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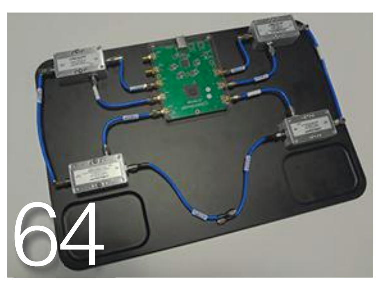

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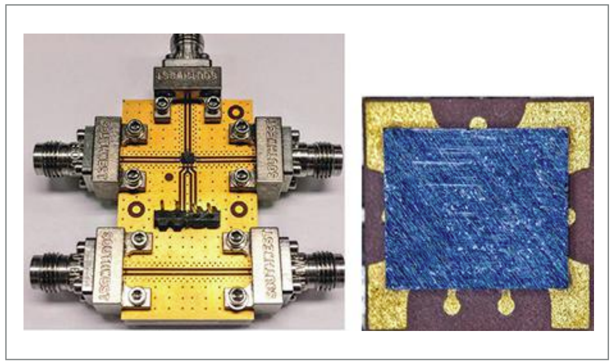
Japan Looks to E-2D Hawkeye for Early Warning and Surveillance

Japan received its first delivery of an E-2D Advanced Hawkeye from Northrop Grumman earlier this year, which provides enhanced security and surveillance capabilities.

https://www.mwrf.com/defense/japan-looks-e-2d-hawkeye-early-warning-and-surveillance



A Practical Design Approach to Custom mmWave SMT Packages

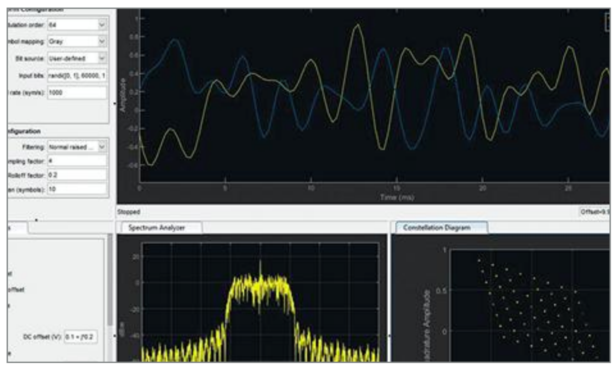
What are the key ingredients for developing customized surface-mount packages that will ultimately achieve good electrical performance from dc to 50 GHz?

https://www.mwrf.com/materials/practical-design-approach-custom-mmwave-smt-packages

Testing Interest in 5G at 2019 IMS Exhibition

The industry's move to higher frequencies is apparent from the growing number of test instruments on display at the 2019 IEEE IMS exhibition.

https://www.mwrf.com/test-measurement/testing-interest-5g-2019-ims-exhibition



Generating Waveforms for Wireless and Radar Systems

Oftentimes, taking an app-based approach simplifies the waveform generation and analysis process for wireless and radar systems. MathWorks' Rick Gentile and Honglei Chen explain in this latest Algorithms to Antenna blog.

https://www.mwrf.com/software/algorithms-antenna-generating-waveforms-wireless-and-radar-systems

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Editorial

JACK BROWNE | Technical Editor
jack.browne@informa.com

Making My Way Around Boston's 2019 IMS Exhibition

ONCE AGAIN, the IEEE is to be congratulated for an excellent technical program and well-attended exhibition hall at the 2019 Microwave Theory & Techniques Society (MTT-S) International Microwave Symposium (IMS). The exhibition, held this past June 4-6 in Boston's Convention and Exhibition Center, is easily the world's largest annual RF/microwave event, and quickly becoming the largest millimeter-wave (mmWave) event as the industry moves into supporting designs at frequencies of 30 GHz and higher.

The two application areas on most exhibitors' and visitors' lips were automotive radars and 5G systems. For an industry that has grown up feeding the demands of specialized military systems requirements, production numbers totaling millions if not billions for components, materials, and test equipment targeting such markets had many talking about the "coming of age" for the very focused RF/microwave arena.

Perhaps not so bizarre, but more than a few mentions of "6G" could be heard on the show floor. Design engineers were anticipating the rapid consumption of bandwidth in 5G systems and the need for even more advanced wireless communications solutions.

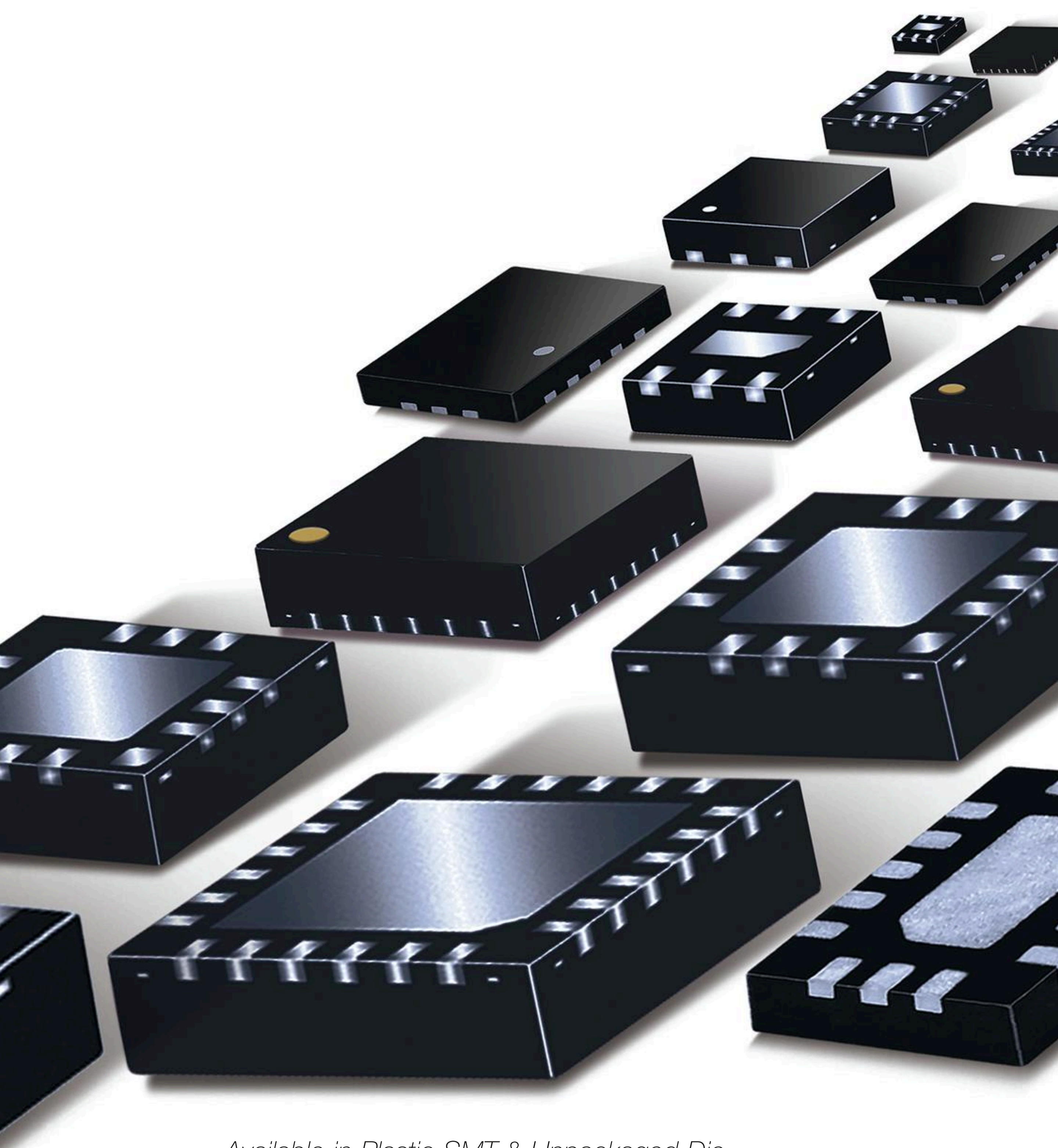
Needing wireless solutions so soon beyond 5G could be explained by many as the "changing of the guard" in the industry. Several family members came to the 2019 IMS exhibition with their parents, now grown and working with and for their parents as part of the industry. Getting to meet some of these young engineers who are part of this industry's next generation was a fortunate and wonderful part of the 2019 IMS.

Even in smaller spaces, such as tucked away in the back half of the show, Anritsu presented one of the most dramatic developments for the next generations of communications and automotive electronics—a signal analyzer using coaxial connectors and on-wafer probes capable of operating to 220 GHz. The analyzer was one thing, but having connections that worked from a few kilohertz to 220 GHz is a tribute to the many innovative people, such as Bill Oldfield at Wiltron/Anritsu, who have driven this industry's advances throughout the years.

But before it's time to say that the high-frequency electronics industry is devoted to supplying products for "just" 5G and automotive electronics, there were more than a few reminders about the health and strength of military and aerospace markets. Military systems designers are just as active as their commercial counterparts, with their own demands for radar, surveillance, electronic countermeasures, etc.

Perhaps the most-often word heard regarding those defense electronics markets at the 2019 IMS was "drones." Discussion surrounded how they would be used in the future, provided that smaller, lighter antennas and transceivers could be developed, including at mmWave frequencies and meeting military size, weight, and power (SWaP) requirements.

Despite the confusion (at least for a New Yorker) in traveling around Boston, it was a well-attended, upbeat IMS. With over 600 companies on the show floor, it was one of the largest-ever IMS exhibitions, and the optimism of each company's representatives was matched by visitor enthusiasm for where this industry was heading. mw



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EDITORIAL

GROUP CONTENT DIRECTOR: **KAREN FIELD** karen.field@informa.com
SENIOR CONTENT DIRECTOR: **BILL WONG** bill.wong@informa.com
EDITOR: **CHRIS DeMARTINO** chris.demartino@informa.com
SENIOR STAFF WRITER: **JAMES MORRA** james.morra@informa.com
TECHNICAL EDITOR: **JACK BROWNE** jack.browne@informa.com
ASSOCIATE EDITOR/COMMUNITY MANAGER: **ROGER ENGELKE** roger.engelke@informa.com

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@informa.com
CONTENT DESIGN SPECIALIST: **JOCELYN HARTZOG** jocelyn.hartzog@informa.com
CONTENT & DESIGN PRODUCTION MANAGER: **JULIE JANTZER-WARD** julie.jantzer-ward@informa.com

PRODUCTION

GROUP PRODUCTION MANAGER: **GREG ARAUJO** greg.araujo@informa.com
PRODUCTION MANAGER: **VICKI McCARTY** vicki.mccarty@informa.com

AUDIENCE MARKETING

USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@informa.com

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REGIONAL SALES REPRESENTATIVES:
AZ, NM, TX: **GREGORY MONTGOMERY** **T** | 480.254.5540 gregory.montgomery@informa.com

AK, NORTHERN CA, OR, WA, WESTERN CANADA: **STUART BOWEN** **T** | 425.681.4395 stuart.bowen@informa.com

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CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, EASTERN CANADA:
ELIZABETH ELDRIDGE **T** | 917.789.3012 elizabeth.eldridge@informa.com

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BELGIUM, NETHERLANDS, LUXEMBURG, UNITED KINGDOM, SCANDINAVIA, FRANCE, SPAIN, PORTUGAL:
JAMES RHOADES-BROWN **T** | +011 44 1932 564999 **M** | +011 44 1932 564998 james.rhoadesbrown@husonmedia.co.uk

ITALY: **DIEGO CASIRAGHI** diego@casiraghi-adv.com

PAN-ASIA: **HELEN LAI** **T** | 886 2-2727 7799 helen@twoway-com.com

PAN-ASIA: **CHARLES LIU** **T** | 886 2-2727 7799 liu@twoway-com.com

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mary.ralicki@informa.com

DIGITAL

GROUP DIGITAL DIRECTOR: **RYAN MALEC** ryan.malec@informa.com

DESIGN ENGINEERING & SOURCING GROUP

GROUP CONTENT DIRECTOR: **KAREN FIELD** karen.field@informa.com
VP OF MARKETING: **JACQUIE NIEMIEC** jacquie.niemiec@informa.com

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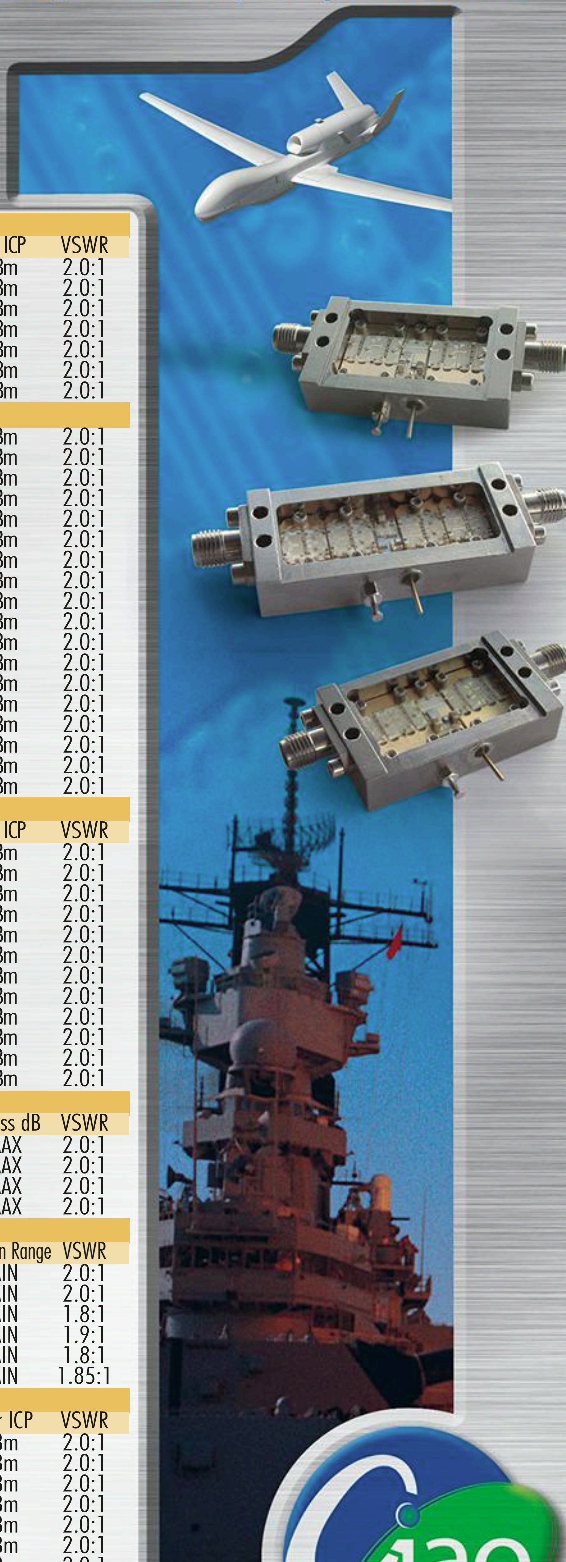

OCTAVE BAND LOW NOISE AMPLIFIERS

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

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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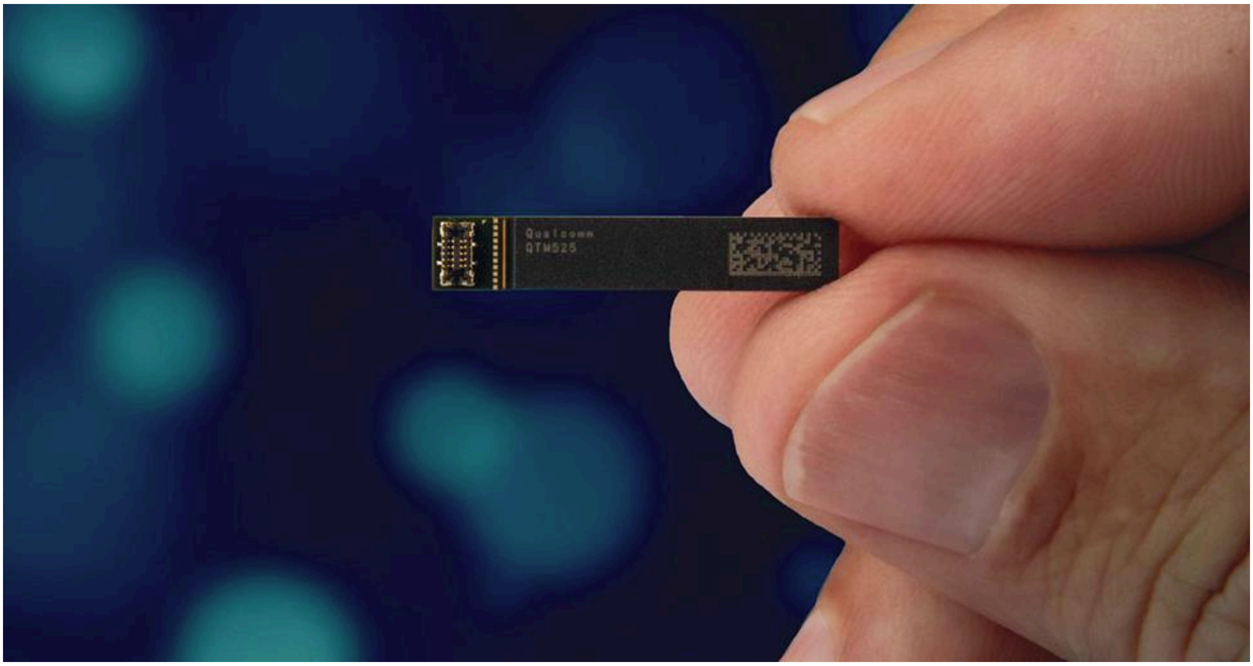
News

Qualcomm Faces Major Setback AFTER LOSING ANTITRUST CASE



Qualcomm, the largest player in the cellphone chip market, makes most of its money selling cellular modems and other components. But the company's biggest profits come from its patent licensing business. Phone manufacturers pay Qualcomm for access to its patents, which it claims covers all the fundamentals of modern cellular communications. Royalty fees depend on an end product's final sale price.

Both customers and international regulators in recent years have accused Qualcomm of unfair licensing practices, adding to the upheaval in its most profitable business. Qualcomm has never had to overhaul its business model despite a spate of legal challenges. One of its biggest triumphs came when Qualcomm resolved its legal battle with Apple, which has started paying royalties after a prolonged boycott.

But the company suffered a major setback in May that could force it to adjust its patent licensing practices. United States District Judge Lucy Koh said that the company had illegally limited competition in the modem market, siding with the Federal Trade Commission in its antitrust case against Qualcomm. She ruled that Qualcomm had leveraged its leadership to extract excessive royalties from phone makers.

She wrote in a 233-page ruling that the company's licensing practices "strangled competition" in the $20 billion baseband modem market. She said that Qualcomm had to change how its business operates. It also needs to renegotiate its existing licensing deals at more reasonable rates. Qualcomm, which holds over 40% market share, must also submit to monitoring for seven years to make sure it follows the rules.

The decision also directs the San Diego, Calif.-based company to start licensing its industry-standard patents to other chip suppliers, which it previously refused to do. Judge Koh argued that hoarding those patents made it much more difficult for other vendors to challenge Qualcomm's dominance. The verdict also forbids Qualcomm from entering exclusive licensing deals with its customers to shut out rivals.

Confronting a slowdown in the smartphone market—global shipments slumped 4% in the first quarter of 2019, according to Strategy Analytics—Qualcomm said it would attempt to delay the order and appeal the decision. "We strongly disagree with the judge's conclusions, her interpretation of the facts and her application of the law," Don Rosenberg, general counsel at Qualcomm, said in a statement.

The decision came more than two years after the Federal Trade Commission accused Qualcomm of holding a monopoly in modem chips. The agency alleged that Qualcomm supplies its modem chips only to phone manufacturers that agree to its disproportionately high royalty rates. Withholding its supply of modem chips, software and technical support makes it easier for Qualcomm to exact more favorable terms.

This requirement reduces competition and reinforces Qualcomm's monopoly power, the FTC said. Qualcomm has long been the leader in the market for modem chips, which are used to connect smartphones to wireless networks. Many of the largest phone manufacturers can't afford to lose access to Qualcomm's chips, so they agree to pay steeper prices than the patents themselves are worth, the FTC said.

This "no license, no chips" policy was at the center of the FTC's case against Qualcomm. The practice is considered a form of double-dipping, with Qualcomm charging for the same intellectual property in its patent licensing fees and in the selling price of its silicon. The FTC also argued that the the practice pushed phone manufacturers to pay Qualcomm unfairly high licensing rates for using rival modem chips.

Qualcomm has amassed a sweeping portfolio of patents central to 3G, 4G and 5G communications. Many of these technologies are part of industry standards, which is why they are referred to as standard essential patents (SEPs). As a result, phone manufacturers have to pay Qualcomm fees whether or not they're using its chips. That makes cellular modems sold by rivals much less attractive, according to the FTC.

Steve Mollenkopf, the chief executive of Qualcomm, has long argued that its patents are vital to making modern smartphones work. That's why it demands Apple and others pay royalties based on the selling price of an end product, not the modem chip inside. But some customers have complained that the device-level licensing allow it to profit off software, hardware and other technologies not covered by its patents.

The chip supplier said in 2017 that the allegations were grounded in "a flawed legal theory, a lack of economic support and significant misconceptions about the mobile technology industry." The $83-billion behemoth stressed in the same statement that it had "never withheld or threatened to withhold chip supply in order to obtain agreement to unfair or unreasonable licensing terms."

The legal dispute played out inside a San Jose, Calif. courtroom in January. Competition in the modem chip market is still cutthroat, Qualcomm argued. adding that its overall market share has slipped in recent years. Customers—including Apple, Samsung and Huawei—implement its modems because they're the best, the company argued. They transfer data faster and consuming less power than rival modems.

Judge Koh said lots of companies have pulled out of the modem chip market because Qualcomm made it too hard to win customers. The companies left have been harmed by Qualcomm's pricing practices, she said. Intel, which called out Qualcomm last year for weaving a "web of abusive patent and commercial practices," recently halted its 5G modem development. The company could not see a path to profitability.

The decision has the potential to drive up demand for modems sold by Samsung, Mediatek and other chip suppliers. Bruce Hoffman, who leads the FTC's competition department, said in a statement that it's "an important win for competition in a key segment of the economy." He added that the FTC would "remain vigilant in pursuing unilateral conduct by technology firms that harms the competitive process."

