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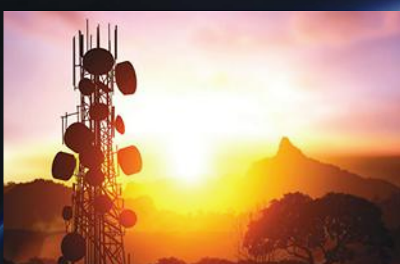

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SDLVA-315M362M-65-CD-1 https://www.pmi-rf.com/product-details/sdlva-315m362m-65-cd-1	315 - 362	-80 dBm	50	-65 to 0	3.75" x 1.5" x 0.5" SMA (F)
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SDLVA-0R71R3-75-CD-1 https://www.pmi-rf.com/product-details/sdlva-0r71r3-75-cd-1	700 - 1300	-70 dBm	40	-70 to +5	3.75" x 1.5" x 0.5" SMA (F)


GMDA-D1007


HADA-D2001


SDLVA-0R5G4G-70dB-100R


SDLVA-0R71R3-75-CD-1

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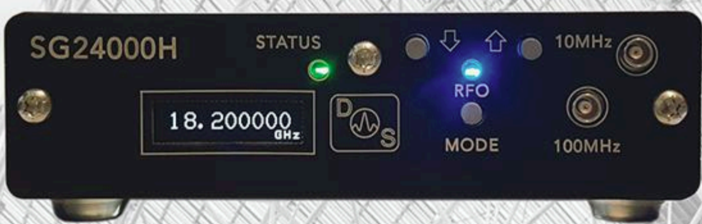

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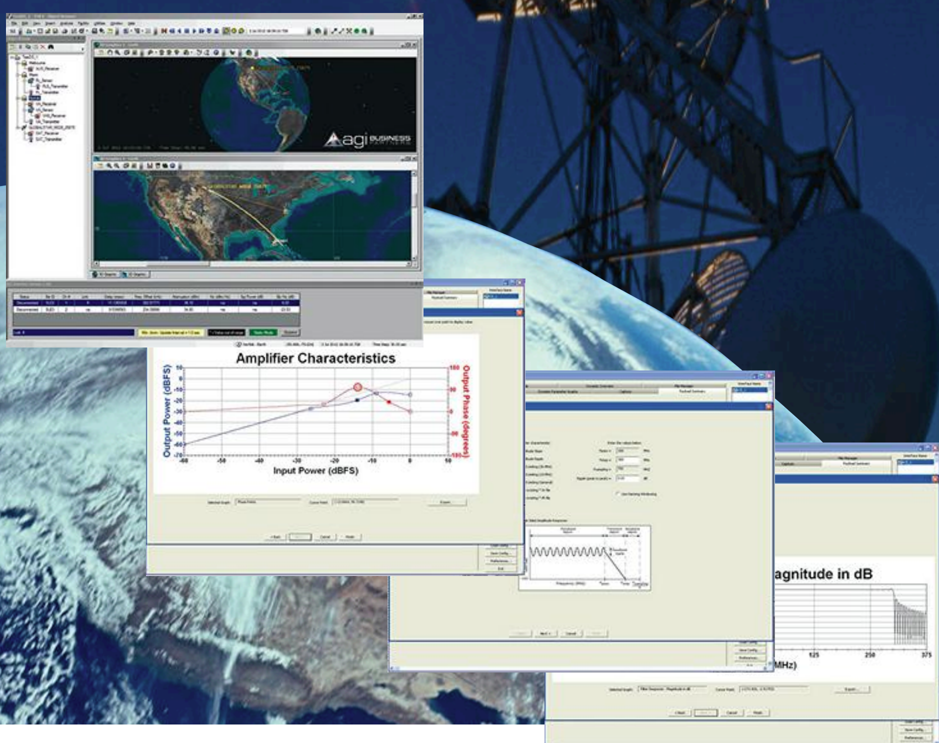

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Connecting Minds. Exchanging Ideas.
BOSTON 2019
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NEWS & COLUMNS

PRODUCTS & TECHNOLOGY

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defense electronics

Starts on page **89**

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Type	Failsafe	Latching	Normally Open	Terminations	SMA	2.92mm	Type-N	7/16, 4.3-10	SC	High Power (CW)	Low PIM (dBc)	Cycle Life
SPDT	✓	✓	✓	50Ω, 2W	✓	✓	✓	✓	✓	2kW	-170	5M
Transfer	✓	✓			✓	✓	✓	✓	✓	2kW	-170	5M
SPMT*	✓	✓	✓	50Ω, 2W	✓	✓	✓	✓	✓	2kW	-170	5M

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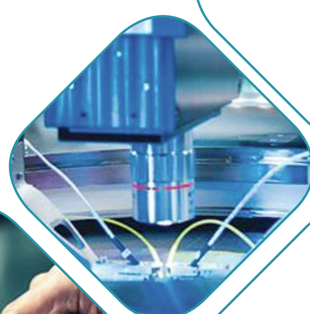

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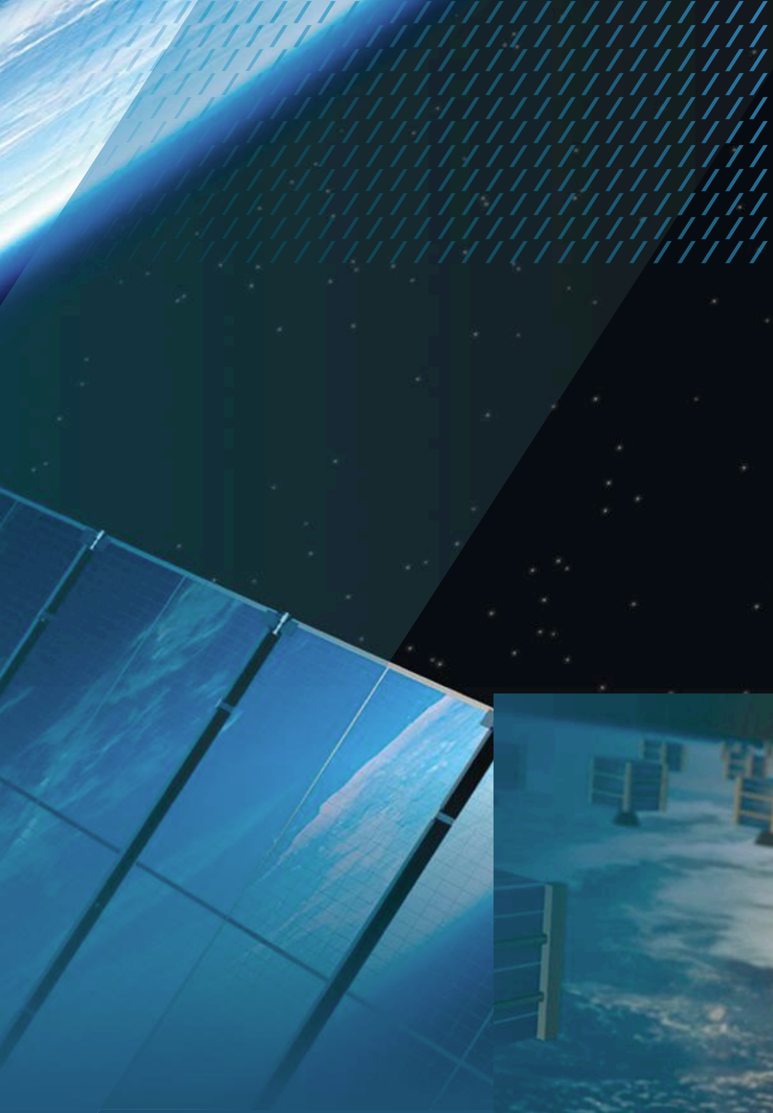
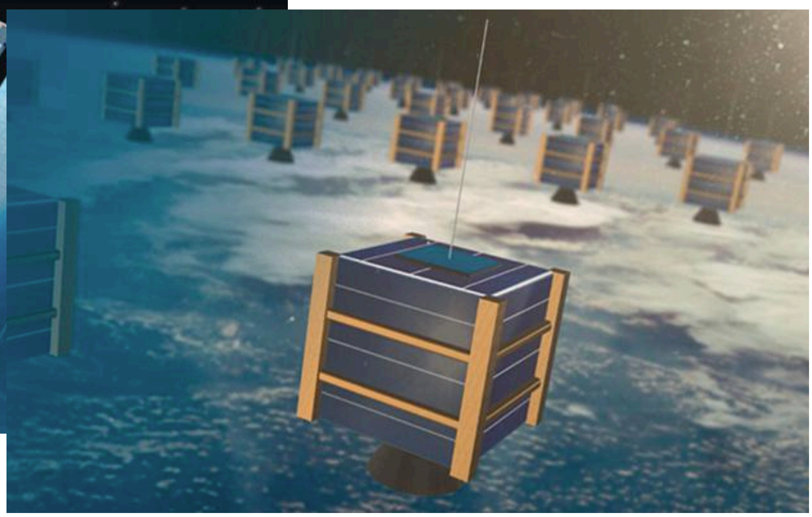
The Demand for 5G connectivity and high-speed mobile internet services is transforming Satellite Communication applications

