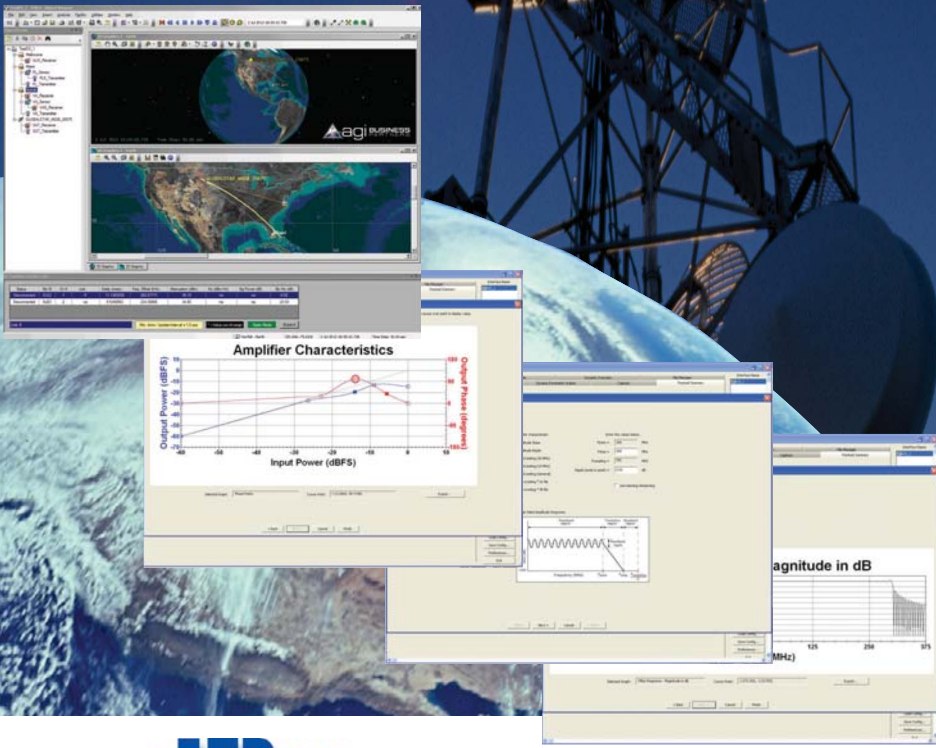
- **Payload and ground station emulation**
- **Multipath, 12 paths @ 600MHz BW**



dBm

RF Test Equipment for Wireless Communications

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