The verdict poses the latest threat to Qualcomm's business model. Qualcomm, the No.6 player in the global semiconductor industry, has clashed with antitrust authorities around the world. China ordered Qualcomm to pay $975 million in penalties in 2015, while South Korea slapped it with $850 million of fines in 2016. The European Union charged it $1.2 billion in 2018 for arranging an illegal chip supply deal with Apple.

Qualcomm has weathered other thorny legal threats. The company's accord with Apple ended a bitter legal battle over the semiconductor supplier's patent fees. As part of the deal, Apple plans to pay Qualcomm $4.5 billion to $4.7 billion for unpaid fees and other costs related to the legal hostilities, which resulted in Apple purging Qualcomm's 4G modem chips from the iPhone last year and replacing them with Intel's.

Qualcomm also agreed as part of the deal to supply modems to Apple, which could be used in future iPhones. The company's 5G modems are considered the most advanced in the world, which may have pushed Apple to make peace with Qualcomm, previously its primary modem chip supplier. Apple also agreed to a six-year licensing deal that analysts estimate will pay Qualcomm between $7 and $9 per device.

Whether Judge Koh's verdict will invalidate Qualcomm's settlement with Apple remains unclear. Qualcomm's shares had soared around 50 percent since the deal with Apple was announced in April. With the legal conflict closed, the company projects its profits to swell by $2 per share as shipments of Apple's iPhone and other devices increase. Its share price plunged 10 percent after the decision.

"To permit Qualcomm to continue to charge unreasonably high royalty rates would perpetuate its artificial surcharge on rival chips, which harms rivals, OEMs, and consumers," Judge Koh wrote. "There is sufficient likelihood that Qualcomm will hold monopoly power in the 5G modem chip market such that exclusive dealing agreements for the supply of modem chips could foreclose competition in that emerging market."

Qualcomm has started to loosen its patent licensing terms in an apparent attempt to prevent more legal conflicts. Last year, the company lowered the cap on patent royalties it charges phone manufacturers. Qualcomm set the selling price of a smartphone for the purpose of calculating its cut at $400, even if the device sold for double that. The company also agreed to prune its licensing fees for 5G technology.

If the verdict stands, Qualcomm may be forced to fundamentally change how it calculates it royalties. Licensing its industry-essential patents to rivals means Qualcomm may have to move from device-level to chip-level licensing rates. That could severely cut into its profits. The company funnels most of these profits into its research and development efforts, which has helped bolster its early lead in 5G cellular chips.

How much money Qualcomm could lose over the long run is still unclear. The company's licensing business reported $1.1 billion of revenue in the second quarter of 2019, down 8% over the last year and up 10% compared to the first quarter. Second-quarter operating profit came to $674 million. Qualcomm expects to earn $1.275 billion in patent royalties in the current quarter, down 11% from the year-ago quarter.

The decision could also face scrutiny from the Trump administration, which has long regarded Qualcomm as important to competing with China for dominance in 5G technology. Last year, the administration blocked Broadcom's proposed buyout of Qualcomm, pointing to the potential damage to American 5G leadership. 5G networks are projected to be at least 10 times faster than current 4G LTE, industry analysts say.

The Justice Department has also waded into the legal conflict, calling for the court not to impose penalties that could adversely affect the market for 5G. Around 1.395 billion phones are set to be shipped in 2019, with 5G unit shipments projected to be around 0.5% of the total, according to market researcher IDC. By 2023, 5G smartphones will represent 26% of all shipments in the 1.542-billion-unit market. ■

SoC SETS SIGHTS on 5G Smartphones

LEVERAGING THE LATEST CPU, GPU, and machine-learning (ML) hardware, MediaTek's 7-nm, FinFET 5G chipset will target high-end smartphones *(see figure)*. The platform incorporates MediaTek's Helio M70 5G modem and Arm's Cortex-A77 CPU cluster, the Arm Mali-G77 GPU, and MediaTek's AI processing unit (APU).

MediaTek's 5G modem supports 2.5-Gb/s upload and 4.7-Gb/s download speeds. Equipped with multimode support for 2G, 3G, 4G, and 5G networks, the modem can operate in standalone (SA) and non-standalone (NSA) mode networks and supports carrier aggregation. The chipset supports sub-6-GHz and 2.5-GHz bands, which could be a challenge for some carriers. The system will also have Wi-Fi and Bluetooth capability. The chip includes comprehensive power-management support with intelligent power-saving modes.

The chip is one of the first to use Arm's quad-core Cortex-A77 CPU combined with the Mali-G77 GPU. The GPU can handle 80-Mpixel cameras with HDR support, as well as 4K video encode/decode streams at 60 frames/s. The system will support the open-source, Open Portable Trusted Execution Environment (OP-TEE).

Says MediaTek President Joe Chen, "Everything about this chip is designed for the first wave of flagship 5G devices. The leading-edge technology in this chipset makes it the most powerful 5G SoC announced to date and puts MediaTek at the forefront of 5G SoC design."

The chipset will be available for sampling in Q3 of 2019, with production underway by Q1 of 2020. ■

MediaTek's latest Helio chipset incorporates the Helio M70 5G modem and ARM's Cortex-A77 CPU cluster, the ARM Mali-G77 GPU and MediaTek's AI processing unit (APU).

ANOKIWAVE APPOINTS UPTON to Chief Strategy Officer

A NEW POSITION has been created within innovative semiconductor supplier Anokiwave, that of Chief Strategy Officer (CSO). Effective as of May 2019, the position has been filled by Alastair Upton, who will report directly to the company's Chief Executive Officer (CEO), Robert Donahue.

This new position will involve the development and execution of Anokiwave's business strategy in all key markets. Anokiwave *(www.anokiwave.com)*, which is based in San Diego, Calif., has been responsible for novel millimeter-wave (mmWave) integrated circuits and active antennas for emerging telecommunications markets, including 5G.

Prior to the new position, Upton served as Senior Vice President of Business Development for Anokiwave where he was a large part of developing new 5G business opportunities as well as expanding existing telecommunications markets. He joined Anokiwave in 2018 and brings more than 35 years of experience in the semiconductor industry to the firm, covering both commercial and defense electronics markets. He will be based out of the company's Billerica, Mass. office. ■

CW RADAR TRACKS Targets Near Shore

SMALL BOATS OPERATING in littoral regions close to shore often need to perform search and track functions, using a radar with antenna masts of limited height. The low mast heights can limit the range of the radar, as does a need to maintain low-power operating in military applications for low probability of intercept (LPI).

Fortunately, a trio of researchers from the Department of Electrical and Computer Engineering of the Naval Postgraduate School (Monterey, Calif.) developed a low-power continuous-wave (CW) bistatic radar system in which transmit and receive actions take place at the same time. Part of their novel system solution was the development of an omnidirectional transmit antenna and digitally patterned receive antenna, operating continuously with simultaneous transmit and receive functions.

For operators of small marine vessels hoping to remain covert, this radar system design promises good coverage without doubling as a beacon for threat surveillance systems. It features closely spaced antenna elements to fit the antennas on a small mast. The receive antennas follow digitally controlled, overlapping receive patterns for continuous reception. Meanwhile, the transmitter uses a phase-coding technique to allow for close placement of the transmit antenna elements with the receive antenna elements without causing interference from transmitter signal leakage.

Since possible beamwidth will change with the number of antenna elements, the arrays were designed with large numbers of antenna elements. Wideband H-plane sectoral horns were used as the antenna elements for an experimental design, for both transmit and receive functions, because they can be closely spaced and suffer low signal loss compared to miniature microstrip antenna elements. The horns cover a frequency range of 18.0 to 26.5 GHz.

For ease of mast mounting, the arrays were formed in cylindrical configurations of vertical elements. Elements were switched as needed, for example, to form 90-deg. vertical azimuth receiving patterns when the antenna had a line-of-sight view of an illuminated target. Design simulations show the potential of this system for effective search and track functions for small boats close to shore, whether for commercial or military applications.

See "An Antenna for a Mast-Mounted Low Probability of Intercept Continuous Wave Radar," *IEEE Antennas & Propagation Magazine*, April 2019, pp. 63-70.

SENSING WHEN RADIO Spectrum is Available

GROWING NUMBERS OF WIRELESS DEVICES, including those in "smart" buildings and cities, are leading to crowded radio spectrum and thus the need to open new spectrum. Cognitive-radio (CR) approaches provide a way to effectively use open frequency bands by dynamic spectrum access. They detect when frequency bands are not occupied by its primary users and allow the use of those frequency bands by secondary users. Secondary users cannot interfere in any way with primary users, requiring dependable detection of signal energy within a frequency band of interest.

In pursuit of CR technology, researchers from the Electrical and Computer Engineering Department of Texas A&M University (College Station, Texas) explored the requirements of spectrum sensors for CR applications and the possible solutions for such spectrum sensors.

Spectrum sensing must provide high sensitivity and fast sensing times to avoid interference with primary users and to identify the times and locations of frequencies not used by primary communications systems. The unused spectrum is typically referred to as white space or spectrum holes; the times and locations are instrumental in guiding the transmit times for a CR system. Spectrum sensing is also useful for interference detection between different wireless communications systems.

Primary narrowband communications signals are typically transmitted at higher levels than the broadband transmissions in ultrawideband (UWB) communications systems. As a result, narrowband signals can act as interference when they fall within the frequency range of an UWB receiver. Spectrum sensing can detect the potential interference and provide a trigger for activating dynamic filtering within an UWB receiver to reject the interfering signals.

Four techniques are currently used for spectrum sensing: spectrum sweeping, compressive sweeping, dispersion frequency-time mapping, and frequency-space mapping. The approaches employ combinations of analog and digital circuitry, as fabricated in CMOS integrated circuits (ICs).

The researchers refer to many examples of how spectrum sensing is applied, such as for CRs operating within television VHF/UHF broadcast white space. Analog system implementations involve downconversion of received signals to baseband (BB) frequencies for analysis of signal activity. The four spectrum-sensing techniques each have drawbacks and benefits for different applications of CR systems, but with room for improvements that can make CR a realistic technology for efficient and cost-effective use of available frequency spectrum.

See "Spectrum Sensing," *IEEE Microwave Magazine*, June 2019, pp. 51-73.

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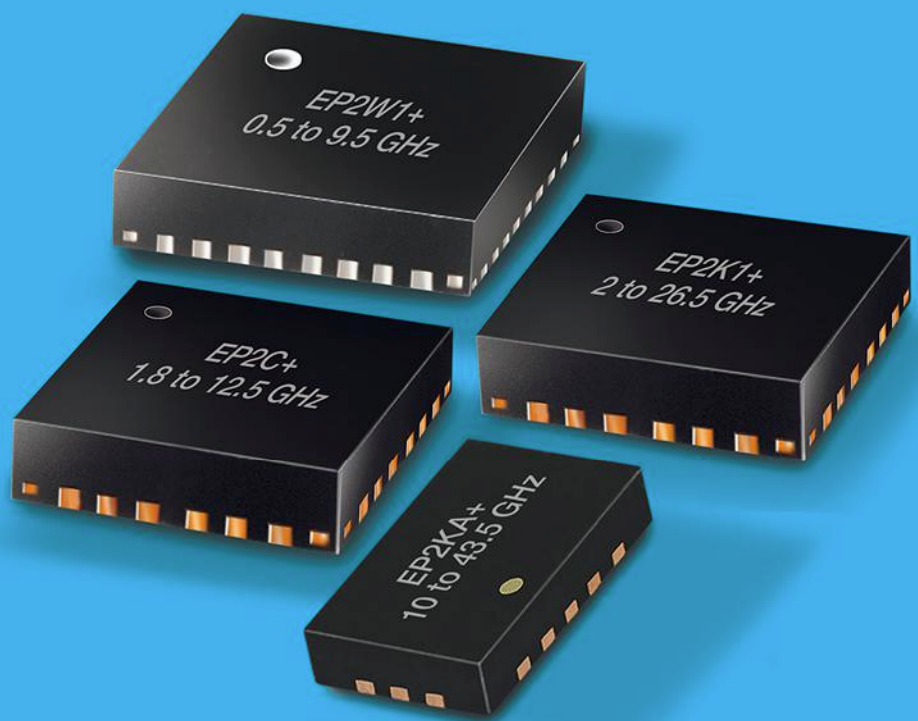

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A Modern Approach to Satcom System Design

With this model-based design platform, engineers are equipped with the tools to design and analyze systems that meet satellite-communication mission requirements.

Several challenges are associated with satellite-communication (satcom) missions, such as latency, channel loss, and moving targets like airplanes or a satellite in orbit. In the case of moving assets, the channel becomes dynamic and dependent on the mission dynamics. Capturing dynamic channel properties, such as delay, Doppler shift, fading, and noise, is critical throughout the design life cycle. This article will discuss the design and analysis of a low-earth-orbit (LEO) satellite custom wideband signal as it goes through the different stages from bits in to bits out. A series of signal impairments are added, including satellite movement dynamics (also known as kinematics).

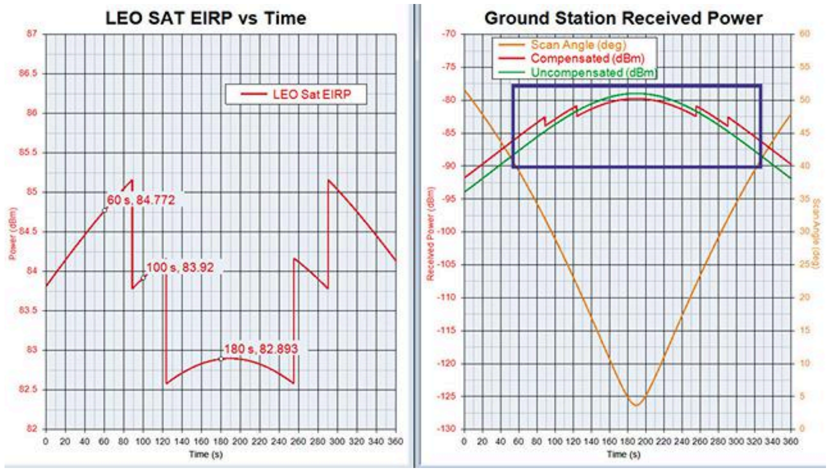
The starting point for any architect of a complex system design is understanding what will be required for mission success. Mission requirements for the satellite downlink in this study call for the following specifications:

- LEO satellite orbit at 1,200 km
- Downlink frequency of 11 GHz
- 10-dB typical carrier-to-noise and distortion ratio (CNDR); single tone. 7-dB worst case
- Error vector magnitude (EVM) < −15 dB
- Wideband signal: dual-polarized 8 sub-band OFDM
- 100-W transmit downlink output average power per sub-band
- Maximum satellite phased-array vertical scan angle of 40 degrees

The first step involves the proper design of the satellite transmitter that consists of an orthogonal-frequency-division-multiplexing (OFDM) modulator, power-amplifier (PA) assembly, and antenna phased array. The receiver design at this planning stage must meet the carrier-to-noise and distortion ratio (CNDR) requirement, which requires proper selection of the antenna configuration, low-noise amplifier (LNA), filters, and downconversion circuitry.

Assuming a worst-case vertical scan angle, the loss was estimated at 180 dB. Using Keysight's SystemVue model-based design platform, the system design was analyzed and optimized using SystemVue's Spectrasys analysis engine to meet the requirements above. The worst-case CNDR was 7.6 dB.

The satellite phased array must provide scanning to illuminate the ground stations properly as it moves across the sky. Scanning phased-array antennas have a beam-widening effect as the antenna beam scans away from boresight. This widening is compensated using antenna-element thinning. The compensation is needed to avoid interference and meet regulatory requirements.



1. This satellite 11-GHz analysis reveals compensated phased-array EIRP (left) and compares received power of compensated and uncompensated phased arrays (right).

COMPENSATED PHASED ARRAY

A uniform-rectangular-array (URA) compensated phased array was designed and analyzed. The URA consists of 54 × 54 elements that's thinned to 48 × 48 at a scan angle of 24 degrees and further thinned to 42 × 42 at an angle of 32 degrees. A SystemVue phased-array analysis was performed with an 11-GHz fixed tone. *Figure 1* reveals the results.

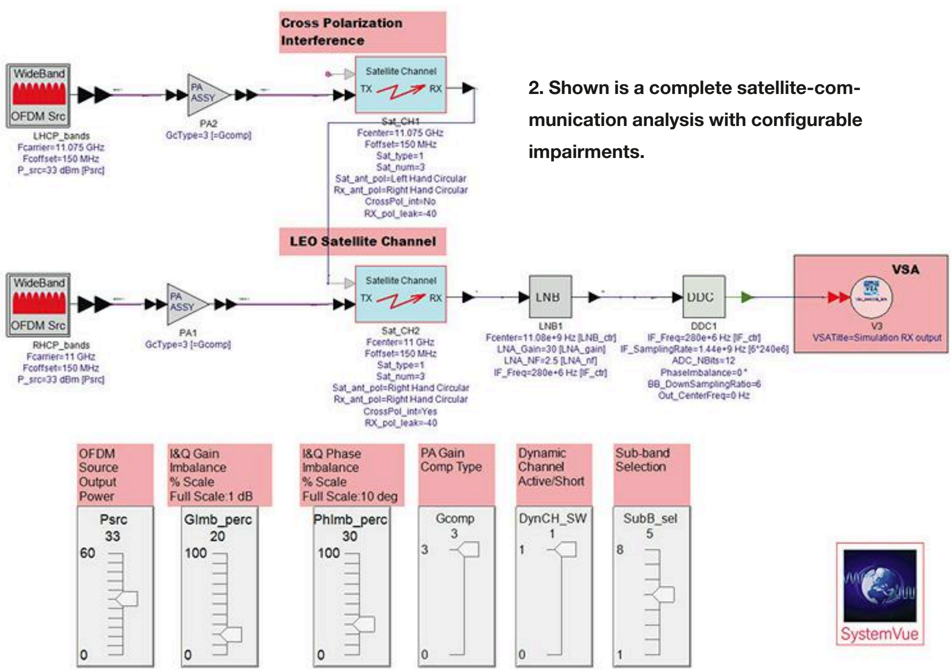
Figure 1 shows the effective isotropic radiated power (EIRP) at the LEO satellite. Notice on the left plot that the EIRP varies over time. This is due to the compensated phased-array strategy being used and the individual antenna element's beam pattern. As the LEO satellite moves across the sky, the scan angle changes relative to the area to be illuminated on the ground. This causes the antenna scan angle to change and, in turn, causes the EIRP changes.

The ground station received power is shown on the right-hand side of *Figure 1*. The green trace assumed a 42 × 42 URA. The red trace is for the compensated 54 × 54 phased array. Note the performance in terms of received power is quite different. In fact, the uncompensated array has a total variation of approximately 9 dB while the compensated array has about 6 dB of total variation. This shows the compensation technique has the added effect of keeping the received power variation to a lower range. Of course, more sophisticated array-compensation techniques are available, but are not part of this study.

SYSTEMVUE ASSEMBLY

A complete SystemVue system from bits in to bits out was assembled (*Fig. 2*). The schematic was fitted with sliders that help facilitate the study of different system parameters and impairments. In this design, the sliders control the following (from left to right):

- ***Source output power:*** Output power of the OFDM source in dBm for each sub-band.



2. Shown is a complete satellite-communication analysis with configurable impairments.

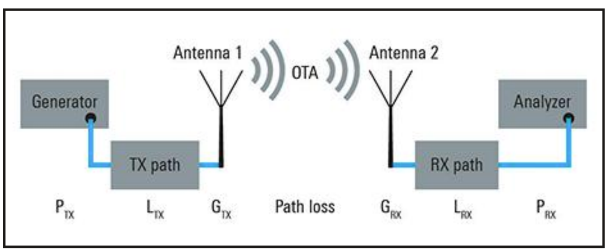
ADVERTORIAL

Master the challenges of OTA calibration

Integrating antennas to the radio frequency chipset without connectors is increasingly common with both low cost IoT devices and especially in highly integrated 5G mobile communication equipment operating at mmWave frequencies. This makes testing a device under test (DUT) over the air (OTA) mandatory. To tackle the challenges of OTA testing it is key to understand the demands of antenna measurement and chamber setup.

Calibration is an important first step in the preparation for OTA testing. The measurement results of a DUT should not be setup-depended, requiring a calibration for each measurement setup. The OTA link adds a significant amount of attenuation to the measurement setup due to the free space path loss (FSPL), in addition to the losses from cables and other connected components. Unlike with cables, a stable measurement distance and perfect mechanical alignment is crucial for OTA measurement accuracy in order to avoid differences in attenuation caused by positioning errors.

Port calibration, for example by using a network analyzer, cannot be conducted to an air interface. Therefore, another type of calibration is required. Commonly, antenna gain measurements are conducted by comparing an unknown antenna to a reference antenna. Following this principle, an antenna with known gain is required to identify the calibration information of the OTA test setup and store these calibration data either on the measurement instrument or some external software controlling the measurement setup.



The high FSPL, longer cables due to the required measurement distance as well as the use of high frequencies require excellent dynamic range from the test and measurement equipment.

To address these different challenges, to calibrate OTA test setups and to carry out OTA measurements, Rohde & Schwarz has a diverse portfolio of vector network analyzers like the R&S®ZNA, vector signal generators, such as the R&S®SMW200A and signal and spectrum analyzers such as the R&S®FSW. Rohde & Schwarz also offers complete OTA test solutions, such as the R&S®ATS1000 antenna test chamber. Combined with Rohde & Schwarz test instruments, it is the ideal environment for 5G antenna characterization throughout the entire process from R&D to production for both active and passive devices.