Parameter	Units	MAAP-011202	MAAP-011298	MAAP-011289	MAAP-011250	MAAP-011140-DIE
Output Power	Watts	2.5	2.3	3	4	6
Frequency Range	GHz	12.7 - 15.4	27 - 31.5	28 - 30	27.5 - 30	27.5 - 30
Small Signal Gain	dB	30	24.5	24	24	24
Input Return Loss	dB	10	10	10	15	12
Output Return Loss	dB	10	10	14	15	12
P1dB	dBm	33.5	32.5	34	34.7	37.5
Psat	dBm	35	34	36	36	39
Output IP3	dBm	41	39	38	40	42
Package	–	5x5 mm 24-lead PQFN	5x5 mm 32-lead AQFN	5x5 mm 32-lead AQFN	5x5 mm 32-lead AQFN	Bare Die





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Algorithms to Antenna: Modeling Micro-Doppler Effects

Micro-Doppler effects are a result of motion with respect to platform motion. This blog post investigates these effects, using pedestrian identification and helicopter-blade-speed estimation as examples.

https://www.mwrf.com/systems/algorithms-antenna-modeling-micro-doppler-effects

Taking a Closer Look at MIMO Radio Systems

What are the factors that push designers to opt for multiple-input, multiple-output systems? Selective and non-selective fading, OFDM, and channel equalization, to name a few.

https://www.mwrf.com/systems/taking-closer-look-mimo-radio-systems

The Wireless Standard Shuffle from 1G to Wi-Fi 6

Wireless standards set the guidelines and limits for equipment manufacturers seeking to comply with the requirements of the latest wireless-communications networks.

https://www.mwrf.com/systems/wireless-standard-shuffle-1g-wi-fi-6

The Critical Role OTA Testing Will Play in 5G

For 5G applications, over-the-air testing will become a significant factor, especially when it comes to replacing traditional cabled measurements.

https://www.mwrf.com/test-measurement/critical-role-ota-testing-will-play-5g

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CHRIS DeMARTINO | Technical Editor
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Does the RF/ Microwave Industry Still Need an Influx of Youth?

Recognizing the importance of youth, this year's International Microwave Symposium places a significant emphasis on students and young professionals.

TWO YEARS AGO, I wrote a column titled, "Does the RF/Microwave Industry Need an Influx of Youth?" Now, as the entire industry prepares for this year's International Microwave Symposium (IMS), it may be worthwhile to once again ask this question.

At a recent industry event on Long Island, I heard one of the speakers say during a presentation that "we're not graduating many RF engineers." If that's a true statement, where does that leave this industry? And is the industry doing enough to attract the next generation of engineers?

The latter question can be addressed somewhat by looking at the program for IMS 2019. This year's event places a heavy emphasis on students and young professionals, evidenced by activities like student design competitions, as well as a student paper competition.

Another competition intended for students and young professionals is the Three Minute Thesis (3MT) competition, which returns to IMS for a third year. In this competition, contestants will give a presentation lasting three minutes or less that's supported by only one static slide.

It doesn't stop there: IMS 2019 also features student volunteer opportunities and a student career fair. In addition, there's the STEM Experience for Students and Teachers, which is a one-day event that introduces middle- and high-school students—as well as their teachers—to the world of microwave engineering.

Not to be outdone, the technical program includes the RF Boot Camp, a one-day course on RF basics. No doubt, students and young engineers stand to benefit from attending the course.

All of these activities demonstrate that the IMS steering committee is dedicated to attracting the next wave of engineers. One question that lingers, though, is whether employers are even willing to send younger engineers to IMS. After all, companies obviously need to spend money to send their personnel to events like this—and some may not consider it to be a worthwhile investment to allow younger staff members to attend. In any case, companies should recognize the value that younger engineers bring not only to themselves, but to the entire RF/microwave industry. It goes without saying that there's no future without them.

Finally, to those attending IMS this year (no matter your age), enjoy the show! mw

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LS0540 P40B	0.5 – 4.0	0.8	1.4:1	+21
LS0560 P40B	0.5 – 6.0	1.3	1.5:1	+21
LS05012P40B	0.5 – 12.0	1.7	1.7:1	+21
LS1020 P40B	1.0 – 2.0	0.6	1.4:1	+21
LS1060 P40B	1.0 – 6.0	1.2	1.5:1	+21
LS1012P40B	1.0 – 12.0	1.7	1.7:1	+21
LS2040P40B	2.0 – 4.0	0.7	1.4:1	+20
LS2060P40B	2.0 – 6.0	1.3	1.5:1	+20
LS2080P40B	2.0 – 8.0	1.5	1.6:1	+20
LS4080P40B	4.0 – 8.0	1.5	1.6:1	+20
LS7012P40B	7.0 – 12.0	1.7	1.7:1	+18

Note: 1. Insertion Loss and VSWR tested at -10 dBm.
Note: 2. Typical limiting threshold: +6 dBm.
Note: 3. Power rating derated to 20% @ +125 Deg. C.

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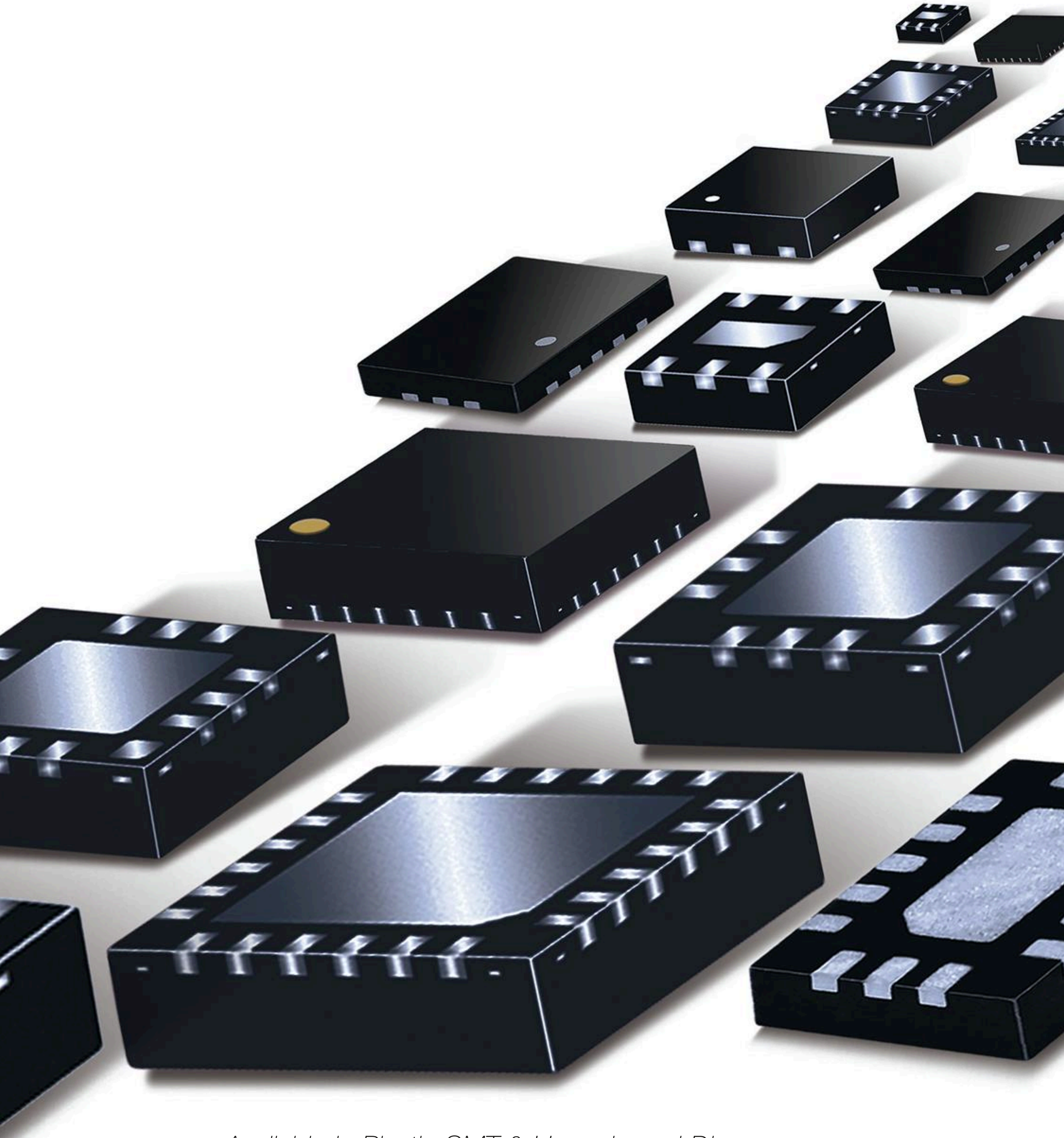

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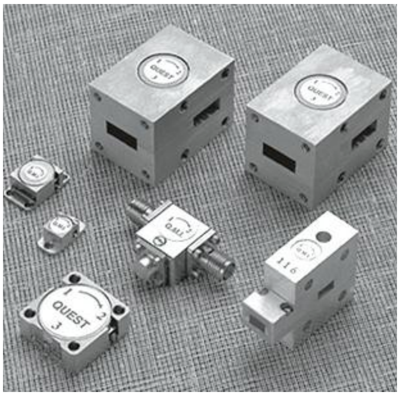

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EDITORIAL

GROUP CONTENT DIRECTOR: **KAREN FIELD** karen.field@informa.com
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

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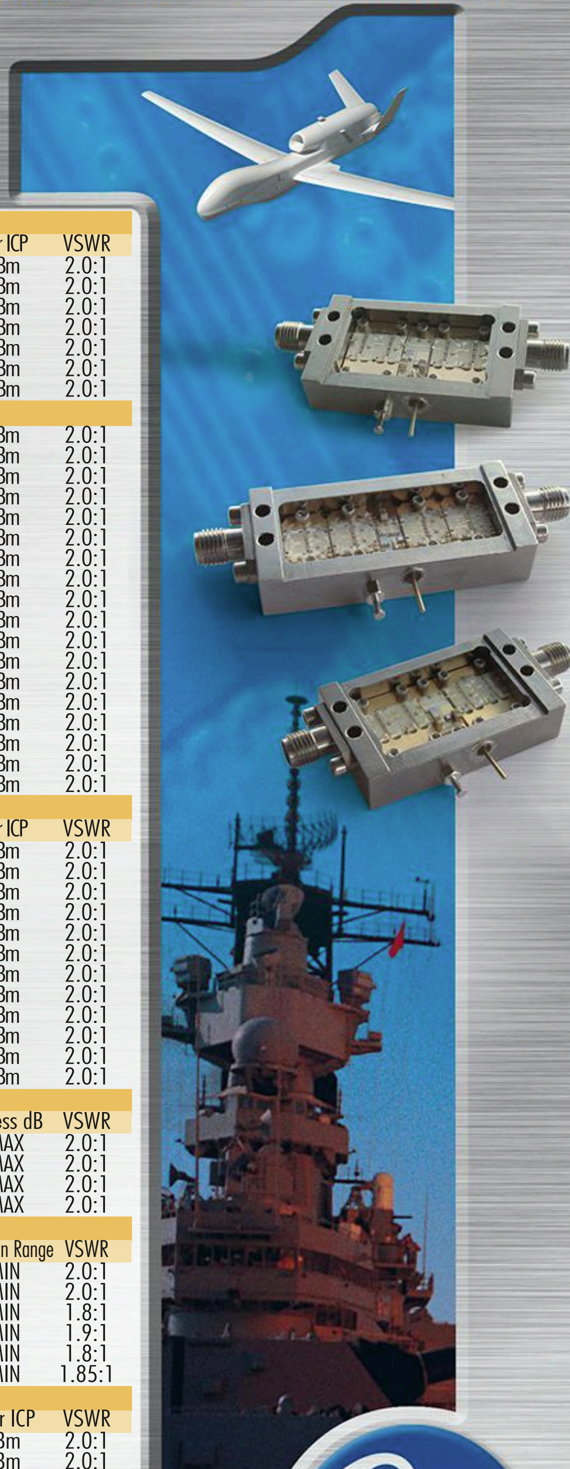

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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News

An All-Encompassing 5G UE TEST SOLUTION

Fully compliant with the 3GPP Release 15 non-standalone (NSA) specification, NI Test UE has the capability to emulate full user-equipment operation.

The NI Test UE gives customers a standard-compliant system ahead of the availability of commercial hardware.

National Instruments *(NI; www.ni.com)* continues to maintain its prominent role in the 5G communications space, demonstrated by the company's recent unveiling of its 5G New Radio (NR) Test User Equipment (UE) *(see figure)*. The NI Test UE is fully compliant with the 3GPP Release 15 non-standalone (NSA) specification. It emulates the entire UE operation and provides real-time performance information when connected to a base station (gNodeB). According to NI, "The NI Test UE can be used to test components, subsystems, and/or full base-station equipment at every earmarked 5G band in the lab or in the field."

The NI Test UE gives customers access to a UE that complies with the Release 15 NSA specification before commercial hardware is even available. According to Sarah Yost, senior solutions marketing manager, SDR, at NI, "As we're getting ready to release 5G, it's really important that we have ways to test out all of these new handsets with the other side of the network, i.e., the base station (gNodeB), in a lab environment and in the field before it gets too far."

Software-defined radio (SDR) lies at the heart of the NI Test UE. Yost explains, "With our Test UE, we've taken all the technology that's in a handset and we've built that up with software-defined radios (SDRs). Even though this is a lot bigger than an actual handset, there's a lot of power and computation happening."

Specifically, NI built the front ends of the Test UE with its own Universal Software Radio Peripheral (USRP) radios. The solution also contains additional amplification to achieve the full UE power level for field trials. In addition, the NI Test UE has a chassis full of FPGAs so that all processing can be performed in real time.

Yost also points out that "one of the great benefits of building the Test UE with SDRs is that we can also upgrade our software. We're currently on Release 15 running NSA. As the standards evolve, we can simply do a software update to get to the latest version and add new features like standalone (SA) mode."

With the NI test UE, users are able to monitor link performance in real time using the visualized measurements on the graphical user interface (GUI). Link performance can be analyzed and debugged offline with additional data logs.

The NI Test UE allows users to select a center frequency anywhere between 500 MHz and 6 GHz. It supports a 4-×-2 multiple-input, multiple-output (MIMO) configuration for 5G NR. Furthermore, NI can provide customers with an optional hard case for easy transporting. ■

VERO: THE PERPETUALLY POWERED Equipment Health-Monitoring System

NIKOLA LABS RECENTLY launched VERO, a perpetually powered health-monitoring system for different types of equipment. An Industrial Internet of Things (IIoT) solution, VERO is an out-of-the-box system for manufacturers to closely monitor process-critical equipment.

For now, the VERO platform will impact the manufacturing industry mostly, but Nikola leaders envision a future in which its wireless power will be used in other industries also.

"Think of how wireless internet revolutionized internet connectivity. Before, the interface was the ethernet cord. Then, Wi-Fi created mobility," said Will Zell, CEO and co-founder of Nikola Labs. "The transition from wired to wireless power delivery is going to have a similar effect. Twenty or thirty years from now, wireless power will be part of our everyday lives."

The proprietary platform uses cells that convert radio-frequency energy into usable direct current. VERO's wireless energy conversion technique was developed and patented at Ohio State University and is licensed exclusively to Nikola Labs.

Perpetually powered wireless sensors save time for facility managers. With VERO, data capture and system maintenance are going to be touch-free, says the company.

"Battery-powered sensors have a life of one to three years. That's okay if you have one device, but imagine if you have a thousand. You'd have to hire a full-time maintenance person who walks around doing nothing but replacing batteries. That's a nightmare," said Zell. "The whole promise of the VERO system is that you can make maintenance more efficient."

According to Nikola Labs, the VERO system can be customized and retrofitted to production equipment of any size or age. Once the system is installed, plant technicians will have immediate access to the sensors' data, and that information will be used by an analyst to provide real-world recommendations.

"If I just give you vibration data and you don't have any context, it's like handing a patient an EKG report and expecting them to figure out what's going on with their heart," explained Zell. "VERO analysts are going to be aware of problems and will proactively recommend action."

The VERO platform allows a manufacturer to shift from a time-based maintenance schedule to a condition-based maintenance schedule. The company claims that customers have found VERO to be more helpful than previous maintenance diagnosis methods.

"No one wants to be walking around taking vibration readings," said Zell. "Even if they do, those infrequent readings will never generate enough data for maintenance managers to implement a condition-based maintenance schedule."

VERO is subscription-based and includes a free trial period. Custom design of the system, professional installation and lifetime hardware and software upgrades are included.

"The Nikola Labs team will continually develop upgrades to the software and hardware connected to the VERO platform, and it is important to Nikola that innovations remain cost-free to customers," said Zell. ■

QUALCOMM AND APPLE Close Door on Ongoing Legal Conflict

APPLE ANNOUNCED THAT it had settled its wide-ranging and long-running legal battle with Qualcomm over patent licensing payments. As part of a broader settlement, Apple said that it had agreed to long-term licensing and chipset supply deals with its former main modem supplier, reestablishing its relationship with Qualcomm just as the smartphone industry shifts from 4G to 5G.

The announcement came as Apple and Qualcomm opened a federal court case over the patent dispute in San Diego, California. In addition to stamping out all ongoing legal conflicts, Apple announced a "multiyear chipset supply agreement" with Qualcomm, opening the door for the world's most profitable phone maker to use Qualcomm's modem chips in the iPhone. Apple also agreed to license Qualcomm's IP for six years.

As its legal skirmishes with Qualcomm escalated in recent years, Apple started to jettison Qualcomm's 4G modems in the iPhones in favor of Intel's, which are used inside all the latest iPhone models. Intel started supplying chips for Apple's 2017 iPhone, sharing orders with Qualcomm. The legal conflict centered on Apple accusing Qualcomm of using illegal patent practices to extract exorbitant royalties and maintain a monopoly on modem chips.

As the conflict continued, Apple and its contract manufacturers stopped paying royalties on Qualcomm's standard essential patents, which are vital to 3G and 4G communications. Qualcomm alleged that Apple was using its IP without paying for it. In November, Qualcomm said Apple was $7 billion behind on its licensing payments—an amount Apple contested. The settlement also includes an undisclosed payment from Apple to Qualcomm.

But amid all of the legal disagreements, the settlement suggests that Apple and Qualcomm needed each other. Qualcomm has long led the development of advanced modem chips, a vital component of 5G technology, which is projected to be more than 10 times faster than 4G networks while lowering latency. Qualcomm's 5G modems are considered the industry's most advanced, while Intel seemed to be struggling with its 5G modem engineering.