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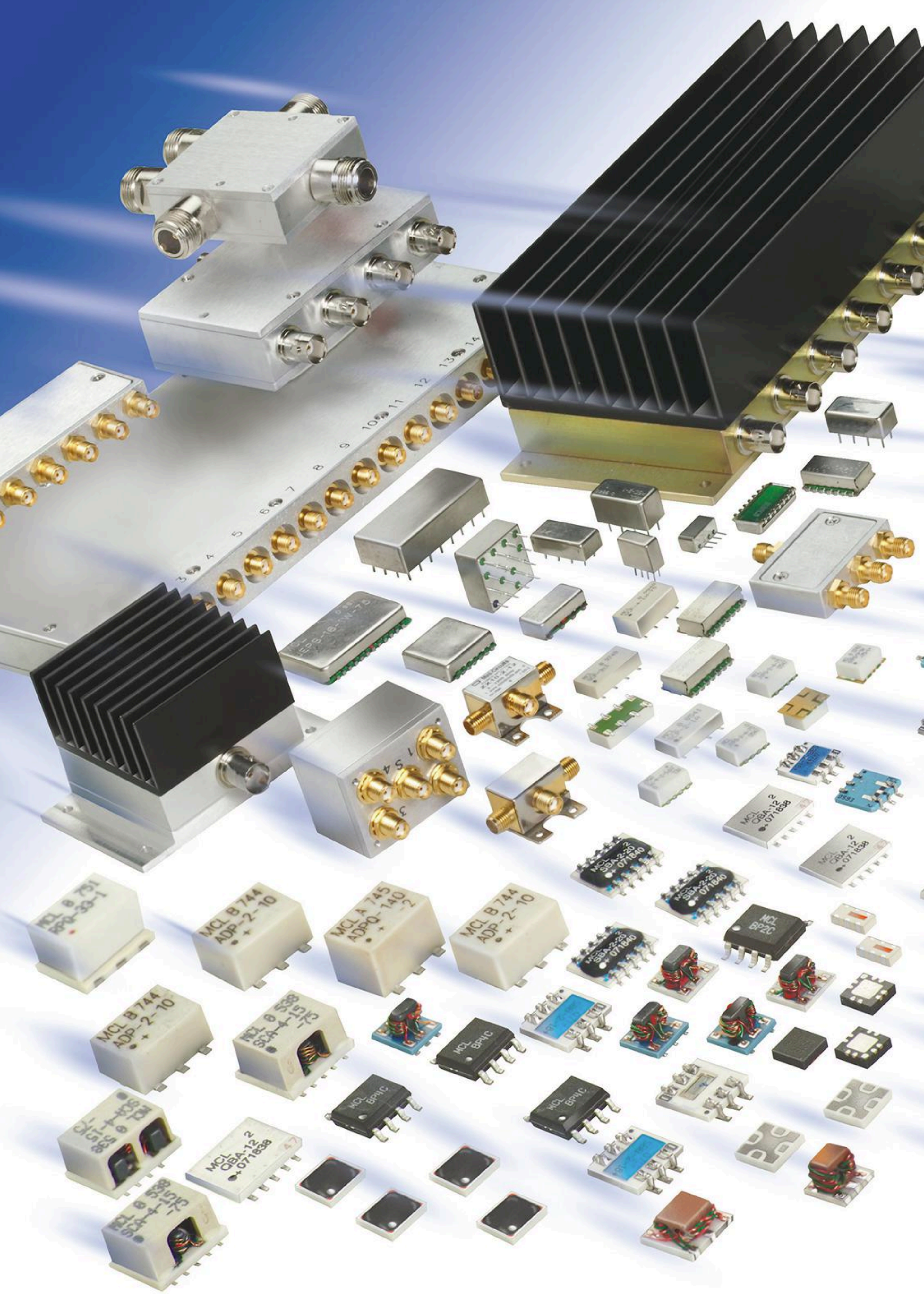
MCL B 744
ADP-2-10
MCL A 745
ADPQ-140
MCL B 538
SCA-4-15
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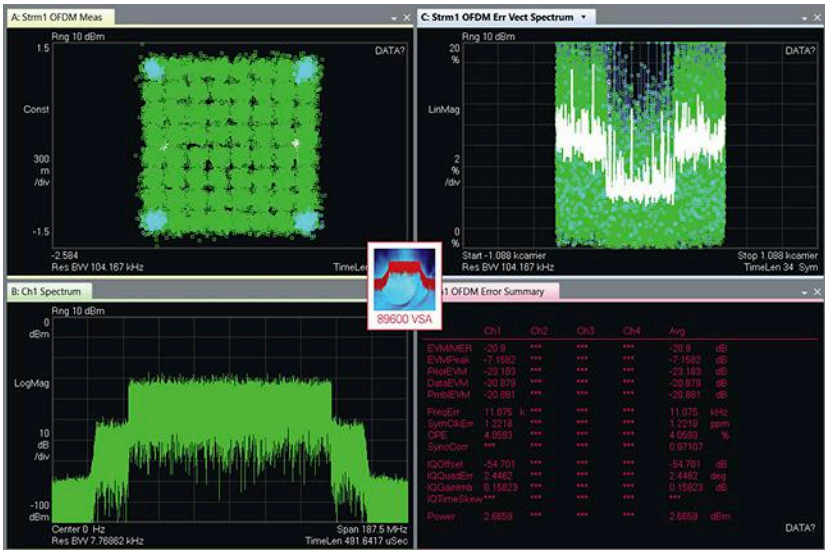
448 Rev V

- ***I/Q gain imbalance:*** I/Q modulator gain imbalance in dB. This slider allows the user to set the imbalance as a percentage of full scale. Full-scale gain imbalance is 1 dB.
- ***I/Q phase imbalance:*** I/Q modulator phase imbalance in degrees. With this slider, the user can set the imbalance as a percentage of full scale. Full-scale phase imbalance is 10 degrees.
- ***PA gain compression:*** Allows the user to vary the PA gain compression from 0 (no compression) to 3, which sets the 1-dB compression point (P1dB) to +60 dBm and the third-order intercept point (TOI) to +70.8 dBm.
- ***Dynamic channel:*** Turns on the kinematic and channel noise temperature effects for the dynamic channel formed between the satellite (transmitter) and the ground station (receiver).
- ***Sub-band selection:*** In this simulation, the right-handed circular polarization (RHCP) sub-band 5 is studied. This slider lets the user select between bands 1 (lowest frequency) to 8 (highest frequency). The low-noise block converter (LNB) will adapt to downconvert the proper sub-band based on this slider.

As part of this study with the complete modulated signal, the sliders were varied in turn. The slider activating the dynamic channel between the satellite transmitter and the ground-station receiver is varied first. These results are considered the initial benchmark for this study. The channel includes amplitude, delay, Doppler, and noise changes as the satellite moves, i.e., the channel kinematics are included.

The orbital kinematics are provided by the Systems Tool Kit (STK) software from Analytical Graphics *(www.agi.com)* and included in this analysis by the SystemVue to STK Link component. The benchmark EVM is –25.5 dB. When demodulating this signal with the Keysight vector-signal-analysis (VSA) software, there's an 11-kHz frequency error due to Doppler shift (*Fig. 3*).



3. This is the vector signal analysis of the receiver output signal.

The effect of cross polarization (i.e., part of the left-handed circular polarization, or LHCP, has been converted to RHCP) was observed. In the error vector spectrum, one can clearly see the effects of sub-bands 4 and 5 of the LHCP wideband signal affecting sub-band 5 of the RHCP (*Fig. 3, again*) at two different EVM levels. A cross polarization of –40 dB has caused a 3.3-dB (from –25.5 to –22.2 dB) degradation in EVM.

Prior analysis assumed a linear PA assembly. The nonlinearities were activated using the *Gcomp* (short for gain compression) slider for this analysis. The 1-dB compression point for each PA in the assembly is +60 dBm. An amplifier with output power of +50 dBm is more than adequate for this application, yet there's still a 0.4-dB degradation in the EVM.

The I/Q modulator model at the heart of the OFDM signal can add I/Q gain and phase imbalance. This analysis was completed adding 0.2 dB of gain imbalance and 3 degrees of phase imbalance at the I/Q modulators. The results show further degradation in EVM from –21.8 dB to –20.9 dB. Also, observe the VSA *IQQuadErr* for phase error and *IQGainImb* for gain imbalance, which closely track the values introduced at the modulator.

CONCLUSION

Insights gained from simulations can greatly reduce time and uncertainty during the build and deployment of a satellite. Today's simulations combine high-fidelity system modeling that closely predicts the performance of the system design before it's deployed. The insight provided by this model-based design platform allows system architects and design engineers to test and validate their designs before launch and ensure a successful mission deployment. mw

WILFREDO RIVAS-TORRES, Ph.D., has worked in wireless and aerospace/defense industries for over 30 years. He has experience with both circuit- and system-level design. Wilfredo holds a Ph.D. in electrical engineering from Florida Atlantic University. Currently, he is an aerospace/defense application engineering scientist at Keysight Technologies. At Keysight, Wilfredo supports space and defense customers with their system design, analysis, and simulations, and their connection with Keysight instrumentation.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First to 5G: Who Will Win?

While carriers are scrambling to be first in the 5G race, determining a clear winner is no simple matter.

The global sprint to be first to 5G continues—from first country to first smartphone to first carrier. In the U.S., while all major carriers make announcements, two of them stand out: Verizon and Sprint. Verizon has already pushed 5G live in parts of Chicago and Minneapolis and announced that 20 cities will have service by the end of the year using a 28-GHz network—part of the millimeter-wave (mmWave) spectrum. It will deliver extreme speeds to users in the cities where available, but, of course, only for those who have a device that can take advantage through a built-in 5G modem, or in some cases, an attachment.

Sprint, on the other hand, announced that 5G is live in nine of its biggest markets. The company is in a unique position compared to other carriers because of the spectrum it has: 120 MHz of bandwidth at 2.5 GHz. Sprint is the only U.S. operator with enough bandwidth for 5G NR and LTE at the same frequency, but it has made no public announcements regarding leveraging mmWave spectrum to date. Instead, the company has taken a different approach, focusing on deploying base stations that leverage multiple-input, multiple-output (MIMO).

So, who will win in the race to be first? Unfortunately, a clear "winner" is not that simple given that 5G involves two sides of the same coin.

The majority of deployments in the next two years will be for sub-6 GHz.

(Image is Courtesy of National Instruments)

While there's still significant interest in mmWave, its development and testing are extremely difficult. There are many reasons for those difficulties, but most notably:

- **Non-line-of-sight scenarios:** Carrier executives have admitted that mmWave isn't suitable for widespread coverage due to the fact that these waves struggle to penetrate materials and can be absorbed by foliage and rain. This shortcoming will be overcome with small-cell technology, but that pushes the timing out even further.
- **Power consumption:** The power required to transmit mmWave even 200 meters eats up massive amounts of energy. Earlier this year at Mobile World Congress, Zhengmao Li, an executive vice president at China Mobile, shared that the power consumption of a 5G base station is three times that of its 4G LTE predecessor. This means costs will be three times as much, too—not insignificant for a carrier's bottom line.
- **Manufacturability:** According to a survey from intelligent supply-chain provider JABIL, about one third of respondents said the 5G equipment currently available did not fit their needs. Another 44% said they lacked the tools for testing and managing 5G. So, while the eagerness is apparent, there's still a disconnect between the grand vision and what's currently available to fully build out mmWave infrastructure.

The progress made in the last five years for mmWave is significant, and it will continue to progress. However, this technology is not at the same maturity level as sub-6 GHz. Even after all evaluating of the aforementioned technological challenges, the economics of mmWave may prove to be a challenge too costly to overcome.

So, what does "5G" mean for consumers who want to be early adopters? While all carriers will be rolling out 5G, the features and functionality available will vary from carrier to carrier for at least the next two to five years. It's important to remember that the deployment process is still in the preliminary stages. It took years for LTE to be deployed, and one can argue that even today it's still not fully deployed—and it's unlikely the timeline for 5G will be any faster.

SO, WHAT'S NEXT?

While initial deployments of 5G are an important milestone, 5G is about much more than making incremental improvements to streaming speeds and capacity. 5G has promised to revolutionize wireless communications and revolutionize the world. What makes 5G different from the previous four generations is its focus on latency, device density, and enabling deep verticals on top of 5G.

The line between deep verticals for 5G and 6G technology can be fuzzy. Some of the latest application trends in wireless communications research include vehicle to everything (V2X), augmented and virtual reality (AR/VR), machine learning/artificial intelligence (ML/AI), non-terrestrial networks, and terahertz frequencies. Terahertz frequencies for communications and sensing are still in their infancy and clearly a 6G technology, while the others could be argued either way.

V2X and AR/VR have been closely linked to 5G, and the key performance indicators (KPIs) written into the 5G spec can address these applications well. Addressing ultra-reliable low-latency communications (URLLC) is advancing in the 3GPP standardization processes, as well as V2X and non-terrestrial networks. Whether they will be completed in release 16 or pushed to release 17 and beyond will depend on the progress that's made.

Outside of the standards, work is being done to determine how to slice networks to deliver specific KPIs to specific applications in an on-demand fashion. In addition, research into edge cloud computing is being done to address URLLC needs.

This is an exciting year for 5G as consumers are just starting to take advantage, but it's just the beginning of being able to realize and harness 5G's potential. When LTE was first being deployed, no one could imagine how the services it enabled, such as Uber, would change our world forever. It's exciting to speculate about how 5G is going to change the world and even more thrilling to watch as it starts to unfold. mw

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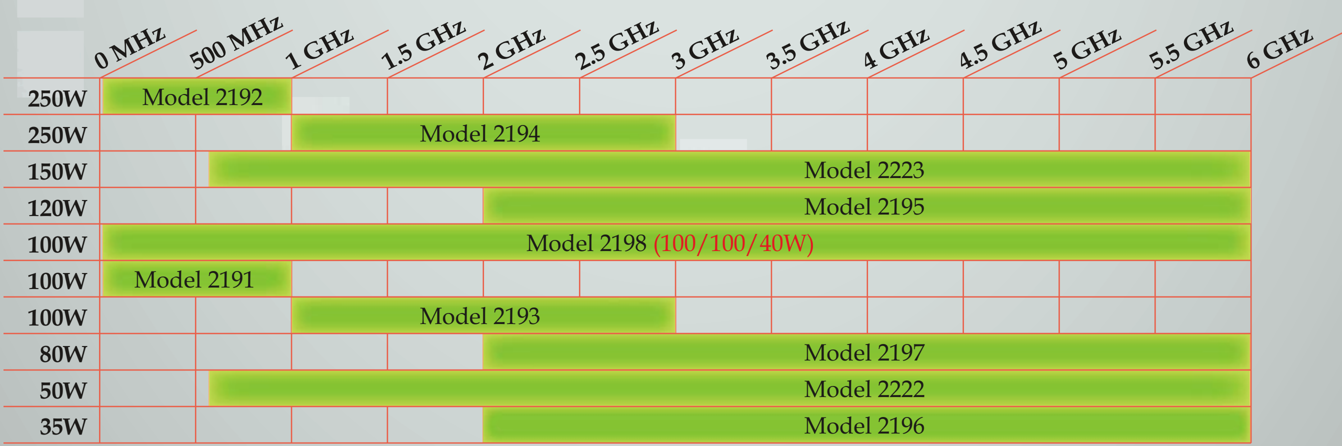

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BAOQUAN HU and CHANGZHONG CHEN | Shaanxi Aircraft Industry (Group) Co., Ltd., Hanzhong Shaanxi, China

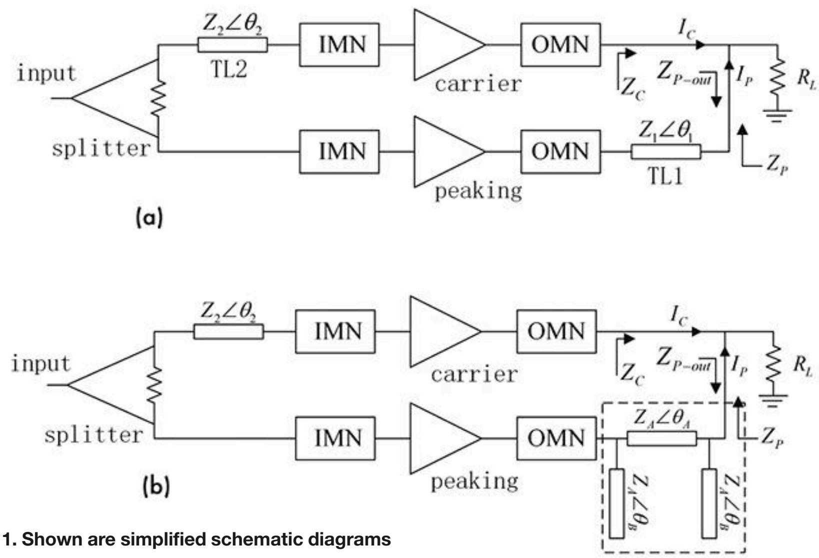
Doherty PAs Go Broadband Using Impedance Adjustment Network

Employing an output impedance adjustment topology in the peaking stage, a Doherty power amplifier that covers a frequency range of 1.4 to 2.6 GHz is designed and fabricated.

Skyrocketing demand for high data throughput in modern wireless communication systems is leading to the use of high peak-to-average-power-ratio (PAPR) signals. This situation poses a challenge to RF power-amplifier (PA) designs for future mobile communication systems. The Doherty PA (DPA) has been widely adopted in base-station infrastructure due to its excellent ability to maintain high efficiency over an extended power range.[1] As a result, DPA bandwidth has become a research hotspot.

In recent years, many efforts have taken place to expand the bandwidth of the DPA. Ref. 2 presents a new configuration for designing broadband DPAs that involves employing a post-matching network and low-order impedance inverters. Furthermore, a novel combiner represents a non-negligible method for implementing broadband DPAs.[3, 4] In Ref. 3, it was shown that adding a shunt LC tank at the drain of the peaking transistor improved the DPA's bandwidth.

Similarly, in Ref. 4, the LC was replaced with a shunt short-circuited quarter-wavelength line to form a new combined network. The novel broadband DPA based on the continuous-mode technique was proposed in Ref. 5, which focused on manipulating harmonic components in a DPA structure to achieve improved bandwidth and efficiency.



1. Shown are simplified schematic diagrams of a conventional DPA (a) and the proposed DPA (b).

From a theoretical point of view, it's important that the output impedance of the peaking PA is infinite, which holds true in the references mentioned. However, it's difficult for the offset line to provide large output impedances for a broadband design. A broadband continuous-mode DPA that was realized through the non-infinite output impedances of the peaking stage broke the previous assumption of peaking output impedances.[6]

After analyzing the influence of the peaking output impedances of the DPA in wideband operation, this article proposes a novel output impedance adjustment topology of the peaking stage for the DPA. A high-impedance, π-type transmission-line network replaces part of the offset line of the peaking PA to adjust the output impedance value and distribution range, improving the DPA performance at the output power back-off (OPBO) level. At the same time, the impedance-matching requirement is still satisfied.

PROPOSED DPA ARCHITECTURE

Figure 1a shows the structure of a conventional DPA. The carrier amplifier operates in Class-AB mode, while the peaking amplifier is biased in Class-C mode. I_C and I_P are the output currents of the carrier and peaking branches, respectively. Based on active-load modulation, $I_P = \gamma I_C$ at saturation and $I_P = 0$ at OPBO, which means the corresponding modulated impedances of carrier and peaking stages, Z_C and Z_P, at OPBO and saturation (Sat) are:

$$Z_C = \begin{cases} (1+\gamma)R_L, & @Sat \\ R_L, & @OPBO \end{cases} \quad (1)$$

$$Z_P = \begin{cases} (1+1/\gamma)R_L, & @Sat \\ \infty, & @OPBO \end{cases} \quad (2)$$

R_L is the load of the DPA, which is considered to be 25 Ω in this design. The characteristic impedance and electrical length of TL1 are $(1 + 1/\gamma)R_L$ and θ_1, respectively. TL1 is tuned so that the output impedance of the peaking PA is infinite. TL2 with an electrical length of θ_2 balances the phase difference between the carrier and peaking branches.

It's assumed that the peaking stage has no effect on the carrier PA due to the off-state ideally being at the OPBO level. However, it's difficult to guarantee that the output impedance of the peaking PA (Z_{P-out}) will be infinite across a wide bandwidth. We specify the Z_{P-out} as:

$$Z_{P-out} = R_{PO} + j \cdot X_{PO} \quad (3)$$

Normally, the real part of Z_{P-out} is too small to be ignored. In Ref. 7, theoretical analysis demonstrates that DPAs require different output impedances of the peaking stage to attain superior performance at different normalized frequencies. However, there's limited bandwidth (50%) to obtain the maximum output power at the corresponding normalized frequency.

In fact, as the $|X_{PO}|$ becomes smaller as the normalized frequency moves further away from the center frequency in a wider bandwidth range, more power leakage is produced at OPBO. That, in turn, degrades the 6-dB back-off drain efficiency until the point of ineffectiveness is reached. This is an important factor that limits the bandwidth of the DPA.

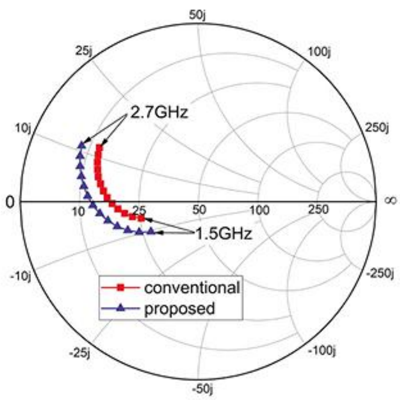
Thus, it's necessary to make the output impedances as close to infinite as possible to reduce the impact on the carrier PA in the broadband range. It also means that the distribution range of the output impedances of the peaking PA is minimized with the center frequency located at infinity, which must be compromised with the pursuit of maximum output power.

A novel output impedance adjustment topology of the peaking PA is therefore proposed *(Fig. 1b)* along with the simplified schematic diagram of the entire DPA. Specifically, a high-impedance π-type network replaces part of the output phase-shift line of the peaking PA found in a conventional DPA structure. The middle high-impedance transmission line is used to reduce the distribution range of output impedances over frequency. The open transmission lines play a role in adjusting the output matching network. It's verified by simulation that the output impedance matching effect of the peaking PA is acceptable.

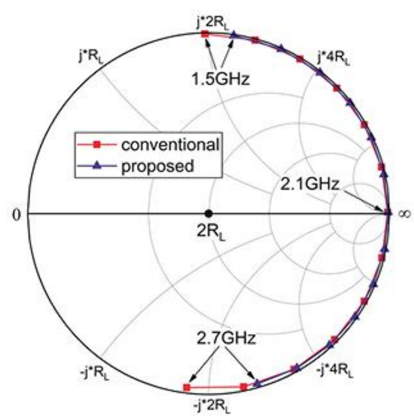
This structure is simple and does not add difficulty to the DPA design. Here, the characteristic impedance Z_A in the proposed network is 85 Ω. The electrical lengths, θ_A and θ_B, are adjusted according to the output matching network (OMN) and the design frequency band. In this design, θ_A and θ_B are 12.5° and 22°, respectively.