The truce is the worst-case-scenario for Intel. Not long after Apple announced the end of its legal skirmishes with Qualcomm, Intel said that it would get out of the smartphone modem chip business. Intel, the largest producer of chips used in personal computers and data centers, no longer intends to sell 5G modems for the smartphone space citing a lack of potential profits. Intel's 5G modem was set to start shipping to customers before the end of 2019. ■

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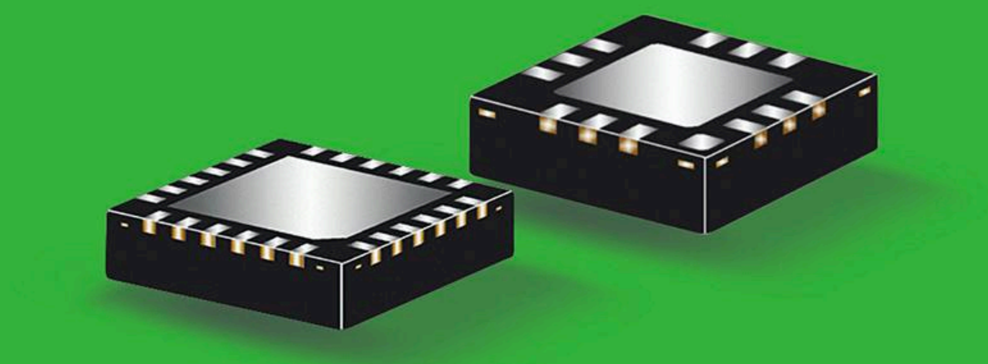

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NXP SEMICONDUCTORS SEES SALES Tumble Less Than Expected

WHEN QUALCOMM SCRAPPED its $44 billion deal for NXP Semiconductors last year, both companies were forced to figure out how to thrive without each other. San Diego, Calif.-based Qualcomm has been trying to muscle into the Internet of Things market, while Eindhoven, Netherlands-based NXP is trying to chart its strategy as artificial intelligence becomes a bigger part of its end markets.

The question of whether NXP will succeed should become clearer in the next few years. But the company's first-quarter results showed that it's not off to a bad start. NXP, the largest player in automotive chips, said that sales declined 8% since last year's first quarter to $2.1 billion, beating its $2.09 billion forecast. Gross profit fell 9% over the last year to $1.07 billion, on the higher end of its projected range.

"Due to a richer mix of sales and good expense control, we successfully delivered improved profitability," Richard Clemmer, NXP's chief executive, said in a statement.

NXP said it will report revenue of around $2.2 billion in the second quarter of 2019, representing a year-over-year sale drop of 4%. The company's gross profit is estimated to be about $1.15 billion. "We continue to believe the demand environment in the second half of 2019 should improve versus the first half, but the macroeconomic environment is still uncertain, especially in China," Clemmer said in the statement.

NXP's sales to the automotive industry fell from $1.13 billion to $1.04 billion over last year. Other automotive chip suppliers, including Texas Instruments and Infineon Technologies, have also sounded the alarm bell on dampened demand for chips used in cars. NXP's advanced driver assistance systems (ADAS) sales rose by more than 10% in the first quarter of 2019 while sales in every other product category slipped.

The company's communications infrastructure unit increased 10% over the last year to $449 million. Eindhoven, Netherlands-based NXP sells a broad range of radio frequency chips to base station OEMs, sales that have surged amid the shift to 5G technology. Industrial and Internet of Things sales slumped 14% over the last year to $368 million as demand for general-purpose microcontrollers declined in China. ■

ANALOG DEVICES NAMES New Chief Technology Officer

ANALOG DEVICES, THE second largest player in analog semiconductors, promoted Daniel Leibholz to chief technology officer. He will lead the company's technology strategy as it rolls out radio frequency, signal processing, power management and other products to its end markets. The hiring came as Analog Devices and the rest of the semiconductor industry struggle to shake a prolonged slowdown in demand.

Leibholz stepped up from his position as vice president of the communications business unit at Analog Devices. Sales of chips used in wireless and wired infrastructure have soared over the last year amid the shift to 5G technology, which enhances speed, reliability, capacity and latency compared to current 4G networks. The company's RF chips are key components in building out a new generation of 5G networks.

Before taking over the communications unit, Leibholz led the digital signal processing and consumer technology businesses. He is replacing Peter Real, who was chief technology officer in 2016, when Analog Devices sealed its $14.8 billion deal to buy Linear Technoloy, moving the Norwood, Massachusetts-based vendor deeper into the power management IC market. Leibholz was hired by Analog Devices in 2008. ■

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FREQUENCY-SELECTIVE SURFACES Go in Circles

A FREQUENCY-SELECTIVE SURFACE (FSS) holds great promise for a wide range of applications, from communications and security systems through radomes and radar surfaces. An FSS can function as a combination antenna, filter, and shield, depending on the shape of the FSS. Although not traditionally used, researchers from Spain and Portugal explored using combinations of multiple semicircles in two different FSS designs: a single-band, band-rejection design (or single-band, bandpass design when configured in reverse) and a dual-band FSS.

The single-band/band-reject FSS design was obtained from four semicircles with a 90-deg. rotation around the center between each other. The dual-band FSS combines eight semicircles in a pattern resembling a square shape, with alternating 270 and 180 deg. rotation around the edge of each semicircle. Such parameters as the conductor thickness and the radius of each semicircle determine the resonant frequencies of the structures.

Both FSS designs were simulated with commercial electromagnetic (EM) simulation software—CST Microwave Studio from Computer Simulation Technology *(www.cst.com)*. The four-semicircle FSS design was designed for resonant frequency of 2.4 GHz and compared with classical FSS designs using square, ring, and swastika configurations.

The four semicircles provided a bandwidth of 330 MHz at 2.4 GHz, compared to bandwidths of 1140, 820, and 680 MHz at 2.4 GHz for the square, ring, and swastika FSS configurations. Similarly, the eight-semicircle FSS was compared with dual-band classical FSS designs. The first resonance at about 3.1 GHz had a bandwidth of 600 MHz; the second resonance, at about 7.2 GHz, had a bandwidth of 275 MHz, or considerably narrower than the earlier dual-band FSS designs.

Measurements on the two FSS designs were made by fabricating the semicircle configurations in large numbers on FR-4 printed-circuit-board (PCB) material and then characterizing the PCBs on commercial test equipment. The single-band FSS was tuned to 2.4 GHz while the dual-band FSS was tuned for both 2.37 and 5.29 GHz. Relatively good agreement between computer simulations and measured results was found when allowing for small deviations in fabricated FSS dimensions.

See "Multi-Semicircle-Based Single- and Dual-Band Frequency-Selective Surfaces," *IEEE Antennas & Propagation Magazine*, April 2019, pp. 32-39.

PATCH ANTENNA, RECTIFIER Harvest 900-MHz Energy

ENERGY SURROUNDS US, which becomes ever-more crucial as demands for energy grow rapidly. Because of the global extent of wireless technologies and almost unlimited amount of electromagnetic (EM) energy being used for wireless communications, energy-harvesting techniques are being explored as ways to recapture some of the energy originally invested in those wireless systems.

Due to the differences in polarization for the many EM waves, energy harvesting relies on the appropriate receiving antenna, such as a circularly polarized (CP) antenna to capture CP EM waves. In that vein, innovators from Singapore have developed a tapered-slit CP patch antenna with a compact rectifier for energy-harvesting purposes. The antenna prototype shows more than 5.8 dBic gain across a bandwidth of 894 to 901 MHz with a 3-dB axial ratio (AR) beamwidth of more than 180 deg. A compact composite-right/left-handed (CRLH) rectifier operating at 900 MHz was designed for use with the antenna for energy-harvesting purposes.

Such a CP antenna is a good fit for energy-harvesting applications, since a CP antenna can harvest RF energy regardless of device orientation while also being relatively insensitive to multipath effects. With a wide AR beamwidth, the antenna can cover a large area and be made as small as practical while still capturing a large amount of available RF energy at 900 MHz. The rectifier converts the received RF energy to reusable dc energy. Ideally, the rectifier provides high RF-to-dc conversion efficiency so that most of the captured RF energy can be reused as dc energy and is not lost as heat.

By using a tapered-slit microstrip radiator patch printed on good-quality, high-frequency substrate material, RO4003 circuit material from Rogers Corp., eight tapered slits with length differences of 1.3% were implanted correspondingly on a patch radiator in the octagonal directions from the patch center. This was done to achieve miniaturization and an effective CP radiation pattern.

Computer simulations were performed with the aid of CST Microwave Studio from Computer Simulation Technology *(www.cst.com)*, which generated, for example, the surface current distributions of the proposed antenna. Most of the surface currents were found to travel around the tapered slits, and the size of the slit can be used to increase the path of the current as needed and to ultimately tune the antenna structure for frequency and gain. Measurements of a prototype design and the computer simulations were quite close, with the simulated AR 3-dB bandwidth from 898 to 903 MHz (5 MHz wide) in comparison to the measured AR bandwidth from 894 to 901 MHz (7 MHz wide).

See "A Wide-Angle Circularly Polarized Tapered-Slit Patch Antenna with a Compact Rectifier for Energy-Harvesting Systems," *IEEE Antennas & Propagation Magazine*, April 2019, pp. 94-100.