To achieve the desired behavior in the proposed design, the OMN of the peaking amplifier must be properly designed. For the frequency range of 1.5 to 2.7 GHz, the range of the optimal load impedances at the device package plane of the amplifier can be obtained via load-pull simulations.

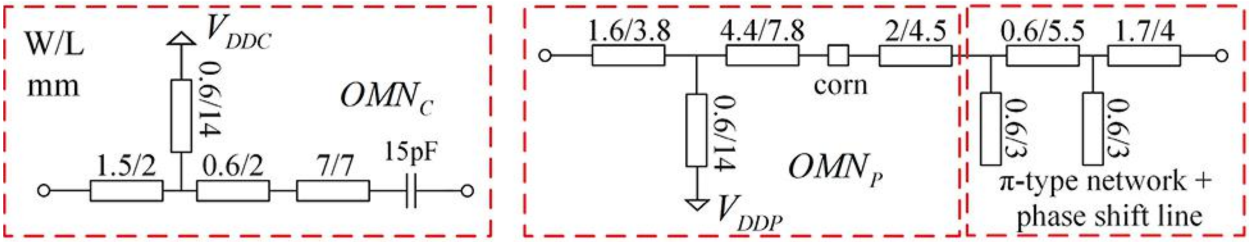
Fully considering the influence of peaking matching impedances on power and efficiency, a broadband OMN of the peaking PA was designed. This broadband OMN also acts as the peaking OMN of the conventional DPA. The simulated peaking matching impedances of the conventional DPA are plotted in *Figure 2.* An offset line should be added to the peaking inverter, providing large output impedances for a broadband design. γ = 1 is determined simply. Obviously, the characteristic impedance of the offset line is suggested to be set as $2R_L$.



2. The Smith chart plots the simulated peaking matching impedances of the conventional DPA and proposed DPA.



3. Here, the distribution of the output impedances of the conventional peaking PA and the proposed peaking PA is shown across the entire band of interest.



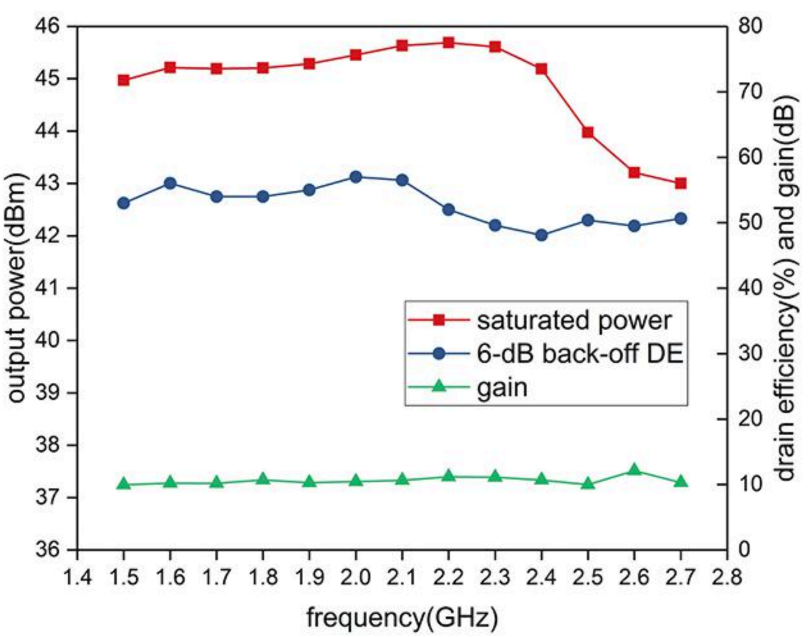
4. These are the output matching circuits of the proposed DPA.

After completing the design of the entire conventional DPA, the proposed DPA was obtained by replacing part of the offset line of the peaking stage with the high-impedance π-type network mentioned. The length of the phase compensation line can be adjusted if necessary. The rest of the DPA remains intact.

As noted, *Figure 2* plotted the simulated peaking matching impedances of the proposed DPA. A simple conclusion, as can be drawn from the simulation experience, is that the distribution range of output impedances of the peaking stage is smaller when the trajectory of peaking matching impedances is closer to the left edge of the Smith chart. It's also verified by comparing the two tracks in *Figures 2* and *3*.

To verify the distribution change of the peaking output impedances and facilitate comparison, *Figure 3* indicates that the output impedance regions of the conventional peaking PA and proposed peaking PA across the entire band of interest are distributed clockwise on the edge of the Smith chart along with the increase in frequency when the center frequency is at infinity. The reference impedance of the Smith chart is set to $2R_L$.

A comparison of the two impedance lines reveals that the new structure reduces the variation range of the off-state output impedances. On the other hand, this also means that DPAs can be designed over a wider frequency range due to reducing the restriction of peaking output impedance.



5. Plotted are the simulated saturated power levels, 6-dB back-off drain efficiencies, and gain.

One area of concern is how the changes in peaking matching impedances will impact DPA bandwidth and performance. Fortunately, by comparing the performance of the two DPAs described, one can see that the output power and efficiency of the proposed DPA are improved at the upper and lower frequency points of the target bandwidth. That is, under the same index, the proposed DPA can be obtained with a wider bandwidth. The method described in this article does not affect the initial DPA design—and it's convenient to implement.

SIMULATION AND MEASUREMENT

For verification, the DPA prototype was implemented using two CGH40010F 10-W gallium-nitride (GaN) high-electron-mobility transistors (HEMTs) from Wolfspeed *(www.wolfspeed.com)* within the targeted frequency band of 1.5 to 2.7 GHz. Taconic's *(www.4taconic.com)* RF-35 substrate used in this design had a dielectric constant of 3.5, a conductor thickness of 35 µm, and a substrate thickness of 0.76 mm. A 3-dB Wilkinson power divider was employed to evenly split the input power.

For Class-AB operation, the bias conditions of the carrier amplifier were V_{GC} = −2.8 V and V_{DDC} = +28 V. For Class-C operation of the peaking amplifier, the bias conditions were V_{GP} = −5.6 V and V_{DDP} = +30 V.

The input matching networks were designed by using the stepped-impedance matching network to cover the required bandwidth. *Figure 4* shows the microstrip dimensions of the output

Ref.	Freq. (GHz)	FBW (%)	P_{out} (dBm)	η_{6db} (%)	η_{Sat} (%)
2015[2]	1.7-2.6	41.9	44.6-46.3	47-57	57-66
2016[4]	1.5-2.5	50	42-44.5	42-53	55-75
2017[7]	1.65-2.7	48.3	43.1-45.2	41-59.6	55.8-72.2
This work	1.4-2.6	60	42.7-45.6	44-51	54-74.5

This is a comparison between various references and the work presented in this article.

The *table* (shown here) compares the performance of this proposed DPA and the other broadband DPA.

matching circuits. Simulations were performed using Keysight's *(www.keysight.com)* Advanced Design System (ADS) with the device model provided by the vendor. The carrier output matching network was designed with consideration of both the saturation and low-power region. To realize the impedance matching from 50 to 25 Ω in the target band, a fourth-order stepped-impedance matching network was used as the post-matching network.

Figure 5 reveals the simulated performances of the broadband DPA. It's clear that the 6-dB back-off drain efficiency is better than 48.1%, while the saturated output power is greater than +43 dBm. Furthermore, the gain is greater than 10 dB.

Figure 6 (page 44) shows a photograph of the final PA. To assess the performance of the fabricated DPA, gain and efficiency versus output power at different frequencies were measured under continuous-wave (CW) operation *(Fig. 7,* page 45*)*.

Due to fabrication errors and the inaccurate capacitor and transistor models, the measurement results have a slight frequency offset in comparison to the simulation design. The measured drain efficiencies from 1.4 to 2.6 GHz are better than 44% and 54% at 6-dB OPBO and the maximum power levels, respectively. The saturated power is greater than +42.7 dBm with a peak of +45.6 dBm. In addition, greater than 8.6 dB of gain is achieved. The *table* compares the performance of this proposed DPA and the other broadband DPA.

A DPA topology with a novel output impedance adjustment network of the peaking stage is proposed in this article. This development can enhance performance by reducing the distribution range of the output impedances of the peaking stage in a broadband scenario.

CONCLUSION

A DPA topology with a novel output impedance adjustment network of the peaking stage is proposed in this article. This development can enhance performance by reducing the distribution range of the output impedances of the peaking stage in a broadband scenario. A DPA based on the proposed configuration was fabricated. An overall fractional bandwidth of 60% (1.4 to 2.6 GHz) was achieved with a drain efficiency greater than 44% at 6-dB back-off power. mw

ACKNOWLEDGMENTS

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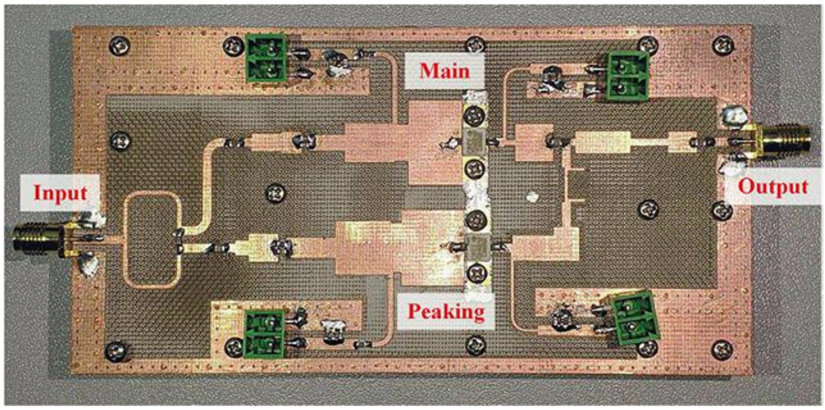
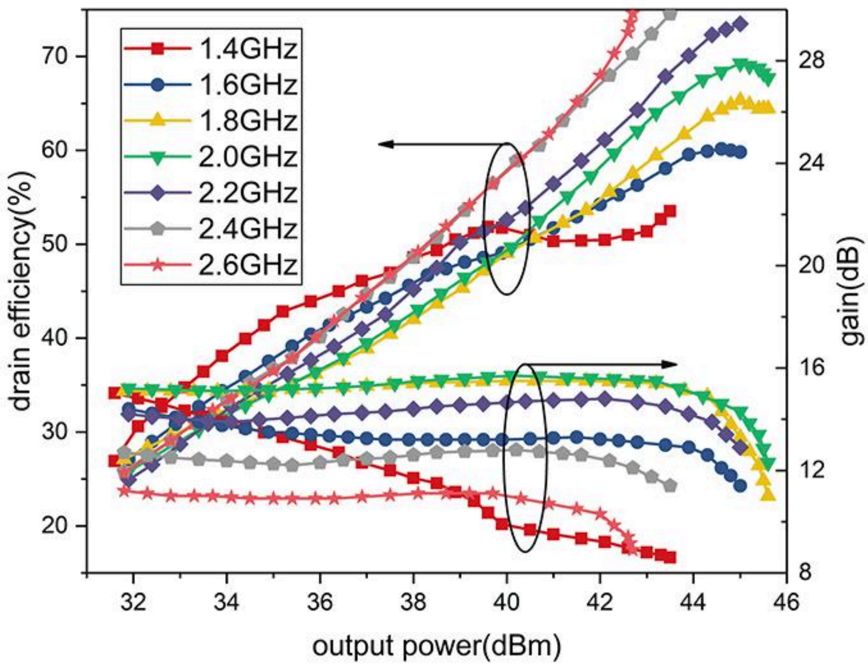


6. This is a photograph of the fabricated DPA.



7. The measured drain efficiencies and gain of the fabricated DPA versus output power are revealed at various frequencies.

REFERENCES

1. Cripps, S. C.: *RF power amplifiers for wireless communications,* Artech House, Norwood, MA, 2006, 2nd ed.
2. Pang, J., He, S., Huang, C., Dai, Z., Peng, J., and You, F.: "A post-matching Doherty power amplifier employing low-order impedance inverters for broadband applications," *IEEE Microw. Theory Tech.*, 2015, 63, (12), pp. 4061-4071, doi: 10.1109/TMTT.2015.2495201.
3. Abadi, M. N. A., Golestaneh, H., Sarbishaei, H., and Boumaiza, S.: "An extended bandwidth Doherty power amplifier using a novel output combiner," *IEEE MTT-S Int. Dig.*, Tampa, FL, June 2014, pp. 1-4., doi: 10.1109/MWSYM.2014.6848510.
4. Chen, S., Wang, G., Cheng, Z., and Xue, Q.: "A bandwidth enhanced Doherty power amplifier with a compact output combiner," *IEEE Microw. Wirel. Compon. Lett.,* 2016, 26, (6), pp. 434-436, doi: 10.1109/LMWC.2016.2558108.
5. Chen, X., Chen, W., Ghannouchi, F. M., Feng, Z., and Liu, Y.: "A broadband Doherty power amplifier based on continuous-mode technology," *IEEE Trans. Microw. Theory Tech.*, 2016, 64, (12), pp. 4505-4517, doi: 10.1109/TMTT.2016.2623705.
6. Shi, W., He, S., Zhu, X., Song, B., Zhu, Z., Naah, G., and Zhang, M.: "Broadband continuous-mode Doherty power amplifiers with noninfinity peaking impedance," *IEEE Trans. Microw. Theory Tech.*, 2018, 66, (2), pp. 1034-1046, doi: 10.1109/TMTT.2017.2749224.
7. Shi, W., He, S., You, F., Xie, H., Naah, G., Liu, Q. A., and Li, Q.: "The influence of the output impedances of peaking power amplifier on broadband Doherty amplifiers," *IEEE Trans. Microw. Theory Tech.*, 2017, 65, (8), pp. 3002-3013, doi: 10.1109/TMTT.2017.2673822.

SRI SRIDHARAN | Product Marketing, Skyworks Solutions Inc.
www.skyworksinc.com

The IoT's Future Banks on LTE Connectivity

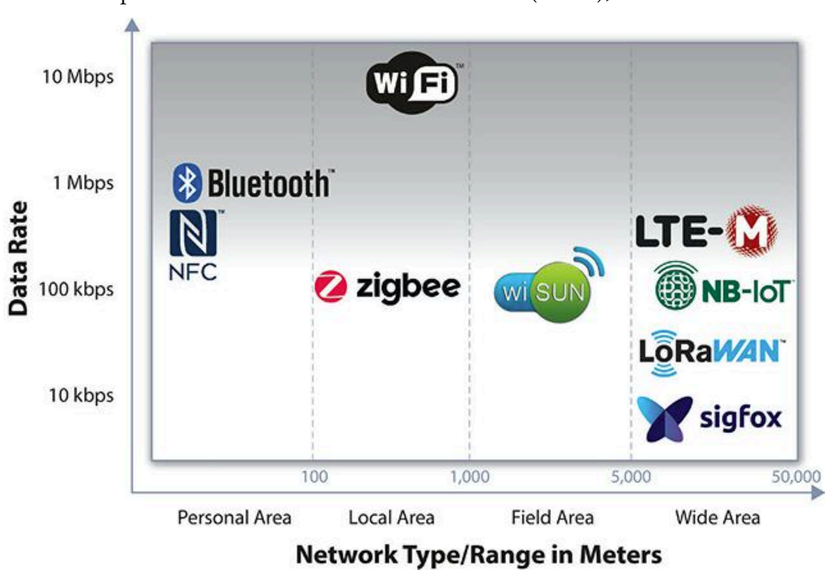
LTE technology has what it takes to address Internet of Things applications across the board, ranging from gaming and mobile computing to smart metering and asset tracking.

Thanks to the wide range of wireless connectivity technologies available today, consumers and enterprises are able to acquire data that can provide a host of marketing, operational, and design insights. Research firm IDC estimates global commerce for the Internet of Things (IoT) will surpass $1 trillion by 2022, spread across consumer, enterprise, healthcare, and industrial applications. As the promise of a wirelessly connected world becomes a reality, there's a growing need for LTE technologies that address low cost, long battery life, security, and reduced complexity—all critical components for the IoT.

CONNECTIVITY OPTIONS FOR IoT DEVICES

Massive growth has turned the IoT into a fragmented market with a diverse set of applications and use cases. Whether indoor or outdoor, fixed or mobile, low or high data rate, there are wide ranging and often differing requirements. To address this fragmentation, IoT device manufacturers are utilizing a broad spectrum of networking protocols in both licensed and unlicensed bands.

Wi-Fi and Bluetooth have been the most popular standards for personal area networks (PANs) and local area networks (LANs), with newcomers like LoRaWAN and WiSUN gaining traction for field area networks (FANs) and wide area networks (WANs) (*Fig. 1*). While these protocols offer various features and benefits, each has tradeoffs in power consumption, coverage, and cost. In this article, we focus on the licensed bands for low-power wide area networks (LPWAN) networks, and in particular, LTE connections for IoT.



1. A range of wireless connectivity protocols target different networks.

BENEFITS OF LTE FOR IoT

Since many IoT devices are sold and used globally, a key requirement is having a secure connection to the internet—anytime, anywhere. To ensure this safe, ubiquitous connectivity, devices may require a cellular connection—whether via 4G LTE, or even legacy 2G or 3G standards. A cellular connection guarantees a level of quality and reliability that cannot be achieved with other technologies.

Developed by 3GPP and built on GSM and UMTS technologies, LTE has become the de facto cellular communication standard. LTE network deployments are extensive, and the technology offers multiple user-equipment categories with varying data rates, performance, and cost. This flexibility enables LTE to address the full spectrum of IoT applications, from high-bandwidth, high-data-rate applications such as gaming and mobile computing, to low-power, low-data-rate applications like smart metering and asset tracking. With the onset of 5G, IoT devices utilizing LTE technology today will need to be forward-compatible with the next-generation standard.

The majority of IoT devices are expected to find homes in low-data-rate applications, which is where LTE's value starts to emerge. Frequently referred to as Mobile-IoT (M-IoT), this includes LTE for machines (LTE-M) and narrowband-IoT (NB-IoT) (*Fig. 2*). These technologies are being deployed on existing LTE networks, with NB-IoT deployments occurring in-band or within the guard bands between higher-category LTE carriers. M-IoT supports data rates below 1 Mb/s and as low as 30 kb/s, offering IoT device makers the flexibility to address both voice- and data-centric applications.

Designers have embraced M-IoT connectivity in their products for a number of reasons. It's ideal for any application requiring secure, real-time device-to-cloud connectivity that can be used for remote monitoring, control, and management. M-IoT enables LPWAN connectivity not only for well-known consumer devices like pet trackers and smartwatches, but also for industrial applications like oil and gas metering, machine monitoring, and factory warehousing. It's also being widely deployed, with more than 100 LTE-M/NB-IoT networks announced or launched as of May 2019, according to the GSMA.[1]

LTE-M and NB-IoT feature an improved power-consumption profile, partly because they work in half-duplex mode, taking turns sending and receiving data instead of simultaneously doing both. The standards also support power-saving modes as a core feature of how the network and device communicate. As such, these technologies are extremely attractive for battery-powered IoT devices.

In addition to the power savings, using half-duplex architecture reduces the complexity and cost of the front end, which is critical for "billions" of connections. To complement LTE-M and NB-IoT, LTE Cat-1 is beneficial for voice-based IoT applications like alarm panels and ATM machines, as well as for music streaming through wearable devices that require higher data rates and lower latency.

Another key benefit of LTE for end users is a more seamless connection experience—no need for passwords or pairing. An LTE-enabled IoT device is always connected to a cellular network and can be remotely provisioned as needed.

The security of LTE provides another differentiator. LTE devices utilize an embedded SIM to identify the device on a network in which the network utilizes multiple authentication and encryption schemes. In addition, quality-of-service (QoS) controls provided by the network ensure the best encrypted data handling and lowest traffic latency possible.

	LTE-Cat-1	LTE-Cat-M1*	LTE-Cat-NB1	LTE-Cat-NB2
3GPP Release	Rel-9	Rel-13	Rel-13	Rel-14
Peak Data Rate	DL: 10 Mb/s UL: 5 Mb/s	DL: 300 kb/s UL: 375 kb/s	DL: 27 kb/s UL: 63 kb/s	DL: 120 kb/s UL: 170 kb/s
Bandwidth	20 MHz	1.4 MHz	180 kHz	180 kHz
Typical Duplex Mode	Full Duplex FDD	Half-Duplex FDD	Half-Duplex FDD	Half-Duplex FDD
Typical Ouput Power	23dBm	23dBm	20dBm	20dBm
Network Deployment	In-band	In-band	In-band Guardband Standalone	In-band Guardband Standalone

**3GPP Rel-14 increases peak DL/UL data rates to 600 kbps / 1 Mpbs*

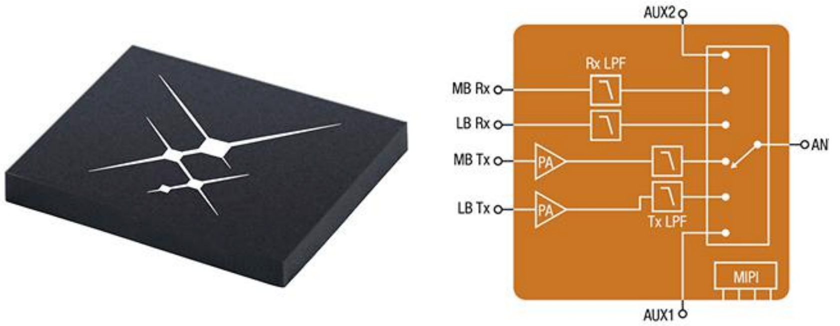
2. This table compares different forms of LTE technology.

DESIGN CONSIDERATIONS FOR ADDING LTE CONNECTIVITY

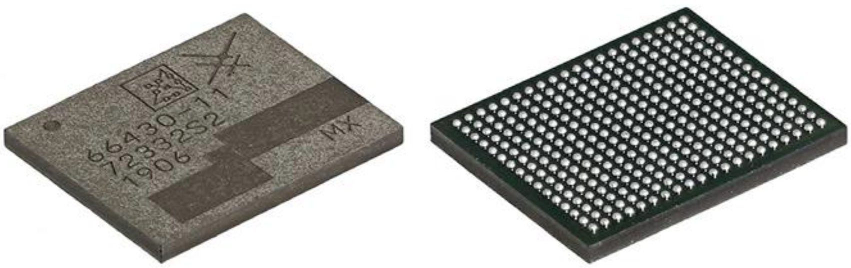
Product designers should address some important considerations up front when incorporating LTE. First, it's imperative to know where the device will operate—if it's a global or a regional SKU. The required band coverage will determine the amount of gain and filtering that will be needed, as well as the network-operator performance requirements.