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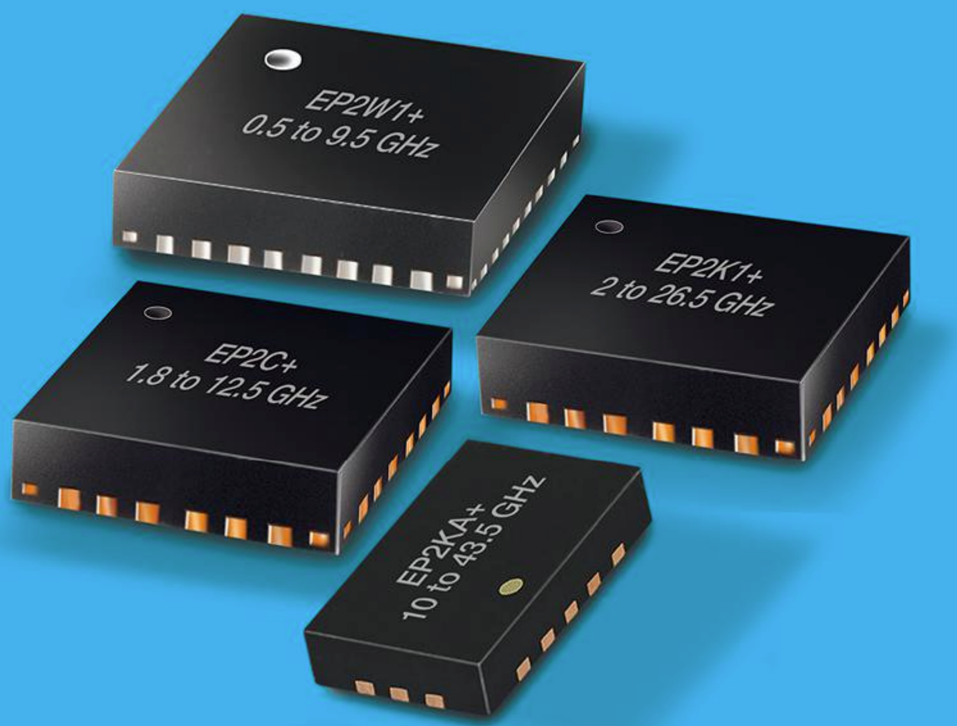

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The 2019 IMS Exhibition Brings High Expectations

During a time when defense electronics technology is strong, the industry readies itself for the global adoption of 5G and electronically steered vehicles.

In a year in which the RF/microwave industry is besieged with heightening demand for high-frequency technology different markets spanning everything from commercial to military, the 2019 IEEE International Microwave Symposium (IMS) will descend on one of the traditional centers of innovation and engineering: Boston, Massachusetts. With the ever-increasing numbers of applications for high-frequency electronics, this year's show promises to be one of the all-time best-attended IMS conferences and exhibitions.

Scheduled for the Boston Convention and Exhibition Center from June 2-7, 2019, the exhibition floor will host over 600 companies, offering an impressive cross-section of the many markets and technical segments of the RF/microwave industry. While any visitor would be hard-pressed to visit every exhibition booth at the 2019 IMS, time spent with any of the exhibitors will not be wasted. What follows is a brief summary of some of exhibitors and the products expected to be on display.

Whether it's for comparing passive components, active components, integrated circuits (ICs), software, or test-and-measurement equipment, visitors to the 2019 IMS will have an opportunity to "go shopping" for some of the latest technologies in the industry, from an array of the industry's best-known suppliers. With only three days, of course, the exhibition time passes quickly with each stop at each exhibition booth, making it difficult to cover a lot of ground on a crowded exhibition floor. Visitors are advised to save datasheets and brochures from each stop for future reference.

Attendees intrigued by what the Fifth Generation (5G) of cellular wireless communications will mean to business and personal lifestyles can receive a quick education with one stop, at the 5G Exhibition Pavilion **(Booth 2000).** This single-booth location offers visitors a chance to meet with representatives from a half-dozen companies involved in 5G systems: Mixcomm, Memtronics, Mixcomm, NanoSemi, Pentek, SynMatrix, and Silicon Solutions.

Memtronics will show where microelectromechanical-systems (MEMS) technology fits into a 5G future with a sampling of some of its components, including RF/microwave switches, phase shifters, and tunable filters. The technology can reach well into the millimeter-wave (mmWave) frequency range to serve applications in both commercial and military systems. Although MEMS components sacrifice a bit in switching speed over purely electronic components, the combination of mechanical and electronic functions in switches and other components is extremely reliable, with outstanding linearity compared to electronic components.

NanoSemi will share how it applies its digital signal compensation to analog radio designs to correct for nonlinear effects. Visitors to the 5G Exhibition Pavilion can also learn more about the specialized mmWave technology developed by Mixcomm from its founders Dr. Harish Krishnaswamy and Dr. Ashwin Sampath. Pentek will show some of its compact board-level solutions for digital signal processing and recording for commercial and military systems, including the latest member of the Jade family of high-performance 3U VPX modules, the

1. The ZVBP Series of compact cavity bandpass filters covers passbands to 15 GHz and stopbands to 20 GHz. *(Courtesy of Mini-Circuits)*

2. The WVBP Series of waveguide bandpass filters, developed jointly with Virginia Diodes, covers frequency bands from 27 to 86 GHz. *(Courtesy of Mini-Circuits)*

model 54851. With RF and optical interconnections, it's built around a high-speed field-programmable gate array (FPGA) and several high-resolution analog-to-digital converters.

SynMatrix will dive into its cloud-based computer-aided-engineering (CAE) tools for speeding and automating the RF/microwave component design process. Usable from almost any computer with access to the internet, these software tools allow such functions as filter design and tuning, circuit analysis, and even thermal analysis of high-power designs. Silicon Solutions will also welcome visitors with news about its semiconductor-based solutions for 5G.

Known to have one of the industry's widest assortments of active and passive components, Mini-Circuits **(Booth 330)** will bring an extensive sampling of its product lines, including the ZVBP Series of cavity bandpass filters *(Fig. 1)* with passbands to 15 GHz and stopbands to 20 GHz. As an example, model ZVBP-10R5G+ is a cavity bandpass filter with a passband from 9750 to 11250 MHz and stopband to 18 GHz. Insertion loss is typically 0.5 dB across the passband with a low VSWR of typically 1.30:1. The rejection across the lower stopband of dc to 5950 MHz is typically 51 dB, while the rejection for the upper stopband of 15.1 to 18.0 GHz is typically 45 dB. The filters are equipped with female SMA connectors and designed for operating temperatures from −40 to +85°C. They measure only 1.65 × 0.79 × 0.75 in. (41.92 × 20.00 × 19.00 mm) and handle input power levels to 1 W.

For compact filters at mmWave frequencies, such as for 5G and 77-GHz automotive radar testing, Mini-Circuits' WVBP Series of waveguide bandpass filters *(Fig. 2)* were developed in partnership with Virginia Diodes and cover frequency bands from 27 to 86 GHz. Equipped with standard rectangular-waveguide (WR) interfaces, these filters have low passband insertion loss and high stopband rejection to suppress unwanted signals. The RoHS-compliant filters are designed for operating temperatures from −40 to +85°C.

As an example, model WVBP-283-WR28+ has a center frequency of 28 GHz with a passband of 27.50 to 28.35 GHz. The lower stopband is 22 to 27 GHz and the upper stopband is 28.85 to 38.00 GHz. Passband insertion loss is typically 0.5 dB and passband return loss is typically 18 dB. The lower stopband rejection is 65 dB at 22 GHz and 30 dB at 27 GHz, while the upper stopband rejection is 39 dB at 28.85 GHz and 31 dB at 38 GHz. The filter includes a WR28 waveguide interface.

Mini-Circuits will also show a new line of LTCC baluns optimized for

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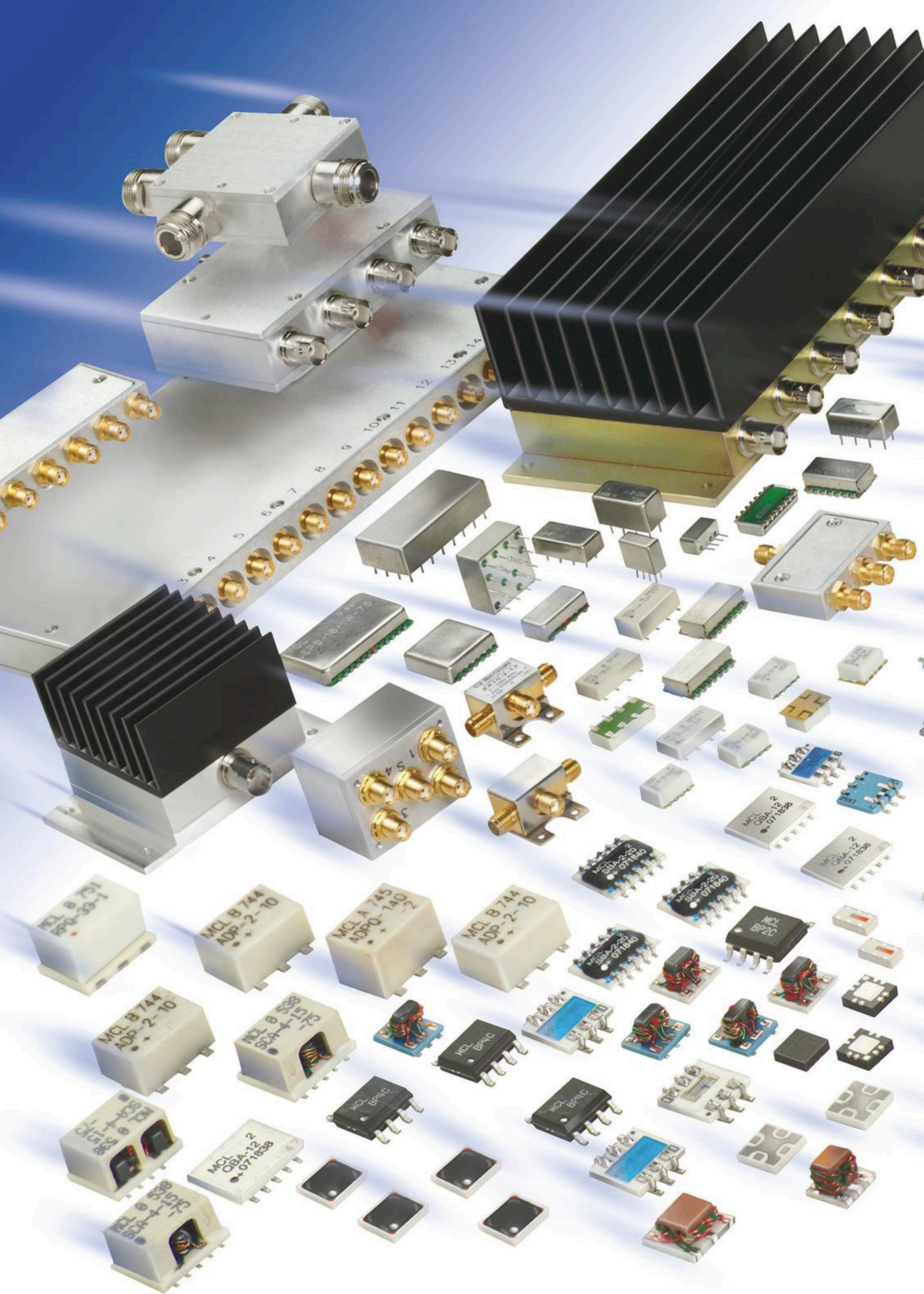

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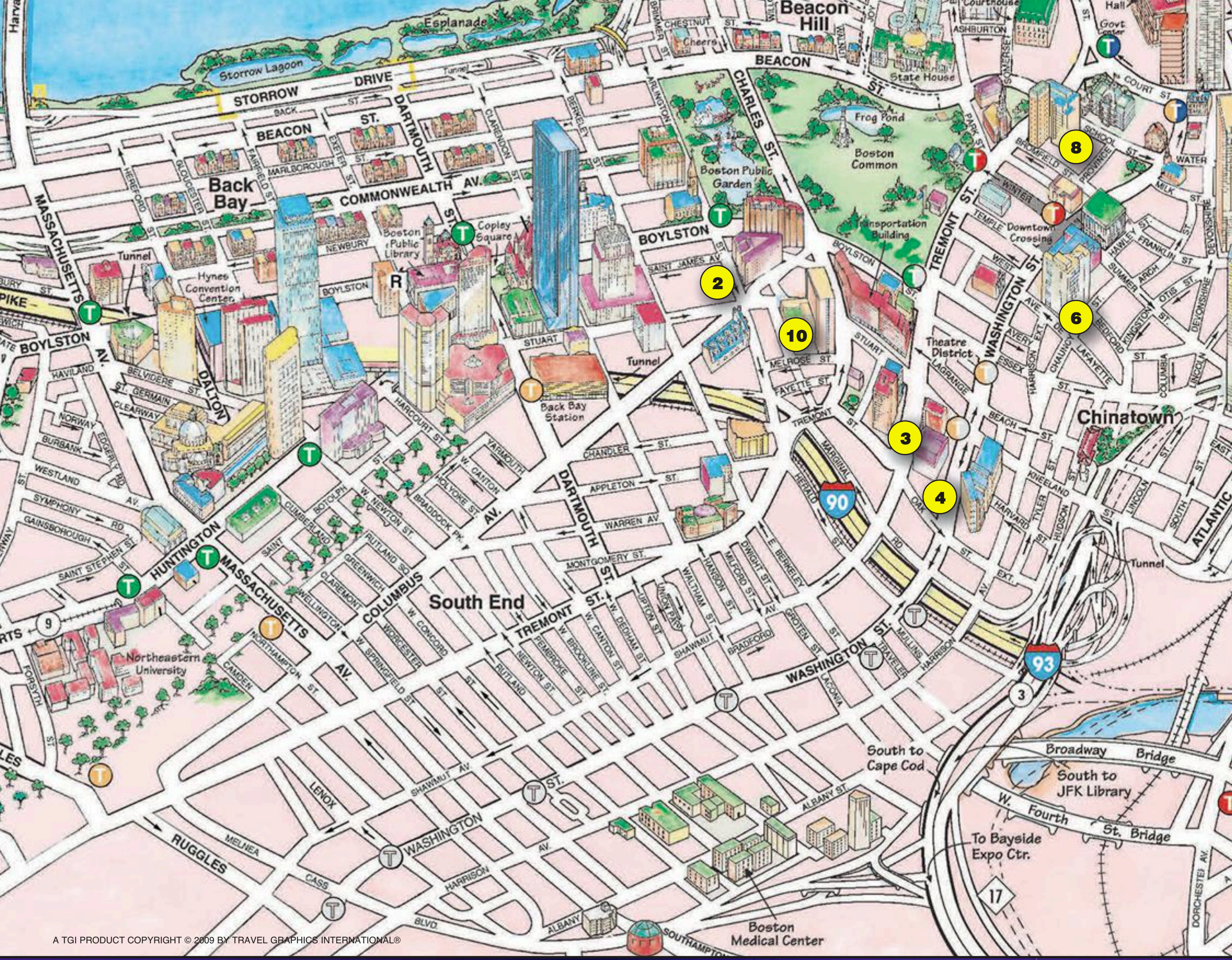

Enabling wideband frequency agility

GaN and GaAs Solid-State Power Amplifiers for Multi-Function, Radar, and EW System Design

Map provided courtesy of CTT, Inc.
Stop by the CTT Booth 1061

Whether your application is narrowband, wideband or ultra-wideband, operating in pulsed or CW mode, CTT's power amplifiers are an especially attractive choice for new multi-function frequency-agile systems that effectively conserve weight, space and power consumption.

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CTT INC.

5870 Hellyer Avenue, Suite 70
San Jose • California 95138
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www.cttinc.com

Wi-Fi, Bluetooth, and Zigbee wireless applications *(Fig. 3)*, including the BLIC, BLGE, and BLNK Series RF transformers and dc blocks. As an example, model BLGE1-252R+ is a 50-Ω LTCC balun RF transformer with 1:1 impedance ratio from 2.4 to 2.5 GHz. It measures just 0.079 × 0.049 × 0.037 in. (2.00 × 1.25 × 0.95 mm) but handles 3 W power at room temperature (+25°C). The RoHS-compliant transformer exhibits low phase unbalance of typically 5 deg. and low amplitude unbalance of typically 0.2 dB. It's designed for operating temperatures from −40 to +85°C, and is just one of many different components to be found at Mini-Circuits' exhibit booth.

3. A line of LTCC balun RF transformers has been optimized for wireless applications. *(Courtesy of Mini-Circuits)*

Charter Engineering **(Booth 660)** will be at the 2019 IMS exhibition with some of its latest RF/microwave switches, including low passive-intermodulation (PIM) models and switches ready for 5G applications from dc to 40 GHz. High-frequency switches *(Fig. 4)* include miniature failsafe single-pole, double-throw (SPDT) switches with SMA female connectors for use from dc to 26.5 GHz in the B1 series and miniature failsafe latching SPDT switches with female SMA connectors in the B10 series for applications from dc to 26.5 GHz.

Weinschel Associates **(Booth 372)** will show it precision components, including dc blocks, power dividers, terminations, and fixed and variable attenuators such as the model VA04 continuously variable attenuator for use from dc to 4 GHz. Available with an attenuation range of 30, 60, or 90 dB, the continuously variable attenuation is a good match for research and testing applications. It handles 5 W average power and as much as 500 W peak power for a 5-µs pulse at a 0.5% duty cycle. The bidirectional variable attenuator is equipped with female SMA female input and output connectors.

4. A broad family of RF/microwave switches from dc to 40 GHz includes models with low PIM. *(Courtesy of Charter Engineering)*

Coming off the cover story in the April issue of *Microwaves & RF*, Krytar **(Booth 825)** will be providing application suggestions on the use of its 100-GHz-bandwidth model 1100110010 directional coupler. Using 1.90-mm female coaxial connectors, the 10-dB coupler covers a frequency range of 10 to 110 GHz. The mainline insertion loss is only 5.5 dB across the full bandwidth, while the maximum VSWR is 2.50:1. The directional coupler is rated for maximum CW power of 20 W and peak power of 3 kW for pulse widths as wide as 100 µs.

GENERATING SIGNALS

Active and passive components are the building blocks for larger, more complex systems, and the IMS exhibition offers a virtual "real-time catalog" of these components in all shapes and sizes, from tiny chips to rack-mount enclosures, and from tiny integrated-circuit (IC) amplifiers to old-school tunable YIG oscillators. Among the many component manufacturers exhibiting at the 2019 IEEE IMS are several signal source suppliers, including clock oscillators, fixed and tunable RF/microwave oscillators, and frequency synthesizers for commercial, industrial, and military applications.