Other key considerations include the required data rate for the device, whether it will support voice commands, or if it will need to maintain backward compatibility with legacy 2G/3G networks. These factors determine which cellular modem platform can be used: LTE Cat-1, LTE-M, NB-IoT, or 2G/3G. The battery choice also greatly impacts how connectivity is implemented. If a direct battery connection is required without the use of a regulator (either internal to the cellular modem platform or external), the RF front end needs to operate over a wide supply voltage range. Therefore, voltage range and current consumption become key factors in power-amplifier (PA) selection.

Further, LTE device certification can be lengthy and time-consuming. Devices need to pass network operator certification (Verizon, AT&T, etc.), 3GPP standards (Global Certification Forum-GCF), as well as industry (Lightweight M2M) and regulatory certification (FCC, CE, etc.). Fortunately for product designers, there are turnkey LTE module manufacturers and modem vendors that address these certifications as part of their product offering.



3. The SKY68020-11 LTE universal multiband front-end module supports cellular LTE-M/NB-IoT transceiver platforms.



4. The SKY66430-11 is a multiband, multichip SiP that operates over a frequency range of 700 to 2,200 MHz.

Finally, since products can incorporate multiple connectivity standards, an LTE-enabled device should not violate coexistence requirements with other radios such as GPS and Wi-Fi. Ensuring coexistence of a mix of RF technologies within the typically confined physical space of an IoT device can be quite challenging.

THE DESIGN DECISION

Product designers face the typical "make-or-buy" decision when looking to add LTE connectivity to any IoT device. Creating a solution in-house offers the most flexibility, but it also carries significant risk. Without a strong understanding of the standard specifications and extensive experience in RF, design engineers can make critical mistakes, resulting in wasted development time and resources.

In addition, a number of common issues often emerge when testing an LTE device: limited range, higher-than-expected current consumption, insufficient output power, degraded receiver sensitivity, and increased spurious emissions. These challenges can typically be traced back to the RF front-end component selection, printed-circuit-board (PCB) layout, antenna design, and PA matching and filtering.

Unfortunately, such problems spring up even when the design looks good in simulation, or even as an engineering prototype. For consumer IoT devices with short product lifecycles, time-to-market is a huge competitive advantage. This is one of the reasons why LTE adoption has been limited to date—manufacturing iterations to optimize LTE connectivity is time- and cost-intensive. To expedite time-to-market, it has become increasingly important for original equipment manufacturers (OEMs) to have a fully integrated, certified connectivity solution.

With its experience in developing innovative solutions over successive technology generations, Skyworks *(www.skyworksinc.com)* enables seamless LTE connectivity for IoT devices. Specifically focused on designing products with IoT applications in mind, Skyworks offers cost-effective RF wireless engines that address requirements such as global band coverage, integrated functionality, direct battery connectivity, and network and regulatory compliance. For example, the SKY680xx series of LTE universal multiband front-end modules are powering millions of IoT devices on networks worldwide through collaboration and reference designs with major modem platform vendors (*Fig. 3*).

Skyworks is also pioneering die-level intelligent integration into M-IoT, leveraging its PA design and system engineering experience with advanced packaging techniques to develop system-in-package (SiP) solutions. The SKY66430-11 is a fully certified all-in-one M-IoT solution that integrates Sequans' *(www.sequans.com)* Monarch platform with the entire RF front end in a single 8.8- × 10.8- × 0.95-mm package (*Fig. 4*). This fully shielded device provides a complete solution for OEMs looking to streamline the design process and expedite commercialization.

With consumers expecting always-on connectivity and IoT devices proliferating across the globe, M-IoT technology will become more prevalent. Manufacturers must be ready to respond with the most advanced wireless solutions that simplify design and support multiple protocols and standards.

On that front, Skyworks has developed discrete and integrated solutions that support full-duplex cellular/LTE, Wi-Fi, Bluetooth, LoRaWAN, Thread, and Zigbee. By taking advantage of a full suite of process and packaging technologies, Skyworks can offer RF front-end solutions to meet the diverse and fragmented needs of the IoT market. **mw**

REFERENCE:

1. GSMA, May 2019, https://www.gsma.com/iot/mobile-iot-commercial-launches/

JACK BROWNE | Technical Editor

Bringing mmWave Signals to the Masses

Frequency spectrum in the mmWave range offers limited propagation distances but almost unlimited bandwidth for the continuing expansion of wireless communications systems and services.

Bandwidth consumption continues unabated for communications, security, transportation, and other applications at frequencies below about 30 GHz, which is approximately where microwave frequencies end and millimeter-wave (mmWave) frequencies begin. As a result, developers for emerging applications such as automotive radar systems, vehicle-to-vehicle (V2V) communications, and vehicle-to-everything (V2X) communications are looking to 24 GHz and beyond to find usable bandwidth with reasonable propagation distances.

Frequency spectrum is being gobbled up as fast as each new wireless application. The masses have growing appetites for wireless connectivity, including via Internet of Things (IoT) technology and in autonomous cars on smart highways in smart cities. And with bandwidth going quickly at frequencies to about 30 GHz, design engineers are turning to higher frequencies in the mmWave range.

MOVING TO mmWAVES

Although their shorter wavelengths mean shorter propagation distances than lower-frequency signals with longer wavelengths, signals in the mmWave frequency spectrum cover wide bandwidths for short-range wireless connectivity, including for personal area networks (PANs) and high-data-rate wireless local area networks (WLANs). For example, the IEEE 802.11ad wireless gigabit (WiGig) standard is based on the use of the unlicensed 60-GHz frequency band and offers maximum data rates to 8 Gb/s at about 10 m.

Once thought experimental or reserved for military use, mmWave frequencies are increasingly finding their way into short-range communications links, medical monitoring devices, full-body security scanners, and automotive and transportation applications. Named for their short wavelengths, 10 to 1 mm for frequencies from 30 to 300 GHz, commercial mmWave devices and components typically range from about 24 to 110 GHz.

Two main application areas are expected to dominate the demand for mmWave devices and components for years to come: short-range, high-data-rate wireless communications, especially as part of 5G wireless cellular communications networks; and electronic safety systems in smart highways and autonomous vehicles and vehicles with advanced driver-assistance systems (ADAS) equipment.

Benefits of systems operating at mmWave frequencies include the small sizes of the antennas and the large available bandwidths. Among the drawbacks to using mmWave technology are the limited signal power from available ICs and discrete components, such as amplifiers, compared to components at lower frequencies, and high attenuation through atmospheric absorption and through barriers such as buildings.

The small sizes of the circuitry needed to support the small wavelengths at mmWave frequencies can also make these components more expensive to fabricate than lower-frequency components with their larger dimensions. Printed circuit boards (PCBs) for mmWave circuits require materials formulated for low loss at higher frequencies, and test equipment must have the frequency coverage and bandwidth to handle the frequency bands of interest.

To help some start at higher frequencies, Pasternack, in addition to its many mmWave components, has a 60-GHz transmit/receive development system for use in the 57- to 64-GHz V-band range. The system includes a silicon-germanium (SiGe)-based transmitter, receiver, and easy-to-use graphical user interface (GUI) that links the system to a PC by means of Universal Serial Bus (USB) cable assembly for testing IEEE 802.11ad, IEEE 802.11aj, and other network designs at V-band frequencies. The system, developed in partnership with Vubiq Networks *(www.vubiqnetworks.com)*, features a 1.8-GHz modulation bandwidth and standard WR-15 rectangular waveguide interface.

SEEKING SEMICONDUCTORS

Semiconductor technologies for mmWave devices range from highly integrated processes such as silicon (Si) CMOS and Si BiCMOS to "more exotic" processes like gallium arsenide (GaAs), gallium nitride (GaN), indium phosphide (InP), and SiGe. Transmitter, receiver, and transceiver ICs for mmWave applications are typically highly integrated, containing most of the components needed for mmWave radios with wide modulation bandwidths.

For example, the HMC6300 transmitter and HMC6301 receiver from Analog Devices *(www.analog.com)* are companion ICs that operate across the V-band frequency range from 57 to 64 GHz with a maximum modulation bandwidth of 1.8 GHz. The ICs are well-suited for 60-GHz WiGig radios and backhaul applications in 5G small cells. The devices come in compact wafer-level ball-grid-array (WLBGA) packages that integrate many different components to minimize requirements for external components in a mmWave communications link.

The HMC6300 transmitter IC features an integrated frequency synthesizer that provides tuning in 250-, 500-, or 540-MHz steps to support modulation as complex as 64QAM in unlicensed 60-GHz ISM-band applications. The transmitter is supplied in a 6- × 4-mm RoHS-compliant WLBGA. When teamed with a user's local oscillator (LO), the transmitter chip supports frequency-shift keying (FSK), minimum-shift keying (MSK), and on-off-keying (OOK) modulation.

The model HMC6301 receiver IC also is housed in a 6- × 4-mm WLBGA. It incorporates a low-noise amplifier (LNA), image-reject filter, RF-to-IF downconverter, IF filter, I/Q downconverter, and frequency synthesizer. As with the transmitter IC, the receiver provides as much as 1.8-GHz modulation bandwidth.

Using its low-power, 45-nm RFCMOS semiconductor process, Texas Instruments *(www.ti.com)* fabricates a complete single-chip FMCW transceiver for E-band frequencies from 76 to 81 GHz. Dubbed the AWR1243, it packs an integrated phase-locked loop (PLL), transmitter, receiver, and baseband circuitry in a tiny flip-chip ball-grid-array (FCBGA) package measuring just 10.7 × 10.7 mm (*Fig. 1*). Built with the firm's low-power, 45-nm RFCMOS semiconductor process, the transceiver has as many as three transmit channels, four receive channels, available bandwidth to 4 GHz, and a receive noise figure of 15 dB or better.

1. This single-chip FMCW transceiver for E-band frequencies from 76 to 81 GHz is contained within an FCBGA package. ***(Courtesy of Texas Instruments)***

The firm is well-known for automotive radar sensors based on the same semiconductor process. For example, the model AWR1443 single-chip FMCW radar sensor builds on the architecture of the AWR1243 transceiver, adding an integrated ARM R4F processor and hardware accelerator for radar data processing from 76 to 81 GHz. It also comes in a 10.7- × 10.7-mm FCBGA package for PCB mounting.

ANTENNAS, AMPLIFIERS, TRANSCEIVERS

Anokiwave *(www.anokiwave.com)* offers extensive lines of mmWave antenna ICs, from 24 GHz through around 40 GHz. As an example, its model AWA-0134 is an active antenna innovator's kit for emerging applications at 28 GHz. Based on the company's AWMF-0108 IC, the kit is fabricated on a surface-mount circuit board, yielding a 256-element active array that's usable from 26.5 to 29.5 GHz with half-duplex transmit/receive operation. It can be utilized for a 256-element single beam or 4-×-64 element MU-MIMO operation with linear polarization.

Although the firm is perhaps better known for its antenna IC technology, it also produces a LNA, the AWL-7186, for E-band point-to-point communications from 71 to 85 GHz. The four-stage GaAs pHEMT amplifier provides 17-dB typical gain across its wide frequency range with better than 3.5-dB noise figure. It achieves +8 dBm output power at 1-dB gain compression and provides a 15-dB gain adjustment range.

Making use of the lower end of the mmWave frequency range, model TRX_024_006 is a transceiver IC from Silicon Radar GmbH *(www.siliconradar.com)* designed for use in the 24-GHz ISM band. It integrates transmitter and receiver circuitry, including quadrature mixers, LNA, and low-phase-noise voltage-controlled oscillator (VCO), in a leadless plastic QFN20 package that measures just 3 × 3 mm^2. Suitable for 24-GHz communications and radar systems, the RoHS-compliant transceiver operates from 2400 to 24.25 GHz on a single +3.3-V dc supply and consumes just 300 mW power. It includes a single-ended transmitter output and a single-ended receiver input and is fully ESD protected.

The company also supports the 24-GHz band with its model LNA_024_004 LNA in a 3- × 3-mm^2 plastic QFN16 package. Covering a frequency range of 21.5 to 28.5 GHz, it has high and low gain modes, with typical gain of 15 dB in the high-gain mode and 8 dB in the low-gain mode. The noise figure is typically 5 dB with low gain

and 3.2 dB with high gain. The RoHS-compliant SiGe-based LNA features low power consumption—only 18 mW from a single +3.3-V dc supply.

In support of higher data rates to and from cellular base stations, Infineon *(www.infineon.com/rf)* has developed a pair of single-chip transceivers for 71 to 76 GHz (model BGT70) and 81 to 86 GHz (model BGT80). The transceivers support full- and half-duplex modes with quadrature amplitude modulation (QAM) and quadrature-phase-shift-keying (QPSK) modulation formats for backhaul wireless interconnections to small cellular cell sites (such as will be used in 5G wireless networks). The transceivers provide as much as +10 dBm output power over their respective frequency bands, with receiver noise figures of 7 dB or better. Both mmWave devices come in compact embedded wafer-level ball-grid-array (eWLB) packages.

Also in the E-band frequency range, the model MAAP-011106 bare-die GaAs pHEMT amplifier from M/A-COM Technology Solutions *(www.macom.com)* for use from 71 to 86 GHz. It's simply matched to 50 Ω with bond wires to a PCB and provides 20-dB small-signal gain across its frequency range. Designed to provide high-data-rate backhaul communications in point-to-point radios, the transmitter amplifier provides +25 dBm saturated output power and +30 dBm output third-order intercept point (OIP3). Each device is 100% tested.

Teledyne Scientific & Imaging *(www.teledyne-si.com)* and its GaAs pHEMT monolithic microwave integrated circuit (MMIC) process offers some of the industry's highest-frequency MMICs. Using its ISO 9001:2008 certified semiconductor process, it can reliably form lithography-defined semiconductor gates with dimensions as small as 0.1 µm. Among its highest-frequency amplifiers, however, is the TO4-3S4C-G1-P1, which is fabricated on an InP substrate. The 1.92- × 0.80-mm die amplifier provides 23- to 30-dB gain from 190 to 250 GHz with typical output power of 50 to 70 mW for an input drive level of 0 dBm.

Sage Millimeter *(www.sagemillimeter.com)*, long in the business of supplying mmWave components, offers extensive lines of high-frequency coaxial amplifiers and waveguide antennas through test equipment and other waveguide components to 325 GHz. For example, model SBL-7531142040-1010-E1 is a LNA with 20-dB gain and 4-dB noise figure from 75 to 110 GHz (*Fig. 2*). It's equipped with a right-angle waveguide connector and draws 30 mA from a

(Continued on page 68)

Product Feature

JACK BROWNE | Technical Contributor

Wideband Synthesizer Integrates Clean VCO

This highly integrated and versatile frequency synthesizer includes a low-noise VCO, simple control interface, and necessary circuitry to generate 57 MHz to 14.6 GHz.

Frequency-synthesizer integrated circuits (ICs) are often designed to work with an external voltage-controlled oscillator (VCO) to create a low-noise signal source. The ICs may contain much of the phase-locked-loop (PLL) circuitry needed to stabilize a VCO, but the VCO is usually extra.

Such is not the case for the ADF5610 frequency-synthesizer IC from Analog Devices: It has an on-chip VCO that would be impressive as a standalone product, with low phase noise and wide frequency range. Capable of generating signals to 14.6 GHz, the frequency synthesizer provides the VCO for use in fractional-N or integer-N frequency synthesis modes. When teamed with external PLL filters and a high-quality reference oscillator, and using on-chip frequency dividers and multipliers, the IC can produce signals over a total range of 57 MHz to 14.6 GHz, with healthy (+5 dBm) output-power levels.

The ADF5610 and its clever signal routing comes in a compact 48-terminal 7- × 7-mm LGA package *(see figure)*. It contains multiple frequency multipliers, frequency dividers, phase/frequency detector, wideband amplifier, VCO tuning circuitry, control circuitry, and the VCO in that tiny package.

The VCO has a fundamental-frequency tuning range of 3650 to 7300 MHz, which is internally doubled to reach a total VCO frequency range of 3650 MHz to 14.6 GHz at single-ended and differential output ports. The differential output allows doubled VCO signals to be divided by as much as 128 to achieve the low-frequency limit of 57 MHz (7300 MHz/128). When lower-frequency signals are not needed, this divider can be disabled to save power. The synthesizer IC is controlled by a simple three-wire serial port interface (SPI)

TUNING THE VCO

The VCO runs on +3.3- and +5-V dc supplies and has a tuning range of –0 to +3.6 V dc. Whether for its fundamental (to 7.3 GHz) or doubled (to 14.6 GHz) frequencies, it exhibits outstanding single-sideband (SSB) phase noise as a starting point for any frequency synthesizer. When measured 100 kHz from the carrier, the VCO's phase noise is typically –115 dBc/Hz from a 7.3-GHz carrier, –114 dBc/Hz from a 10-GHz carrier, and –109 dBc/Hz from a 14.6-GHz carrier. It has good spectral purity, with typical second and third harmonics of –30 dBc over its fundamental range of 3650 to 7300 MHz.

Third harmonics for divided VCO signals are typically –30 dBc for VCO divided-by-1 outputs and typically –16 dBc for VCO divided-by-2 outputs. The VCO's power-supply pushing is typically 67 MHz/V when measured at +1.65 V dc.

The ADF5610's VCO is a step-tuned oscillator that combines varactor diodes and digital techniques for tuning. It's based on two VCO cores for consistent tuning across the wide frequency range. Typical tuning sensitivity is 101 MHz/V at 7.3 GHz, 128 MHz/V at 11.0 GHz, and 96 MHz/V at 14.6 GHz. The temperature sensitivity is 0.5 MHz/°C at 7.3 GHz and 1.02 MHz/°C at 14.6 GHz.

The ADF5610, a wideband frequency-synthesizer IC in an LGA package with integrated VCO, can generate frequencies to 14.6 GHz.

Not to be forgotten, the VCO is part of a wideband PLL frequency-synthesizer IC that operates with a reference source of typically 50 MHz (accepting sources to 350 MHz). The synthesizer IC features a wide phase-detector bandwidth of dc to 100 MHz in both fractional and integer synthesize modes. It can achieve better than 40-μs frequency-hopping speed with autocalibration enabled and, depending on the PLL bandwidth, boasts typical synthesizer frequency lock time of 100 μs.

The frequency-synthesizer IC is a low-power device, with typical power consumption of 815 mW and maintaining several power-down modes for the VCO and the PLL circuitry, including a low-power mode with less than 700-mW power consumption. The ADF5610 is designed for operating temperatures from –40 to +85°C and is well-suited for commercial and military applications. mw

ANALOG DEVICES Inc., One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; (781) 329-4700, www.analog.com.

JACK BROWNE | Technical Editor

Supersized-Screen Scopes Pack the Power

These versatile oscilloscopes provide 11.6- and 13.3-in. capacitive touchscreens with a wide range of options for versatile measurements through 1.5 GHz.

Oscilloscopes are among the most useful of electronic test instruments, and the latest two series of scopes from Tektronix (*www.tek.com*) deliver more than the usual amount of measurement power through 1.5 GHz into vertical packages that fit almost anywhere. Despite the slim silhouette, the 3 Series mixed-domain oscilloscopes (MDOs), with their 11.6-in.-diagonal capacitive touchscreens, and the 4 Series mixed-signal oscilloscopes (MSOs), with 13.3-in.-diagonal capacitive touchscreens, show traces without fatigue. Up to 12-b vertical resolution is available in the larger oscilloscopes. Both oscilloscope series also come with a host of options to make them even more powerful and versatile.

The 3 Series MDOs and 4 Series MSOs are designed for ease of use, with a settings bar that appears on the bottom of the display screen. By tapping on that part of the screen, it's possible to turn on channels, add waveforms (such as math and reference waveforms), enable digital channels (if available), and enable any of the additional measurement functions that might be incorporated as options. Such options include the spectrum analyzer, the arbitrary function generator, and the digital voltmeter.

LEVERAGING USER INPUT

These new oscilloscopes have been designed with the slogan "built from the engineer up" to explain the many features, options, and upgradability. By working closely with users, who consistently asked for larger display screens, both series of oscilloscopes were designed with the largest possible, bright display screens that would still allow ease of placement for the instrument.

The smaller of the two oscilloscopes, the 3 Series MDOs, have been put to the test on a variety of work surfaces: on top of different types of desks, on workbenches, even on the floor. By designing the instruments around a capacitive touchscreen with clear, visual triggering, the oscilloscopes can be made easily upgradable in terms of function and performance. They're also easier to "future-proof" than earlier models of digital storage oscilloscopes. The scopes can be remotely upgraded at any time without returning them to the factory, and they feature a smaller footprint for more convenient placement on a laboratory workbench (*Fig. 1*).

Because the 3 Series MDOs are only 5.9 in. (149 mm) deep, several of them can fit closely together on a workbench. The product line includes models with two and four channels and instruments with bandwidths of 100, 200, 350, 500, and 1000 MHz. A decision on bandwidth at purchase time is totally noncommittal, however, since the four lower-frequency models are upgradable to higher frequencies, ultimately to a 1-GHz bandwidth. Upgrades to 500 MHz can be performed without returning an instrument, while an upgrade to 1 GHz does require that the instrument be returned to a Tektronix service depot.

All 3 Series MDOs show measurements on a bright 11.6-in.-diagonal capacitive touch display screen with 8-b vertical resolution and 1920- × 1080-pixel resolution for clarity. When teamed with an automated power supply, these MDOs make quick and reliable measurements of voltage, current, power, switching losses, harmonics, ripple, and modulation across a designated range.

1. The 3 Series MDOs are the smaller of the two new lines of oscilloscopes, with an 11.6-in.-diagonal capacitive touchscreen to show results.

What may be as enticing about these MDOs is the number of available options, such as including up to 16 optional digital channels with 121.2-ps timing resolution. Additional options make it possible to include spectrum-analyzer functionality from 9 kHz to 1 GHz or 9 kHz to 3 GHz. This is not just an "add-on" spectrum analyzer, as evidenced by low phase noise of typically −101 dBc/Hz offset 100 kHz from a 1-GHz CW carrier and typically less than −122 dBc/Hz offset 1 MHz from the same carrier. Crosstalk from the oscilloscope channels to the spectrum analyzer is at least 40 dB for frequencies below 800 MHz and better than 60 dB for frequencies above 800 MHz.

In addition, the 3 Series MDOs maintain low displayed average noise levels (DANLs) across their full spectrum-analyzer measurement ranges. For the lowest-frequency measurements, from 9 kHz to 50 kHz, the DANL is typically less than 100 dBc/Hz. From 50 kHz to 5 MHz, the DANL is less than –130 dBc/Hz. From 5 MHz to 2 GHz, the DANL is typically less than –136 dBc/Hz, and from 2 to 3 GHz, less than –120 dBc/Hz.

An optional serial bus decoder handles PC, PCI, RS-232, RS-422, RS-485, UART 2.0, CAN, CAN FD, LIN, FlexRay, MIL-STD-1553, ARINC429, and audio standards. If that isn't enough, an optional function generator can also incorporate as many as 13 predefined waveform types, with 128-kb arbitrary generator record length and a 50-MHz waveform generator operating at a 250-Msample/s arbitrary generator sample rate. Including its 13 predefined waveform types for easy reference, this arbitrary waveform generator is able to provide quick test signals when needed.

In addition, a digital voltmeter/frequency counter comes free when a new MDO is registered. It can perform 4-digit DC, AC RMS, and DC + AC RMS voltage measurements as well as five-digit frequency measurements.

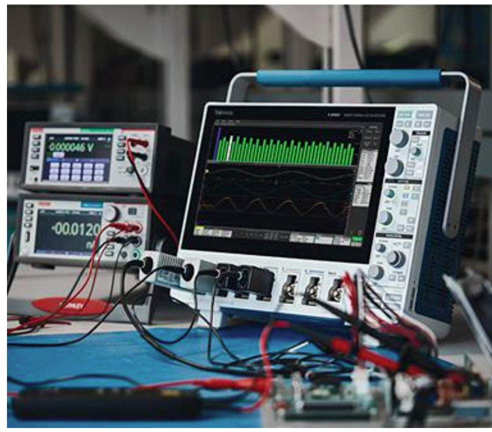
Each 3 Series MDO provides series bus decode, trigger, and search functions and is capable of a waveform capture rate of better than 280,000 waveforms/s. Each instrument is well-equipped with control/data ports, with four USB 2.0 ports and one Ethernet connection.

JUMBO SCREENS

The 4 Series MSOs feature a larger 13.3-in. (338-mm), TFT color capacitive touchscreen with 12-b vertical, 1920- × 1080-pixel resolution (16-b vertical resolution in high-resolution mode) and sampling rate of 6.25 Gsamples/s on all channels. Available with four or six FlexChannel inputs, these compact instruments measure just 9.8 × 17.7 × 6.1 in. (249 × 450 × 155 mm) and weigh just 16.8 lbs (7.6 kg) for easy movement and placement in a work area (*Fig. 2*). Models are available with bandwidths of 200 MHz, 350 MHz, 500 MHz, 1 GHz, and 1.5 GHz, with all narrower-bandwidth models readily upgradable to the widest bandwidth of 1.5 GHz without ever leaving the workbench.

2. The 4 Series MSOs provide bandwidths as wide as 1.5 GHz on a larger, 13.3-in. display screen.

Oscilloscopes in the 4 Series provide standard 31.25 Mpoints record length and 62.5 Mpoints record length as an option. Featuring a standard manufacturer's warranty of three years, they benefit from a new application-specific integrated circuit (ASIC) and the FlexChannel technology developed previously for the company's 5 Series and 6 Series oscilloscopes. The 4 Series MSOs, which feature a waveform capture rate of better than 500,000 waveforms/s, provide serial bus decode, trigger, and search functions and come with five USB 2.0 ports for control and data interconnections (*Fig. 3*).



3. The 3 Series MDOs and 4 Series MSOs (shown here) leave room for other instruments, even on the most crowded test benchtops.

As with the 3 Series MDOs, the 4 Series MSOs are available with an enticing collection of options, including power measurements and Spectrum View software to deliver the functionality of a spectrum analyzer. For example, Spectrum View allows an operator to put peak markers on a measured waveform for ease of analysis. An optional 50-MHz single-channel waveform generator can also be built into a 4 Series MSO as an option.

As these innovative and handy test instruments demonstrate, not all test-equipment updates or upgrades require a trip by the equipment back to the factory. In the cases of the 3 Series MDOs and 4 Series MSOs, many of the performance and functional updates can be made without the instruments ever leaving the test bench. The large screens and small footprints of these oscilloscopes is going to make it hard for them to leave a test bench, once they have found their proper place. But if they do leave the bench, large handles and sturdy packaging mean that they will travel well.

P&A (MSRP): $3,850 and up (3 Series), $7,550 and up (4 Series). mw

TEKTRONIX INC., 14150 SW Karl Braun Dr., P. O. Box 500, Beaverton, OR 97077; (800) 833-9200, www.tek.com.

CHRIS DeMARTINO | Editor

Taking a Cloud-Based Approach to Computer-Aided Engineering

In this Q&A, Dr. Masha Petrova, VP of marketing at OnScale, talks about her company's cloud-based methodology for solving problems, the 5G arena, and more.

Can you first give us an overview of OnScale?

OnScale *(www.onscale.com)* is developing and commercializing engineering simulation software, empowering engineers to accelerate innovation across multiple industries, including next-generation technologies such as MEMS, semiconductors, 5G, biomedicine, and autonomous vehicles. OnScale combines powerful multiphysics solver technology used and validated by Fortune 500 companies for over 30 years, with the limitless speed and flexibility of cloud high-performance computing (HPC). By removing the constraints of legacy simulation tools, OnScale allows engineers to dramatically reduce cost, risk, and time-to-market for cutting-edge technologies.

What prompted the company to adopt a cloud-based approach?

OnScale computer-aided engineering (CAE) tools are based on proprietary multiphysics solvers that were developed and validated for over 30 years by one of the largest engineering consulting firms in the world for DARPA, the U.S. Department of Defense (DoD), and large commercial customers. The CAE solvers were designed for highly parallel mainframe computers to handle very large engineering simulation problems and are a perfect fit for modern cloud-based, high-performance computing.

A cloud-based approached is necessary to enable engineers to fully take advantage of these powerful solvers, give them the ability to solve very large, real-world problems, and to realistically set up and conduct design of experiments (DoE).

Tell us about OnScale's role in the 5G arena.

5G is being heralded as the next great innovation in technology, as it ushers in a new era of connectivity—with everything being connected to everything else with almost zero latency. One of the biggest markets for 5G is mobile communications—namely cell phones, with AT&T and Verizon already announcing 5G network coverage in the US.

However, there are massive technological challenges in fully commercializing this technology, mainly in reducing the front-end footprint and power consumption while incorporating more advanced components. To meet these challenges, there's a tremendous global research-and-development (R&D)

effort underway to develop the next-gen antennas and RF filters needed to make 5G a reality.

Prototyping is an iterative process that can cost from $100K to $1M per foundry run, depending on the complexity of the process. In addition, prototyping is time-consuming and can significantly increase time-to-market. Simulation that can handle large-scale, real-world problems allows companies to reduce the number of prototyping iterations required as well as cut costs and time-to-market—all while mitigating the risks that come with developing new technology.

When it comes to design, most design groups are only able to explore a few different paths due to limitations of prototyping costs and/or engineering simulation tools. They have to rely on the "gut instinct" of engineers to drive design directions. As technology becomes more sophisticated, engineering software must advance to allow for testing exponentially larger numbers of design permutations. It's not practical to explore all of these possibilities empirically. However, OnScale's simulation software enables exploration of multiple designs in parallel.

Advanced packaging techniques for MEMS-CMOS integration, including chip-scale packaging (CSP) and die bonding, induce significant effects on device performance. Process failures lead to reduced yield, and in-service failures lead to returns and poor consumer experiences. Good designs often fail due to packaging challenges such as:

- Thermal: delamination, induced stress from stacked die, packaging stress, interconnect failure
- Environmental: vibration, shock, moisture, ESD
- Process: material variations, dimensional tolerances

Simulation with OnScale allows engineers to identify these issues faster and more cost-effectively than with prototyping alone or the use of legacy CAE software.

How is OnScale supporting RF filter design specifically?

The best way to answer this question is to describe how some of our customers are using OnScale for RF filter design.

Two large chip manufacturers, Qorvo and WISOL, are both using OnScale to quickly explore vast design spaces for optimizing gigahertz RF filter configurations in full 3D for virtual prototyping of blue-sky 5G filter design. This capability was previously impossible with legacy design tools, forcing engineers to constantly fabricate and test to assess hypotheses.

With OnScale being a new company, how are engineers adapting to the company's solution?

We're seeing that more and more Fortune 500 original equipment manufacturers (OEMs) are putting forth large cloud initiatives. In the last few years, it's become very clear that the cloud is not just a fad. Amazon Web Services (AWS) and Google Cloud Platform (GCP) are hyper-aware that data security is critical to adoption of the cloud. Both AWS and GCP have made great strides to assure companies in the manufacturing and R&D space that their data is just as (if not more) safe than on their own servers. With companies like Salesforce paving the way, we're seeing a much more accepting outlook toward cloud-based solutions.

In addition, we have heard from multiple customers that OEMs and large suppliers are looking for innovative and novel solutions and technologies. Even companies in well-established and traditionally very conservative industries, like oil and gas, have initiatives in place to encourage innovation within their suppliers.

Smaller suppliers and engineering firms welcome OnScale's solutions with open arms because of the flexibility of our pricing model. They no longer need to pay tens or even hundreds of thousands of dollars for an annual license that they might need for a 1-month project. To get started with OnScale, they don't even need to talk to an account manager! Simply sign up for a free account on our website, go through a few online tutorials, and you're ready to run your simulations. If a customer does need additional core hours for larger simulations, they can simply pay with a credit card. mw

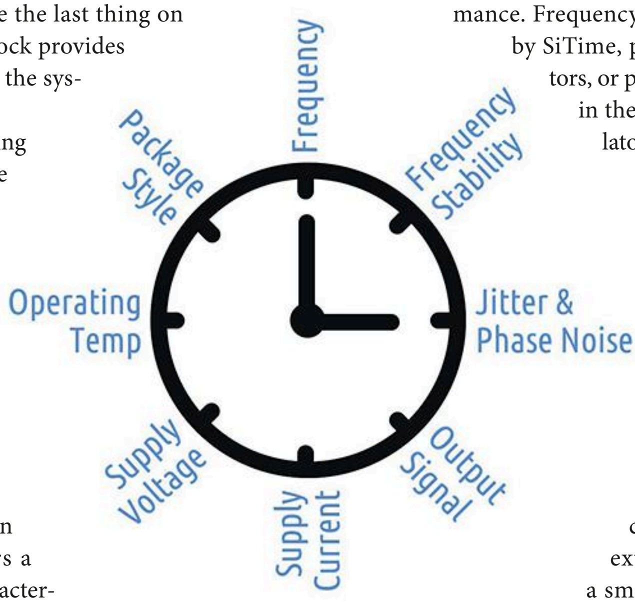
JIM HOLBROOK | Director, Custom Engineering, SiTime
www.sitime.com

What are the 8 Most Important OSCILLATOR SPECS?

Choosing the right oscillator typically involves weighing multiple factors. Here are eight parameters that should be at the top of the list.

What's the first thing you think of when selecting electronic components? Chances are it's the processor or something else central to the system. The timing component may be the last thing on your mind, even though the clock provides the heartbeat that all signals in the system depend on.

Selecting these essential timing components may appear to be a straightforward process, but one must consider a number of factors that affect system performance. So, what are the most important specifications and considerations? Here's a short rundown of the top oscillator parameters and why they're important. Of course, there are more details to consider, so we've created an in-depth glossary that covers a broader range of oscillator characteristics (*Fig. 1*).



1. Engineers should consider these eight parameters when selecting an oscillator.

1. FREQUENCY

The most basic parameter for any oscillator is the frequency, which is the repetition rate (cycle) of the signal output from the oscillator. Frequency is measured in hertz (Hz), i.e., cycles per second. SiTime's (*www.sitime.com*)oscillators are currently available in frequencies as low as 1 Hz for low-power devices and as high as 725 MHz. The frequency of SiTime's oscillators is programmable within this range to six decimals of accuracy.

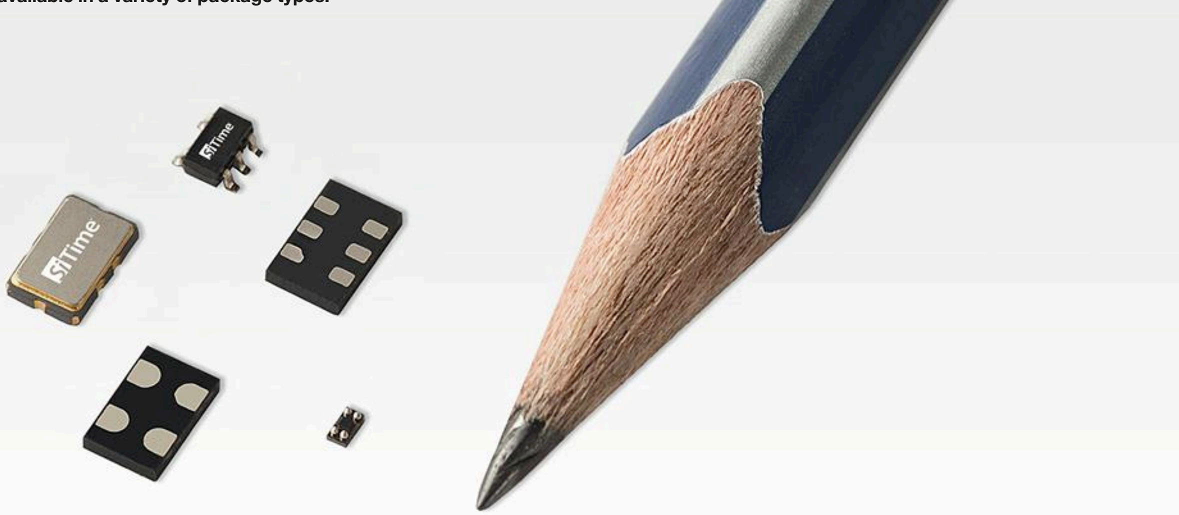
Using custom frequencies can optimize system performance. Frequency can be factory-programmed by SiTime, programmed by key distributors, or programmed for lower volumes in the customer's lab using an oscillator programmer.

2. FREQUENCY STABILITY

Frequency stability is a fundamental performance specification for oscillators. It's typically expressed in parts per million (ppm) or parts per billion (ppb) referenced to the nominal output frequency. It represents the deviation of output frequency from its ideal value due to external conditions. Therefore, a smaller stability number means better performance.

The definition of external conditions can vary for different oscillator categories, but it usually includes temperature variation and initial offset at 25°C. It may also include frequency aging over time, solder-down frequency shift, and electrical conditions like supply voltage variation and output load variation.

Some specialized oscillators, such as oven-controlled crystal oscillators (OCXOs), are housed in significantly larger packages. They often measure 25.4 × 25.4 mm and can range from 9.7 × 7.5 mm to 135 × 72 mm (*Fig. 2*).



2. Oscillators are available in a variety of package types.

3. JITTER AND PHASE NOISE

Phase noise and its time-domain counterpart, jitter, are often considered the most important characteristics of an oscillator after frequency stability. Phase noise and jitter have a direct impact on system performance, affecting such parameters as bit-error-ratio (BER) in serial data systems. Phase noise and jitter are two methods for quantifying noise on a clock signal. Phase noise measures clock noise in the frequency domain; jitter measures the noise impact on the clock in the time domain.

Because jitter and phase noise are the main contributors to system timing errors, it's critical to account for this clock noise when evaluating the total timing budget. This is not necessarily a simple matter. Not all oscillator manufacturers specify jitter in the same way. Jitter requirements vary by application, and there are various types of jitter and different integration ranges for integrated phase jitter measured in the frequency domain.

To help sort this out, the SiTime glossary includes definitions for cycle-to-cycle (C2C) jitter, integrated phase jitter (IPJ), long-term jitter, period jitter, and phase noise. And the SiTime application note, "Clock Jitter Definitions and Measurement Methods," provides even more information. SiTime also offers an online *Phase Noise and Jitter Calculator* that generates phase-noise plots of families at specific frequencies. The integrated phase jitter (IPJ) can also be calculated for standard integration ranges as well as user-specified integration ranges.

4. OUTPUT SIGNAL FORMAT

Chipset vendors may specify the required output signal mode for timing chips, or the system designer may have some leeway. Output types fall into two categories: single-ended or differential. Single-ended oscillators are lower cost and easier to implement, but have limitations. They are somewhat sensitive to board noise and therefore are typically better suited for frequencies below 166 MHz.

Low-voltage CMOS (LVCMOS) is the most common single-ended output type that swings rail-to-rail. SiTime also offers NanoDrive output, which is similar to LVCMOS, but has programmable output swing down to 200 mV to match the input requirements of the downstream chip as well as minimize power consumption.

The eight parameters listed are the most common specifications that designers inspect when selecting an oscillator. But depending on the application, it's possible that many other characteristics and features should be considered. These include EMI reduction features, pull range options for fine-tuning frequency, startup time, and quality/reliability (Q, DPPM, MTBF, FIT rate).

Differential signaling is a more expensive option, but it enables better performance and is preferred for higher-frequency applications. Since any noise common to both differential traces will be zeroed out, this mode is less sensitive to external noise and generates lower levels of jitter and EMI. The most commonly used differential signal types are LVPECL, LVDS, and HCSL.

5. SUPPLY VOLTAGE

Supply voltage, specified in volts (V), is the input power required to operate the oscillator. Supply voltage powers the oscillator through the VDD pin and hence is sometimes referred to as VDD. Standard voltages for single-ended oscillators include 1.8, 2.5, and 3.3 V. Voltages for modern differential oscillators typically range between 2.5 and 3.3 V.

SiTime offers oscillators that operate as low as 1.2 V for regulated supply applications such as coin-cell or supercap battery backup. The supply voltage of most of the company's oscillator families is programmable, which reduces the need for external components like level translators or voltage regulators.

6. SUPPLY CURRENT

Supply current is the maximum operating current of an oscillator. It's measured in microamps (μA) or milliamps (mA) at the maximum and sometimes nominal supply voltage. Typical supply current is measured without load.

7. OPERATING TEMPERATURE

The operating temperature range specifies the ambient temperature under which the device is expected to operate and meet the datasheet specifications. Common temperature ranges are:

- Commercial, Automotive Grade 4: 0 to +70°C
- Extended Commercial: −20 to +70°C
- Industrial, Automotive Grade 3: −40 to +85°C
- Extended Industrial, Automotive Grade 2: −40 to +105°C
- Automotive Grade 1: −40 to +125°C
- Military: −55 to 125°C
- Automotive Grade 0: −40 to 150°C

8. PACKAGES

Oscillators are usually housed in metal, ceramic, or plastic packages. They come in a variety of industry-standard package dimensions. The pad (pin) arrangements may vary among vendors, but the overall x-y dimensions are standardized. Common oscillator package sizes for single-ended oscillators, which usually have four pins, include:

- 2016: 2.0 × 1.6 mm
- 2520: 2.5 × 2.0 mm
- 3225: 3.2 × 2.5 mm
- 5032: 5.0 × 3.2 mm
- 7050: 7.0 × 5.0 mm

Differential oscillators, which have six pins, are typically available in the larger 3225, 5032, and 7050 package sizes.

Some specialized oscillators, such as oven-controlled crystal oscillators (OCXOs), are housed in significantly larger packages. They often measure 25.4 × 25.4 mm and can range from 9.7 × 7.5 mm to 135 × 72 mm (*Fig. 2*).

In addition to these standard package sizes, SiTime offers a few unique packages to solve difficult design challenges. One is a tiny 1508 (1.5 × 0.8 mm) chip-scale package (CSP), which is the smallest oscillator package available. Another option is a leaded SOT23-5 package for applications that require higher board-level reliability and easier visual inspection during board assembly.

OTHER PARAMETERS

The eight parameters listed are the most common specifications that designers inspect when selecting an oscillator. But depending on the application, it's possible that many other characteristics and features should be considered. These include EMI reduction features, pull range options for fine-tuning frequency, startup time, and quality/reliability (Q, DPPM, MTBF, FIT rate).

For high-performance applications, a number of additional stability-related specifications should be considered beyond basic frequency stability. These include aging, frequency versus temperature slope (ΔF/ΔT), thermal hysteresis, Allan deviation, Hadamard variance, holdover, and retrace.

To learn about these parameters and more, see the SiTime glossary—one of the most extensive oscillator definition guides available. mw

Test and Measurement

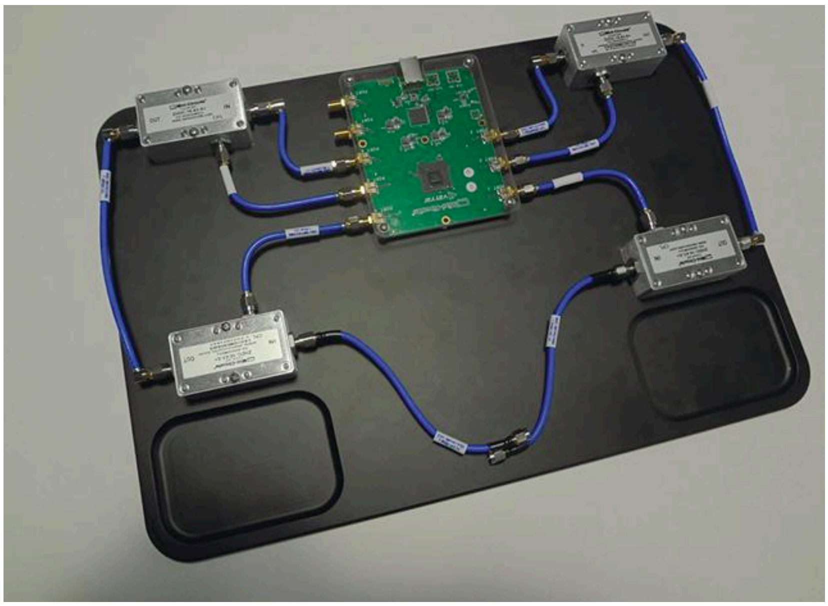
CHRIS DeMARTINO | Editor

Bridging the Gap Between the Classroom and Lab

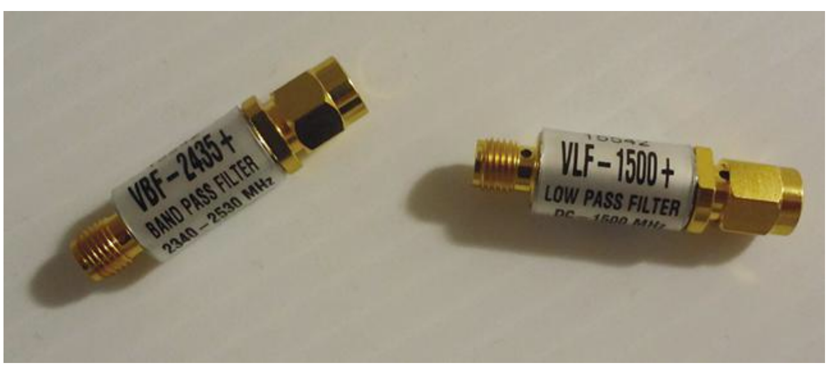
This long-standing company is offering a research and educational tool that allows engineering students to build a vector network analyzer on their own.