For example, Synergy Microwave Corp. **(Booth 750)** will highlight some of its many high-performance RF/microwave components, including frequency mixers, frequency synthesizers, and voltage-controlled oscillators (VCOs). One of the VCOs, model DCM02260-5, is a wideband unit with a tuning range of 220 to 600 MHz when fed tuning voltages of 0.5 to 24 V. The VCO, housed in a miniature surface-mount package, draws maximum current of 35 mA at +5 Vdc and provides at least +2 dBm output power across an operating temperature range of −40 to +85°C. The SSB phase noise is −108 dBc/Hz offset 10 kHz from the carrier, with typical harmonic suppression of 10 dB. The surface-mount VCO, with typical tuning sensitivity of 15 to 25 MHz/V, exhibits frequency pushing of typically 2 MHz/V and frequency pulling of typically 5 MHz into a 1.75:1 VSWR load.

At higher frequencies, Synergy will also have its model FSW85150-50 intelligent interactive frequency synthesizer for applications from 850 to 1500 MHz. Based on Synergy's patented REL-PRO technology, the extremely compact, RoHS-compliant frequency synthesizer is supplied in a miniature surface-mount package *(Fig. 5)*. It tunes in 500-kHz steps and settles to a new frequency of 5 ms or less. It's designed for use with a 10-MHz frequency reference and provides +4 dBm output power by means of a buffered 50-Ω output port. The high-frequency source achieves 85-dB typical spurious suppression and 20-dB typical harmonic suppression. It exhibits typical phase noise of −90 dBc/Hz offset 1 kHz from the carrier, −93 dBc/Hz offset 10 kHz, and −120 dBc/Hz offset 100 kHz. It includes a 3.3-V CMOS lock-detect

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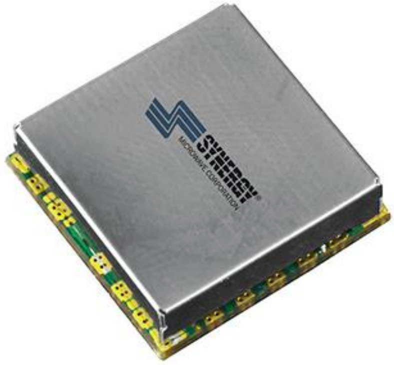


5. Model FSW85150-50 is an intelligent interactive frequency synthesizer for use from 850 to 1500 MHz. *(Courtesy of Synergy Microwave Corp.)*

indicator and is designed for operating temperatures from −40 to +85°C.

Of course, Synergy will have a great deal of company at the 2019 IMS in terms of oscillator and frequency-synthesizer suppliers, with many different source technologies represented. Micro Lambda Wireless **(Booth 1104)** will present a sampling of its extensive lines of YIG-tuned oscillators and low-noise frequency synthesizers, with wide tuning ranges and frequency coverage from 0.5 to 40.0 GHz. Oscillators come in miniature surface-mount-technology (SMT) packages, 1- and 1.24-in. cubes, 2-in.-diameter cylinders, and metal packages with coaxial connectors. For visitors in search of low phase noise at microwave and mmWave frequencies, these YIG oscillators can meet or beat the lowest noise levels available, with the ruggedness required for military applications.

The firm will also show some of its high-performance frequency synthesizers based on those YIG oscillators, for applications from 250 MHz to 33 GHz. For example, the MLMS-Series frequency synthesizers, capable of fitting into a single-slot PXI module, include models to 16 GHz with frequency tuning of 1 kHz. While current-tuned YIG oscillators offer outstanding phase noise, they lack tuning speed compared to other oscillator formats.

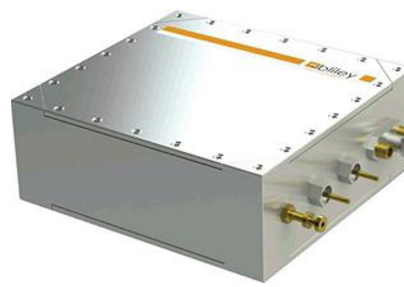
For applications requiring fast tuning speed, the MLVS-Series "LUXYN" frequency synthesizers are based on voltage-controlled oscillators (VCOs) rather than YIGs *(Fig. 6)*. They cover frequency ranges of 50 MHz to 10 GHz ad 50 MHz to 21 GHz with 50-µs tuning speed and phase noise of only −125 dBc/Hz offset 10 kHz from a 10-GHz carrier. They are well-suited for wideband receivers and test equipment.

6. The MLVS-Series LUXYN frequency synthesizer provides low-noise figures from 50 MHz to 21 GHz. *(Courtesy of Micro Lambda Wireless)*

Z-Communications **(Booth 155)** will present some of its many high-frequency signal sources, including fixed-frequency and tunable oscillators. For example, model SFS9280C-LF is a phase-locked oscillator (PLO) designed to produce a fixed-frequency output signal at 9280 MHz when operating with a 10-MHz reference oscillator. The PLO achieves phase noise of −80 dBc/Hz offset 1 kHz from the carrier, −100 dBc/Hz offset 10 kHz from the carrier, and −120 dBc/Hz offset 100 kHz from the carrier. It delivers 0-dBm output power while drawing 90 mA from a +5-Vdc supply and 11 mA from a +3-Vdc phase-locked-loop supply. The harmonic suppression is typically −30 dBc while spurious suppression is −65 dBc. The PLO comes in a compact housing measuring just 1.0 × 1.0 × 0.22 in. With an operating temperature range of −40 to +85°C, the PLO is a good fit for satellite-communications (satcom) applications.

The company should also have its model CRO4187E-LF RoHS-compliant VCO on display. With a frequency range of 4187 to 4188 MHz, the VCO is also a match for satcom systems and test-and-measurement equipment. It fits in a SMT package measuring 0.5 × 0.5 × 0.22 in. and draws 30 mA current from a +8-Vdc supply. It delivers +3.5 dBm output power into a 50-Ω load over temperatures from −40 to +85°C. Phase noise is −108 dBc/Hz offset 10 kHz from the carrier.

Bliley Technologies **(Booth 252)** will show its wide assortment of crystal oscillators, from temperature-compensated crystal oscillators (TCXOs) and oven-controlled crystal oscillators (OCXOs) to its advanced gravitation (g) compensated oscillators for satellite and space applications.



7. This low-g-compensated OCXO is available for fixed frequencies from 5 to 130 MHz. *(Courtesy of Bliley Technologies)*

For example, the Poseidon 2 low-g compensated OCXO *(Fig. 7)* is designed for high-vibration environments where dynamic phase-noise performance is critical. These OCXOs are built for much improved acceleration sensitivity over standard oscillators, with performance of 0.02 ppb/g. Available with fixed frequencies between 5 and 130 MHz, the OCXOs feature −130 dBc/Hz phase noise offset 10 Hz from the carrier with an almost unnoticeable aging rate of ±0.25 ppm for 20 years.

DRIVE BY CLOCK

CTS Corp. **(Booth 312)** will have some of its latest clock oscillators on dis-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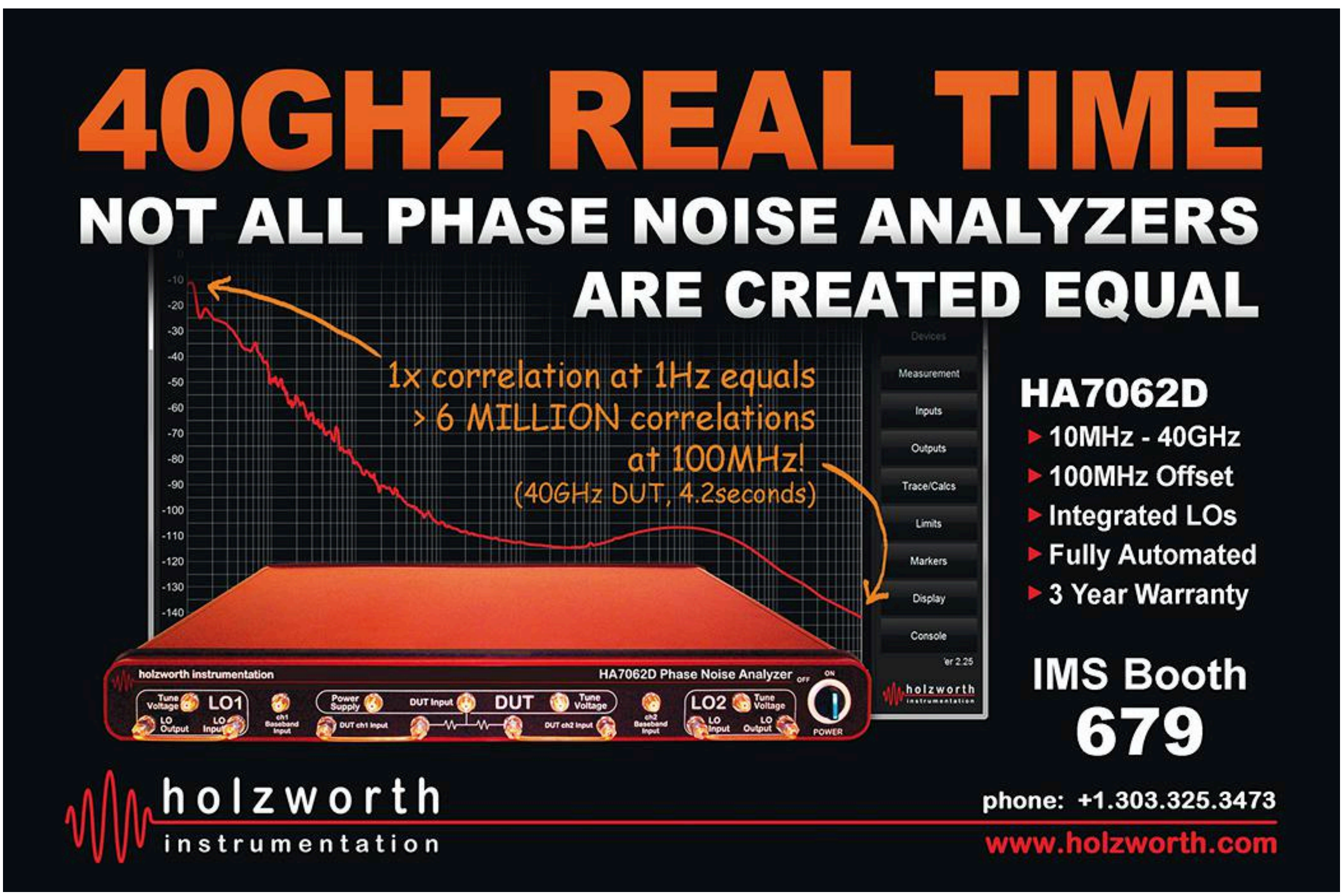
play at 2019 IMS, with some tailored for the growing automotive electronics markets. Typical clock frequencies include 12, 20, 25, 40, 50, and 125 MHz. The clock oscillators feature wide operating temperature ranges of –40 to +125°C for automotive, industrial, and commercial applications and –55 to +125°C for military and aerospace applications.