With a history that dates back 50 years, Mini-Circuits *(www.minicircuits.com)* is one of the most recognizable names in the RF/microwave industry. Known as a supplier of high-frequency components, Mini-Circuits offers an enormous number of products, which includes the likes of amplifiers, filters, mixers, and couplers, just to name a select few.

However, in 2018, Mini-Circuits made news by unveiling a product unlike anything the company had previously offered. Dubbed the UVNA-63, it's a vector-network-analyzer (VNA) kit intended for the academic community *(Fig. 1)*. Mini-Circuits describes it as a research and educational tool—a do-it-yourself (DIY) kit that contains everything engineering students need to build a fully functional VNA. In Mini-Circuits' own words, the UVNA-63 "bridges the gap between textbook theory in the classroom and practical, real-world measurements in the lab." Mini-Circuits partnered with Vayyar *(www.vayyar.com)* to develop the VNA kit.



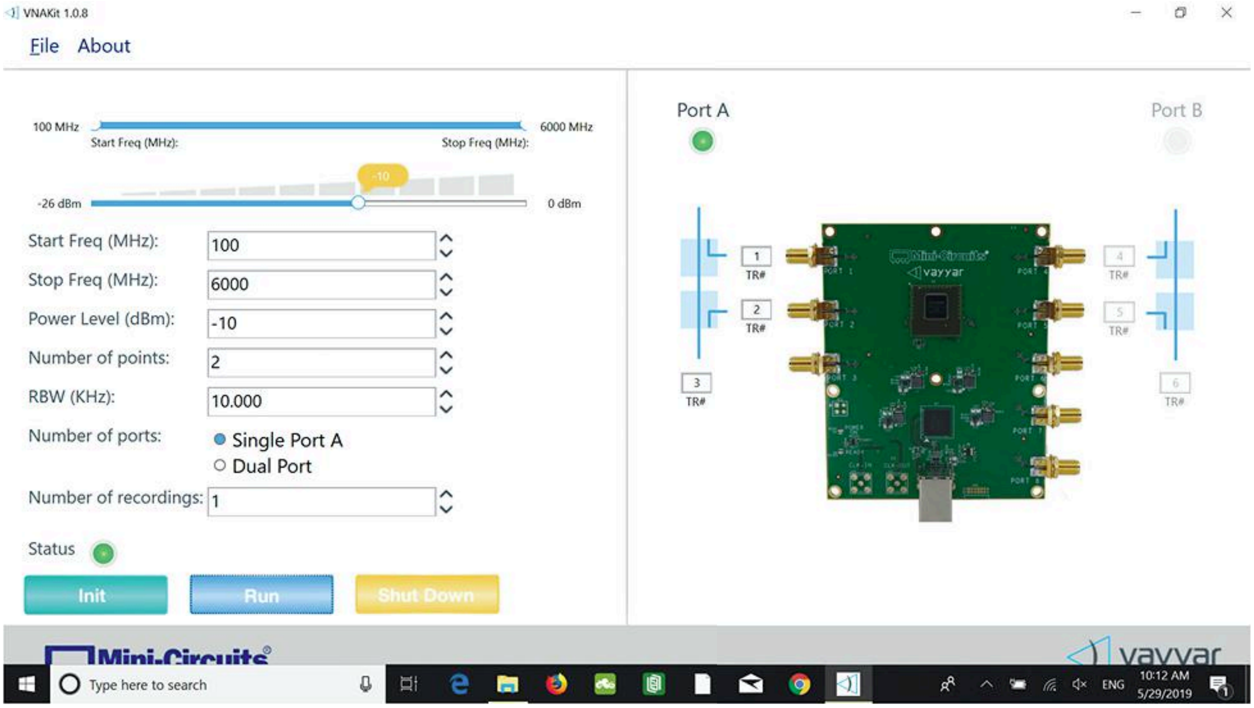
1. The UVNA-63 VNA kit gives students the opportunity to build a VNA themselves.



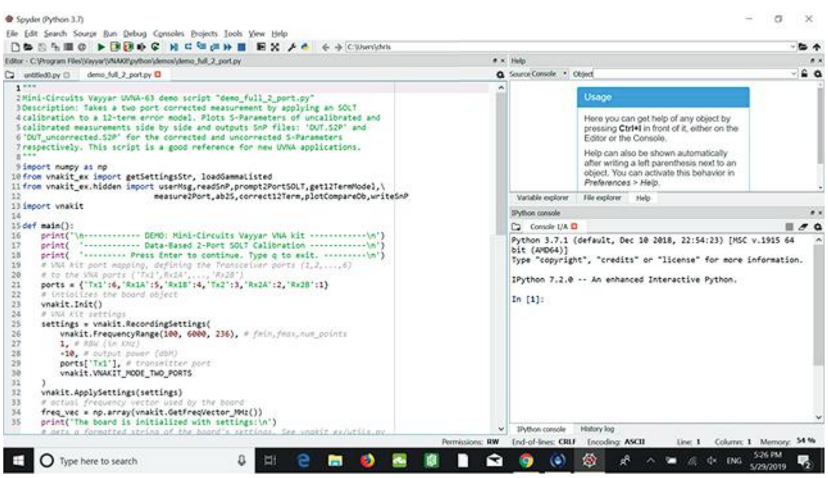
2. A VBF-2435+ bandpass filter and a VLF-1500+ lowpass filter are two of the DUTs included with the kit.

WHAT'S INCLUDED

So, what does the UVNA-63 kit consist of? Foremost is the transceiver board, which houses the transceiver system-on-chip (SoC) developed by



3. With this GUI, users can control the transceiver and save data to a file.



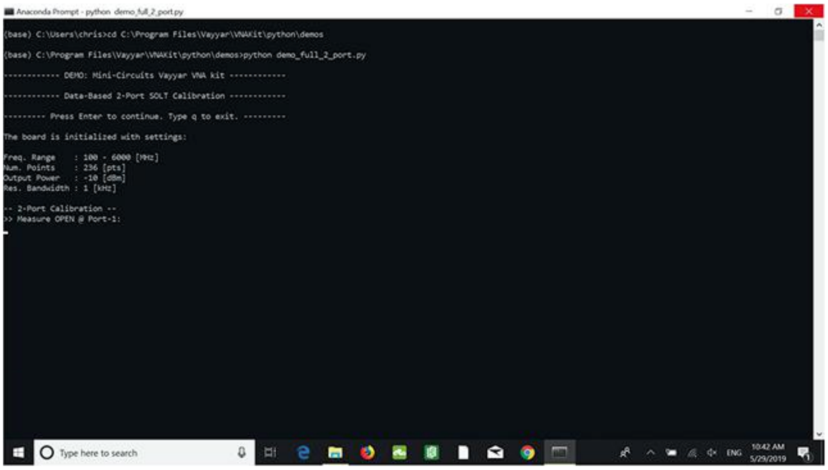
4. The *demo_full_2_port* Python script performs two-port corrected measurements by applying a short-open-load-thru (SOLT) calibration to a 12-term error model.

Vayyar. The transceiver board has multiple ports, providing the transmit and receive functionality needed to create a VNA. The board connects to a PC via a USB cable.

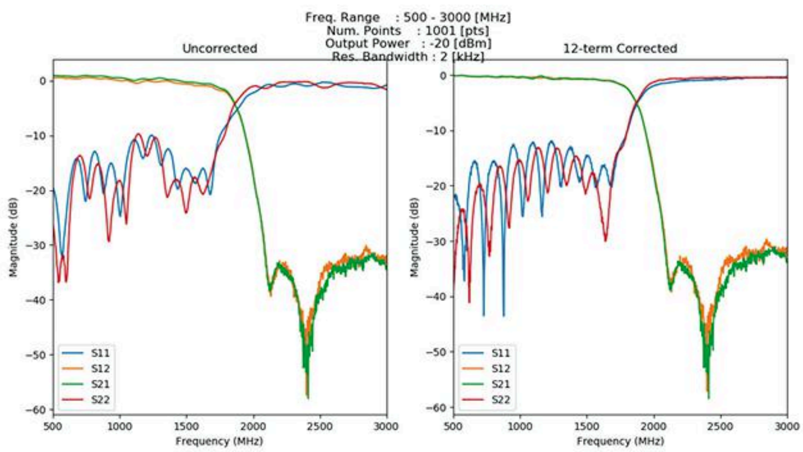
The UVNA-63 kit also features four Mini-Circuits couplers: two ZHDC-16-63-S+ 16-dB couplers and two ZHDC-10-63-S+ 10-dB couplers. Also included are several of Mini-Circuits' cables to connect everything together. The UVNA-63 kit comes unassembled out of the box, meaning that students must put the VNA together on their own. Mini-Circuits offers an assembly manual that students can use as a guide when assembling the kit. After assembly, one then has a fully functional VNA with an operating frequency range of 100 MHz to 6 GHz.

A VNA is a sophisticated test instrument, but it doesn't have much use if there's nothing to test. Hence, the UVNA-63 kit provides several devices under test (DUTs). The DUTs, which are all Mini-Circuits products, include a VBF-2435+ bandpass filter and a VLF-1500+ lowpass filter *(Fig. 2)*. Also in the mix are a 3-dB attenuator, 6-dB attenuator, 15-dB attenuator, and 50-Ω termination. One active DUT is included: the TB-410-84+ evaluation board, which houses the GVA-84+ amplifier.

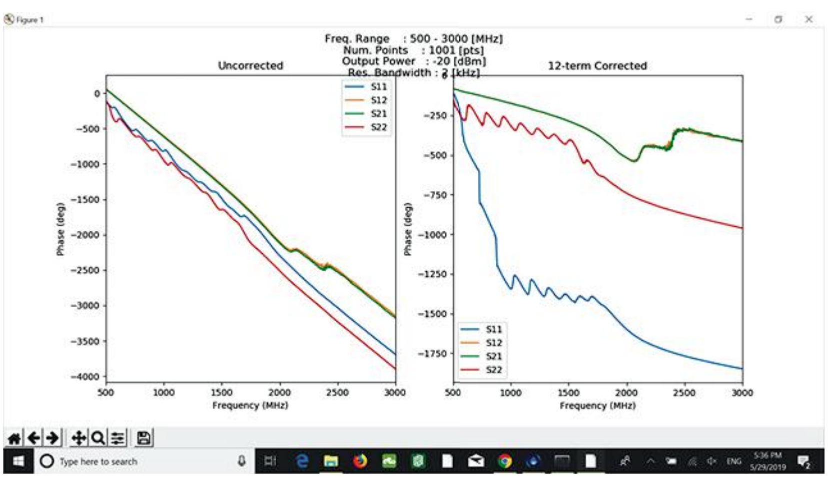
Since calibration is an essential aspect of a VNA, the UVNA-63 kit also has a complete calibration kit that includes open, short, load, and thru standards—all of which are built with SMA female connectors. The topic of calibration is explored much deeper in two UVNA-63 application notes published by Mini-Circuits. The first application note, "Error Correction," explains the sources



5. Executing the *demo_full_2_port* Python script prompts users to perform a two-port calibration and then measure the DUT.



6. Shown are uncorrected and corrected measurement plots of the VLF-1500+ lowpass filter.



7. Uncorrected and corrected phase measurements can be carried out by modifying the *demo_full_2_port* script. Here, phase measurements of the VLF-1500+ lowpass filter are shown.

of systematic error in a network analyzer. The document goes on to discuss vector error correction (VEC) before explaining the 12-term error model and more.

The "Error Correction" application note is intended to serve as a prerequisite to the second application note titled, "Calibration Standards and the SOLT Method." In this document, Mini-Circuits defines a calibration method: Specifically, it's a procedure in which a set of standardized components (a calibration kit) is measured and then used to construct an error-correction model. The app note goes on to explain the calibration standards in more detail before discussing both data- and model-based standards.

Students are encouraged to read both application notes to gain a better understanding of the concepts behind a VNA. The documents also reveal corresponding functions that students can use to program the UVNA-63 VNA kit.

THE UVNA-63 IN ACTION

It's now time to put the UVNA-63 VNA kit to work. A software program can be downloaded from Mini-Circuits' website, providing students with a graphical user interface (GUI) they can use to control the transceiver *(Fig. 3)*. The GUI lets users set the frequency range, transmitter power level, and more.

With the GUI, one can select between two settings: *Single Port A* and *Dual Port*. Selecting *Single Port A* sets *Port 3* of the transceiver board as the transmitting port, while *Port 1* and *Port 2* are both set to be receiving ports. All other ports are inactive. Selecting *Run* will record the data from the ports and save it to a file, which can be specified as either a CSV or MAT file.

The data for each port is presented in terms of I/Q components. For the *Single Port A* setting, *Port 3* data is zero at all frequencies, since this port is the transmitting port. The data for all inactive ports is also zero at all frequencies.

With the *Dual Port* setting, one port is transmitting, while all other ports are receiving. Hence, the data file generated when running the program with this setting is zero at all frequencies for the transmitting port. For all other (receiving) ports, the data file contains the measured values.

Of course, Mini-Circuits could have provided a GUI that includes all of the functionality needed to operate a VNA. However, that would defeat the purpose of the UVNA-63 VNA kit, which, again, is to "bridge the gap between textbook theory in the classroom and practical, real-world measurements in the lab." Therefore, instead of just simply operating the VNA with a few clicks of a mouse, students must develop their own real-time S-parameter algorithms with either Python or MATLAB. Mini-Circuits provides the documentation needed to program the UVNA-63.

The company does offer some example code to help students get started. For example, the *demo_full_2_port* Python script is a good place to begin *(Fig. 4)*. Executing this script will first configure the VNA settings, which includes a frequency range of 100 MHz to 6 GHz along with 236 measurement points.

Users are then prompted to perform a two-port calibration to allow for the construction of a 12-term error model *(Fig. 5)*. The script subsequently prompts users to measure the DUT. After the DUT is measured, two touchstone files that contain the measurement data are saved to a directory. One of the touchstone files contains the uncorrected S-parameters, while the other reveals the corrected S-parameters.

In addition to the touchstone files, uncorrected and corrected measurements are plotted side by side. *Figure 6* shows the plots generated when measuring the VLF-1500+ lowpass filter with a modified version of the *demo_full_2_port* Python script. In this case, the default settings for the frequency range, number of points, output power, and resolution bandwidth have all been changed. Note that the uncorrected plots reveal a fictitious insertion loss of greater than 0 dB throughout the passband.

Students can modify the *demo_full_2_port* script to create their own customized version, too. As a very simple example, phase measurements can be performed by making the appropriate code modifications. *Figure 7* shows plots of uncorrected and corrected phase measurements of the VLF-1500+ lowpass filter that were executed by simply modifying the *demo_full_2_port* script.

In addition to the *demo_full_2_port* script, Mini-Circuits provides other Python examples, such as the *demo_deembed script* and more. Furthermore, students can program the UVNA-63 with MATLAB as opposed to Python.

CONCLUSION

The UVNA-63 kit is certainly a creative idea that should be a great benefit to engineering students everywhere. Rather than simply pressing one button to perform VNA measurements without really thinking about how a VNA operates, the kit gives students the opportunity to build a VNA themselves and bridge the gap between textbook theory and real-world measurements. Let's hope the UVNA-63 kit is one tool that helps better equip the next generation of engineers. **mw**

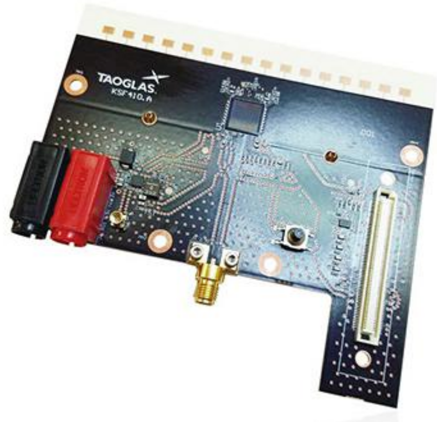
(Continued from page 54)

+8-V dc supply. The broadband amplifier is ideal for communications, imaging, and radar systems across those frequencies.

2. This LNA provides 20-dB gain and 4-dB noise figure from 75 to 110 GHz. *(Courtesy of Sage Millimeter Inc.)*

Millitech, part of Smiths Interconnect *(www.smithsinterconnect.com)*, maintains lines of coaxial amplifiers for mmWave applications through 110 GHz, with amplifiers available for commercial and military applications. The connector interfaces support frequency ranges from dc to 40 GHz (2.92-mm connectors), dc to 50 GHz (2.4-mm connectors), and dc to 65 GHz (1.85-mm connectors) with rectangular waveguide interfaces from WR-42 through WR-10 supplied on amplifiers for higher frequencies.

On the cusp of the mmWave frequency range, the model KSF410.A beam-steering antenna from Taoglas *(www.taoglas.com)* is a 16-element linear phased-array antenna for use from 27.50 to 28.35 GHz (*Fig. 3*). It provides 17-dBi gain across a 3-dB beamwidth for wide angular coverage in azimuth, with most of the energy within 45 deg. of the main beam. To save propagation losses, the beamwidth of the antenna is reduced as the antenna gain increases. The antenna has been conceived for 5G Ka-band fixed-access applications.



3. Here, a 16-element linear phased-array antenna is mounted on a PCB for use from 27.50 to 28.35 GHz. *(Courtesy of Taoglas)*

The KSF410.A antenna features a small-size, low-profile, and lightweight structure for ease of integration in different operating environments. Beam-steering is achieved at higher frequencies using amplitude and phase shifting or beamforming networks. Antennas within the array are organized into groups of four antenna elements, each with an IC phase shifter, LNA, and power amplifier for a wide field of view of ±45 deg. **mw**

Synthesized Signal Generator Tunes 10 MHz to 15 GHz

MINI-CIRCUITS' MODEL SSG-15G-RC is a compact, synthesized signal generator with 0.1-Hz frequency resolution across a broadband tuning range of 10 MHz to 15 GHz. It features ±1-ppm frequency accuracy when working with its own internal frequency reference. Output power can be set from –50 to +16 dBm and typical settling time when tuning to a new frequency and power level is only 3.5 ms, making the signal source well-suited for design and production testing. Worst-case output-power flatness is ±0.95 dB from 12 to 15 GHz with flatness of ±0.7 dB or better at lower frequencies. Harmonics are typically –9 dBc from 10 MHz to 2 GHz, –25 dBc or better from 2 to 10 GHz, and –30 dBc from 10 to 15 GHz. Spurious levels are typically –70 dBc. The signal generator measures just 5.1 × 3.6 × 1.0 in. with a single 50-Ω female SMA connector on the output port. It's equipped with USB and Ethernet control interfaces and can be controlled from any Windows or Linux PC. The generator is shipped with several accessories, including a 6.6-ft. USB cable and a 6-V power adapter.
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500; https://www.minicircuits.com/WebStore/dashboard.html?model=SSG-15G-RC

MMIC Amplifier with Shutdown Boosts 22.0 to 43.5 GHz

MINI-CIRCUITS' MODEL TSS-44+ is a broadband MMIC amplifier with shutdown feature designed for a wide range of applications from 22.0 to 43.5 GHz. Supplied in a 12-lead, 3- × 3-mm surface-mount MCLP package with integrated dc blocks and bias tee to save space, the three-stage 50-Ω gain block offers 17.6-dB typical gain with ±0.9-dB gain flatness across the frequency range. Based on GaAs E-pHEMT technology, the shutdown feature allows the amplifier to be shut down with pulsed signals to save power. The high 28-dB typical active directivity may eliminate the need for an isolator. The RoHS-compliant amplifier achieves low noise figure across its bandwidth, with typical noise figure of 3.7 dB at 22 GHz, 3.2 dB at 30 GHz, 3.5 dB at 40 GHz, and 4.2 dB at 43.5 GHz.
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=TSS-44%2B

Evaluation Kit Explores mmWave Imaging and Sensing

TEAMING WITH VAYYAR (www.vayyar.com), Mini-Circuits has developed the VTRIG-74 mmWave evaluation kit, which lets users explore three-dimensional (3D) imaging and sensing at mmWave frequencies. The kit includes a front-end and analog baseband signal-chain PCB with signal paths for as many as 40 antennas. A frequency synthesizer generates frequency-stepped CW waveforms for the transmit antennas. Key performance parameters for the receive antennas, including resolution bandwidths, start and stop frequency points, and number of frequency points, can be fully adjusted with choice of three transmit profiles to investigate 3D imaging and sensing from 62 to 69 GHz. A Vayyar application programming interface (API) installed on a PC provides easy-to-use control of the noncontact mmWave sensors. The API runs on the MS Windows operating system (OS) and is compatible with Python and MATLAB software for research and experimentation of the capabilities of mmWave sensors.
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=VTRIG-74

Low-Noise VCO Tunes 810 to 900 MHz

MODEL DCO8190-5 is a surface-mount voltage-controlled oscillator (VCO) for applications from 810 to 900 MHz. Based on a planar resonator design, the compact VCO measures just 0.3 × 0.3 in. Constructed with patented lead-free REL-PRO technology, the oscillator tunes with typical sensitivity of 4.5 to 9.0 MHz/V and achieves phase noise of –115 dBc/Hz offset 10 kHz from any carrier and –135 dBc/Hz offset 100 kHz from any carrier. Typical frequency pulling is 1.5 MHz/V, and 2 MHz for a 1.75:1 VSWR load. The VCO follows a tuning-voltage pattern of 0.5 V for 810 MHz, 5 V for 820 MHz, 8 V for 840 MHz, 12 V for 875 MHz, and 16 V for 900 MHz. The 50-Ω oscillator delivers at least +1-dBm output power across its frequency range with an operating temperature range of –40 to +85°C. It draws maximum current of 34 mA at +5 V dc.
SYNERGY MICROWAVE CORP., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800, FAX: (973) 881-8361
E-mail: sales@synergymwave.com, www.synergymwave.com

Dynamic Power Analyzer Studies WBG Semiconductors

MODEL PD1500A is a power-analyzer measurement system designed for dynamic measurements on wide-bandgap (WBG) semiconductors, such as those based on gallium-nitride (GaN) and silicon-carbide (SiC) substrates. When used with the firm's B1505A and B1506A power device analyzers for static measurements, the dynamic measurement system can provide double-pulse device characterization and parameter extraction for power semiconductors with performance parameters to 1.2 kV and 200 A. Since the measurement system is modular, additional modules will be added to the system when higher power levels must be tested. When used with the PD1000A design and simulation software, the dynamic power analyzer can be used to develop accurate and effective semiconductor device models.

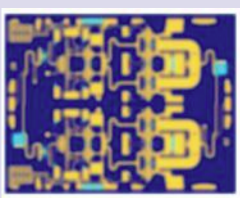
KEYSIGHT TECHNOLOGIES INC., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403-1738; (303) 662-4748, www.keysight.com

VNA Integrates Modulation Distortion

THE OPTIONAL S93070XB modulation distortion application is available integrated in the PNA-X vector network analyzer (VNA). The application is designed to provide a wide dynamic range (with low noise floor) with the lowest possible error vector magnitude (EVM) when characterizing a device under modulated conditions. High signal fidelity is achieved at the device under test (DUT) by means of a unique PNA calibration technique, which is a simplified calibration approach for "vector-corrected" EVM measurements.

KEYSIGHT TECHNOLOGIES INC., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403-1738; (303) 662-4748, www.keysight.com

Wideband GaN Chip Powers 32 to 38 GHz



MODEL TGA2222 ifrom Qorvo is a wideband power amplifier MMIC sold in die form for applications from 32 to 38 GHz. Across that frequency range, it provides 16-dB gain with +40 dBm (10 W) saturated output power. The RoHS-compliant balanced amplifier, fabricated with a 0.15-μm GaN-on-SiC semiconductor process, is matched to 50 Ω at both ports and achieves better than 22% power-added efficiency. It draws 640 mA from a 24-V dc supply in CW operation and 640 mA from a 26-V dc supply in pulsed operation. The amplifier dice measures 3.43 × 2.65 × 0.05 mm.

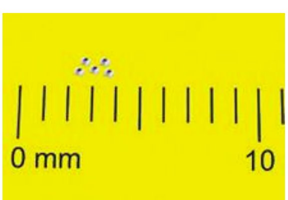
RFMW LTD., 188 Martinvale Lane, San Jose, CA 95119; (877) 367-7369, E-mail: sales@rfmw.com, www.rfmw.com

Power Amp Drives 13.0 to 15.5 GHz

MODEL QPM2239 is a Ku-band power amplifier from Qorvo that provides 29-dB typical small-signal gain from 13.0 to 15.5 GHz. It delivers +49 dBm saturated output power when fed with a +25-dBm input signal, with better than 25% typical power-added efficiency. The amplifier, which is fabricated with a GaN-on-SiC process, is designed for drain voltage of +28 V dc, quiescent drain current of 800 mA, and gate voltage of typically –2.5 V dc. It's supplied in a surface-mount package measuring 19.05 × 19.05 × 4.5 mm.

RFMW LTD., 188 Martinvale Lane, San Jose, CA 95119; (877) 367-7369, E-mail: sales@rfmw.com, www.rfmw.com

Wirewound Inductors Range from 0.5 to 14.0 nH



WIREWOUND INDUCTORS IN the 0201DS Series come in 52 inductance values from 0.5 to 14.0 nH. The 0603-sized inductors feature quality-factor (Q) values to 64 at 1.7 GHz and self-resonant frequencies higher than 24 GHz. The RoHS-compliant inductors are based on ceramic core material and exhibit a temperature coefficient of inductance (TCL) of +25 to +125 ppm/°C. They are tested to MIL-STD-202 Method 215 plus an additional aqueous wash for PCB washing and have an operating temperature range of better than –40 to +125°C. The inductors are available in C425 Designer Kits for experimentation.

COILCRAFT INC., 1102 Silver Lake Rd., Cary, IL 60013; (800) 322-2645, (847) 639-6400, E-mail: sales@coilcraft.com, www.coilcraft.com

Coaxial Attenuators Reach 100 dB at 18 GHz

A SERIES OF direct-reading coaxial attenuators provides precise attenuation levels from 2 to 18 GHz with minimal loss—as much as 100 dB attenuation is available from a single unit. Using a noncontacting method of varying attenuation, these attenuators exhibit maximum insertion loss of 0.5 dB for models to 60-dB attenuation and maximum insertion loss of 1.0 dB for models above 60 dB attenuation. Available with Type N or SMA female coaxial connectors, the attenuators handle 10 W average power and 5 kW peak power with 0.1-dB or better resettability. They are constructed with an aluminum body that features stainless-steel connectors.

ARRA INC., 15 Harold Court, Bay Shore, NY 11706; (631) 231-8400, FAX: (631) 434-1116, E-mail: sales@arra.com, www.arra.com

Power Divider/Combiner Handles 30 W to 40 GHz

MODEL 802-3-29.000 IS a two-way coaxial power divider/combiner for use from 18 to 40 GHz. Supplied with 2.92-mm female connectors, it handles 30 W average input power with 1.8-dB typical insertion loss and 0.5-dB typical amplitude balance. The phase balance between the two division arms is 8 deg. or better. The input VSWR is typically 1.30:1, while the output VSWR is typically 1.17:1. The power divider/combiner provides 22-dB typical isolation between ports.

MECA ELECTRONICS INC., 459 E. Main St., Denville, NJ 07834; (866) 444-6322, (973) 625-0661 FAX: (973) 625-9277, E-mail: sales@e-MECA.com

Upconverter Generates Outputs from 24 to 44 GHz

MODEL ADMV1013 is a frequency upconverter that provides high-frequency output signals from 24 to 44 GHz via direct upconversion from baseband in-phase/quadrature (I/Q) input signals or single-sideband (SSB) frequency upconversion from intermediate-frequency (IF) input signals from 0.8 to 6.0 GHz. It has a local-oscillator (LO) input frequency range from 5.4 to 10.25 GHz. Well-suited for mmWave point-to-point radios, radar systems, and electronic-warfare (EW) systems, the frequency upconverter is also a good match for automatic-test-equipment (ATE) applications. It comes in a 40-terminal land-grid-array (LGA) package and has an operating temperature range of –40 to +85°C.

ANALOG DEVICES INC., One Technology Way, P. O. Box 9106, Norwood, MA 02062; (800) 262-5643, (781) 329-4700, www.analog.com

Mixer Rejects Images From 6 to 10 GHz

MODEL CMD257C4 IS an in-phase/quadrature (I/Q) mixer with low conversion loss from 6 to 10 GHz. Constructed with two double-balanced mixer cells and a 90-deg. hybrid, it can be used as an image-reject mixer (with an external IF hybrid) or single-sideband frequency upconverter. Typical conversion loss is 6 dB or better across the full frequency range. The RoHS-compliant mixer has an RF and local-oscillator (LO) range of 6 to 10 GHz and an IF range of dc to 3.5 GHz, and can handle RF and LO power levels to +27 dBm. Image rejection is typically 31 dB. LO-to-RF isolation is typically 37 dB, while LO-to-IF isolation is typically 17 dB. The mixer features an input third-order intercept point (IP3) of typically +24 dBm. It comes in a 4- × 4-mm surface-mount-technology (SMT) package and is designed for operating temperatures of –40 to +85°C.

CUSTOM MMIC, 300 Apollo Dr., Chelmsford, MA 01824; (978) 467-4290, FAX: (978) 467-4294, www.custommmic.cm

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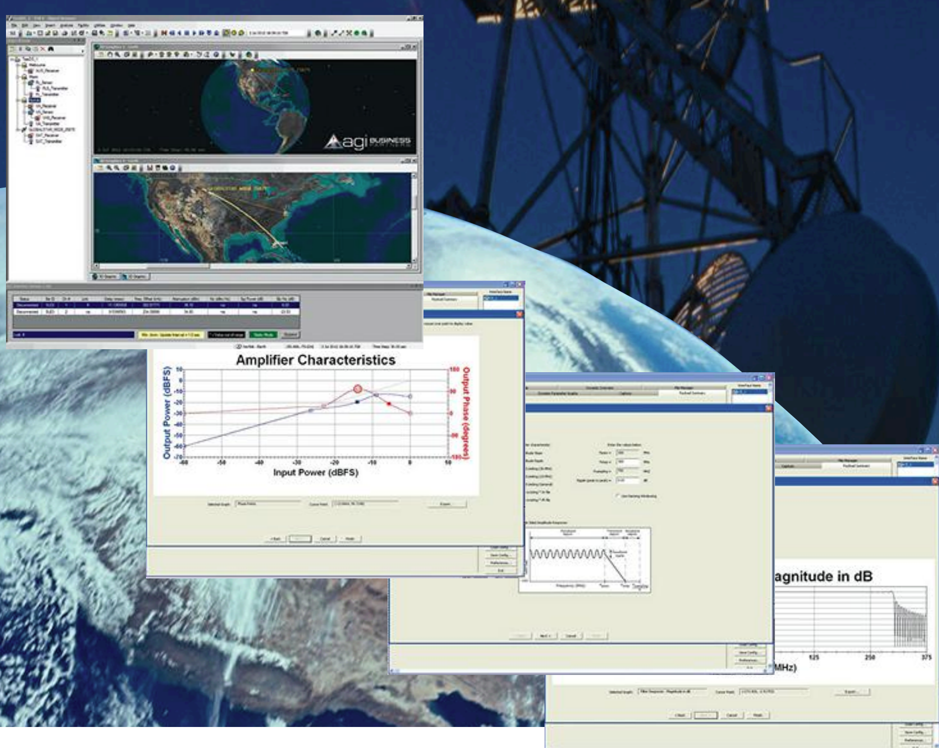
- **Payload and ground station emulation**
- **Multipath, 12 paths @ 600MHz BW**



dBm

RF Test Equipment for Wireless Communications

email: info@dbmcorp.com

dBm Corp, Inc

32A Spruce Street ◆ Oakland, NJ 07436

Tel (201) 677-0008 ◆ Fax (201) 677-9444

www.dbmcorp.com

Wireless Standards 2019

Microwaves&RF

TRUSTED ENGINEERING RESOURCE FOR OVER 50 YEARS

5G COMMUNICATIONS

Sub-6-GHz Frequencies

NR Operating Band	Uplink (MHz)	Downlink (MHz)	Mode Supplementary Downlink (SDL) Supplementary Uplink (SUL) Frequency Division Duplex (FDD) Time Division Duplex (TDD)
n1	1920 – 1980	2110 – 2170	FDD
n2	1850 – 1910	1930 – 1990	FDD
n3	1710 – 1785	1805 – 1880	FDD
n5	824 – 849	869 – 894	FDD
n7	2500 – 2570	2620 – 2690	FDD
n8	880 – 915	925 – 960	FDD
n12	699 – 716	729 – 746	FDD
n14	788 – 798	758 – 768	FDD
n18	815 – 830	860 – 875	FDD
n20	832 – 862	791 – 821	FDD
n25	1850 – 1915	1930 – 1995	FDD
n28	703 – 748	758 – 803	FDD
n30	2305 – 2315	2350 – 2360	FDD
n34	2010 – 2025	2010 – 2025	TDD
n38	2570 – 2620	2570 – 2620	TDD
n39	1880 – 1920	1880 – 1920	TDD
n40	2300 – 2400	2300 – 2400	TDD
n41	2496 – 2690	2496 – 2690	TDD
n47	5855 – 5925	5855 – 5925	TDD
n48	3550 – 3700	3500 – 3700	TDD
n50	1432 – 1517	1432 – 1517	TDD
n51	1427 – 1432	1427 – 1432	TDD
n65	1920 – 2010	2110 – 2200	FDD
n66	1710 – 1780	2110 – 2200	FDD
n70	1695 – 1710	1995 – 2020	FDD
n71	663 – 698	617 – 652	FDD
n74	1427 – 1470	1475 – 1518	FDD
n75	N/A	1432 – 1517	SDL
n76	N/A	1427 – 1432	SDL
n77	3300 – 4200	3300 – 4200	TDD
n78	3300 – 3800	3300 – 3800	TDD
n79	4400 – 5000	4400 – 5000	TDD
n80	1710 – 1785	N/A	SUL
n81	880 – 915	N/A	SUL
n82	832 – 862	N/A	SUL
n83	703 – 748	N/A	SUL
n84	1920 – 1980	N/A	SUL
n86	1710 – 1780	N/A	SUL
n89	824 – 849	N/A	SUL

Millimeter-Wave Frequencies

NR Operating Band	Uplink/Downlink Frequency Band	Mode
n257	26.50 - 29.50 GHz	TDD
n258	24.25 - 27.50 GHz	TDD
n260	37.0 - 40.0 GHz	TDD
n261	27.5 - 28.35 GHz	TDD

CELLULAR COMMUNICATION

LTE

FDD

Band	Uplink (MHz)	Downlink (MHz)	Bandwidth UL/DL (MHz)	Duplex Spacing (MHz) Supplementary Downlink (SDL)
1	1920 - 1980	2110 - 2170	60	190
2	1850 - 1910	1930 - 1990	60	80
3	1710 - 1785	1805 - 1880	75	95
4	1710 - 1755	2110 - 2155	45	400
5	824 - 849	869 - 894	25	45
7	2500 - 2570	2620 - 2690	70	120
8	880 - 915	925 - 960	35	45
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95
10	1710 - 1770	2110 - 2170	60	400
11	1427.9 - 1447.9	1475.9 - 1495.9	20	48
12	699 - 716	729 - 746	17	30
13	777 - 787	746 - 756	10	-31
14	788 - 798	758 - 768	10	-30
17	704 - 716	734 - 746	12	30
18	815 - 830	860 - 875	15	45
19	830 - 845	875 - 890	15	45
20	832 - 862	791 - 821	30	-41
21	1447.9 - 1462.9	1495.9 - 1510.9	15	48
22	3410 - 3490	3510 - 3590	80	100
24	1626.5 - 1660.5	1525 - 1559	34	-101.5
25	1850 - 1915	1930 - 1995	65	80
26	814 - 849	859 - 894	35	45
27	807 - 824	852 - 869	17	45
28	703 - 748	758 - 803	45	55
29	N/A	717 - 728	11	SDL
30	2305 - 2315	2350 - 2360	10	45
31	452.5 - 457.5	462.5 - 467.5	5	10
32	N/A	1452 - 1496	44	SDL
65	1920 - 2010	2110 - 2200	90	190
66	1710 - 1780	2110 - 2200	70/90	400
67	N/A	738 - 758	20	SDL
68	698 - 728	753 - 783	30	55
69	N/A	2570 - 2620	50	SDL
70	1695 - 1710	1995 - 2020	15/25	300
71	663 - 698	617 - 652	35	-46
72	451 - 456	461 - 466	5	10
73	450 - 455	460 - 465	5	10
74	1427 - 1470	1475 - 1518	43	48
75	N/A	1432 - 1517	85	SDL
76	N/A	1427 - 1432	5	SDL
85	698 - 716	728 - 746	18	30
87	410 - 415	420 - 425	5	10
88	412 - 417	422 - 427	5	10

TDD

Band	Uplink and Downlink (MHz)	Bandwidth (MHz)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 -2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200
44	703 - 803	100
45	1447 - 1467	20
46	5150 - 5925	775
47	5855 - 5925	70
48	3550 - 3700	150
49	3550 - 3700	150
50	1432 - 1517	85
51	1427 - 1432	5
52	3300 - 3400	100
53	2483.5 - 2495	11.5

CDMA2000 1x/1xEV-DO

Band	Uplink (MHz)	Downlink (MHz)
Band Class 0	815 - 849	860 - 894
Band Class 1	1850 - 1910	1930 - 1990
Band Class 2	872 - 915	917 - 960
Band Class 3	887 - 925	832 - 870
Band Class 4	1750 - 1780	1840 - 1870
Band Class 5	410 - 483	420 - 493
Band Class 6	1920 - 1980	2110 - 2170
Band Class 7	776 - 788	746 - 758
Band Class 8	1710 - 1785	1805 - 1880
Band Class 9	880 - 915	925 - 960
Band Class 10	806 - 901	851 - 940
Band Class 11	410 - 483	420 - 493
Band Class 12	870 - 876	915 - 921
Band Class 13	2500 - 2570	2620 - 2690
Band Class 14	1850 - 1915	1930 - 1995
Band Class 15	1710 - 1755	2110 - 2155
Band Class 16	2502 - 2568	2624 - 2690
Band Class 18	787 - 799	757 - 769
Band Class 19	698 - 716	728 - 746
Band Class 20	1626.5 - 1660.5	1525 - 1559
Band Class 21	2000 - 2020	2180 - 2200

GSM/GPRS/EDGE/EDGE Evolution

Band	Uplink (MHz)	Downlink (MHz)	Duplex Spacing (MHz)
T-GSM-380	380.2 - 389.8	390.2 - 399.8	10
T-GSM-410	410.2 - 419.8	420.2 - 429.8	10
GSM-450	450.4 - 457.6	460.4 - 467.6	10
GSM-480	478.8 - 486.0	488.8 - 496.0	10
GSM-710	698.0 - 716.0	728.0 - 746.0	30
GSM-750	777.0 - 793.0	747.0 - 763.0	-30
T-GSM-810	806.0 - 821.0	851.0 - 866.0	45
GSM-850	824.0 - 849.0	869.0 - 894.0	45
P-GSM-900	890.0 - 915.0	935.0 - 960.0	45
E-GSM-900	880.0 - 915.0	925.0 - 960.0	45
R-GSM-900	876.0 - 915.0	921.0 - 960.0	45
ER-GSM-900	873.0-915.0	918.0 - 960.0	45
DCS-1800	1710.0 - 1785.0	1805.0 - 1880.0	95
PCS-1900	1850.0 - 1910.0	1930.0 - 1990.0	80

TD-SCDMA/TD-HSPA/TD-HSPA+

Band	Uplink and Downlink (MHz)	Bandwidth (MHz)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 -2620	50
39	1880 - 1920	40
40	2300 - 2400	100

W-CDMA/HSPA/HSPA+

Band	Uplink (MHz)	Downlink (MHz)	Bandwidth (MHz)	Duplex Spacing (MHz)
I	1920 - 1980	2110 - 2170	60	190
II	1850 - 1910	1930 - 1990	60	80
III	1710 - 1785	1805 - 1880	75	95
IV	1710 - 1755	2110 - 2155	45	400
V	824 - 849	869 - 894	25	45
VI	830 - 840	875 - 885	10	45
VII	2500 - 2570	2620 - 2690	70	120
VIII	880 - 915	925 - 960	35	45
IX	1749.9 - 1784.9	1844.9 - 1879.9	35	95
X	1710 - 1770	2110 - 2170	60	400
XI	1427.9 - 1447.9	1475.9 - 1495.9	20	48
XII	699 - 716	729 - 746	17	30
XIII	777 - 787	746 - 756	10	-31
XIV	788 - 798	758 - 768	10	-30
XIX	830 - 845	875 - 890	15	45
XX	832 - 862	791 - 821	30	-41
XXI	1447.9 - 1462.9	1495.9 - 1510.9	15	48
XXII	3410 - 3490	3510 - 3590	80	100
XXV	1850 - 1915	1930 - 1995	65	80
XXVI	814 - 849	859 - 894	35	45
XXXII	N/A	1452 - 1496	44	Supplementary Downlink (SDL)

WIRELESS CONNECTIVITY

Name	Standard	Frequency Band	Data Rate
WLAN	IEEE 802.11a (Wi-Fi 2)	5 GHz	54 Mbps
	IEEE 802.11b (Wi-Fi 1)	2.4 GHz	11 Mbps
	IEEE 802.11g (Wi-Fi 3)	2.4 GHz	54 Mbps
	IEEE 802.11n (Wi-Fi 4)	2.4 GHz 5 GHz	600 Mbps
	IEEE 802.11ac (Wi-Fi 5)	5 GHz	7 Gbps
	IEEE 802.11ax (Wi-Fi 6)	2.4 GHz 5 GHz	9.6 Gbps
	IEEE 802.11ad	60 GHz	7 Gbps
Bluetooth EDR		2.4 - 2.5 GHz	3 Mbps
Bluetooth 5		2.4 - 2.5 GHz	Up to 2 Mbps
Zigbee®	IEEE 802.15.4	2.4 - 2.5 GHz	250 Kbps
LoRaWAN™		915 MHz (U.S.) 868 MHz (Europe)	0.3 to 50 Kbps
Z-Wave		908.42 MHz (U.S.) 868.42 MHz (Europe)	Up to 100 Kbps
THREAD	IEEE 802.15.4	2.4 - 2.5 GHz	250 Kbps
SIGFOX		915 MHz	100-600 bps
NFC		13.56 MHz	424 Kbps
WiSun	IEEE 802.15.4g	902-928 MHz	50-300 Kbps
WirelessHART		2.4 GHz	250 Kbps
Weightless		< 1 GHz	Up to 10 Mbps
LTE Cat-1		Cellular bands	Up to 10 Mbps
LTE-M		Cellular bands	Up to 1 Mbps
Narrowband IoT (NB-IoT)		Cellular bands	Tens of Kbps

GNSS (GLOBAL NAVIGATION SATELLITE SYSTEM)

GPS	
L1	1575.42 MHz
L2	1227.60 MHz
L3	1381.05 MHz
L4	1379.913 MHz
L5	1176.45 MHz

GALILEO	
E1	1575.42 MHz
E5	1191.795 MHz
E5a	1176.45 MHz
E5b	1207.14 MHz
E6	1278.75 MHz

BEIDOU	
B1	1561.098 MHz
B1-2	1589.742 MHz
B2	1207.14 MHz
B3	1268.52 MHz

GLONASS	
L1	1598.0625 - 1605.375 MHz
L2	1242.9375 - 1251.6875 MHz
L3	1202.25 MHz