The CA Series oscillators are manufactured on TS16949-certified production lines and are AEC-Q200 qualified and PPAP-compliant for automotive, commercial, medical, and test-and-measurement applications, while the CHT Series oscillators are more aimed at military and aerospace applications over the wider temperature range. The oscillators are supplied in compact hermetic surface-mount packages. Each model delivers a CMOS output with typical rise/fall time of 5 ns. Frequency stability is as good as ±100 ppm for the CHT Series across the −55 to +125°C temperature range and ±25 ppm for the CA Series across the −40 to +85°C temperature range.

With its extensive lines of crystal oscillators (XOs) and oven-controlled crystal oscillators (OCXOs), Wenzel Associates **(Booth 680)** will be exhibiting numerous stable frequency reference sources. The firm's ONYX Series XOs *(Fig. 8)* provide low-noise fixed-frequency outputs from 10 to 160 MHz in many different mechanical configurations.

For example, models 501-22578e-01 through 501-22578e-06 are 10-MHz XOs well-suited for addition to PCBs with their through-hole mounting. Featuring low-g sensitivity and low phase noise, the oscillators are supplied in nickel-plated steel packages measuring just 1.0 × 1.0 × 0.5 in. They provide +10 dBm output power with ±2-dB output power flatness into a 50-Ω load. The SSB phase noise for the -01, -02, and -03 versions is −125 dBc/Hz offset 10 Hz from the carrier, −160 dBc/Hz offset 1 kHz from the carrier, and −165 dBc/Hz offset 100 kHz from the 10-MHz carrier. Phase noise for the -04, -05, and -06 versions is −135 dBc/Hz offset 10 Hz from the carrier, −163 dBc/Hz offset 1 kHz from the carrier, and −165 dBc/Hz offset 100 kHz from the 10-MHz carrier. The

8. The ONYX Series crystal oscillators (XOs) offer fixed-frequency outputs from 10 to 160 MHz. *(Courtesy of Wenzel Associates)*



9. The MXO families of multiplied crystal oscillators can be customized to fixed-frequency outputs from 200 MHz to 12 GHz. *(Courtesy of Wenzel Associates)*

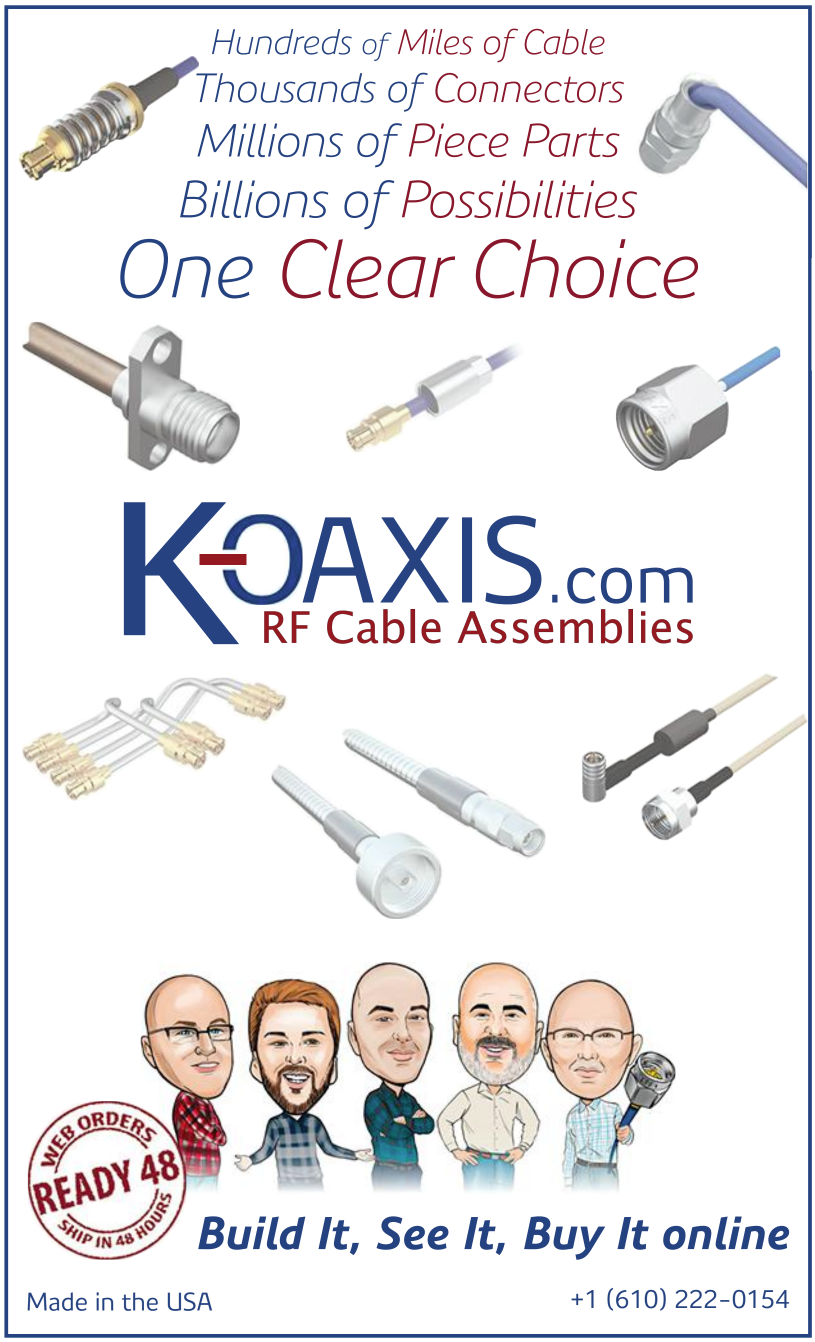
aging rates for all units are ±5 × 10-10/day after 30 days and ±5 × 10-8/year after 180 days. The ONYX oscillators are equipped with an internal voltage regulator and have an option for a TTL-compatible output.

At higher frequencies, the MXO families of multiplied crystal oscillators *(Fig. 9)* can be customized to fixed-frequency outputs from 200 MHz to 12 GHz. The multiplied sources incorporate an XO with integrated frequency multipliers, amplifiers, and filters supplied in a nickel-plated machined aluminum case to handle the most demanding environmental conditions. SMA connectors and solder pins are mounted on the side of the package. Standard output power is +13 dBm, with an option for output levels as high as +21 dBm. Typical phase noise is –160 dBc/Hz offset 100 kHz from a 500-MHz carrier, –154 dBc/Hz offset 100 kHz from a 1-GHz carrier, and –132 dBc/Hz offset 100 kHz from a 10-GHz carrier. The MXO sources can also be specified with an option for phase locking to an external reference source, such as a cesium time standard, a GPS signal, or an OCXO time standard.

BUILDING ON MATERIALS

Rogers Corp. **(Booth 448),** a well-known supplier of high-frequency materials for printed circuit boards (PCBs), will be among several circuit material developers at the 2019 IMS exhibition offering its latest materials for the mmWave circuits targeted at emerging 5G and autonomous-vehicle applications. Among their high-performance materials, Rogers will be showing RO3003G2, RO4835T, and RO4450T circuit materials.

The RO3003G2 ceramic-filled laminates are based on the popular RO3003 circuit materials, but enhanced for higher mmWave circuits. Ideal for 77-GHz automotive radar circuits, the laminates exhibit a dielectric constant of 3.00 ± 0.04 at 10 GHz and 3.07 at 77 GHz. The dissipation factor is a low 0.0011 at 10



GHz, while the thermal coefficient of dielectric constant is −35 ppm/°C in the z axis at 10 GHz from −50 to +150°C. The RO3003G2 materials feature low-profile electrodeposited (ED) copper and achieve extremely low insertion loss. The laminates can be transformed into microwave and mmWave circuits using standard PTFE circuit-board processing techniques with some minor modifications.

RO4835T materials are well-suited for multilayer circuit assemblies, with low loss and consistent dielectric constant for circuits fabricated on the inner layers. These spread-glass-reinforced ceramic thermoset laminates are flame retardant and available in 2.5, 3.0, and 4.0-mil thicknesses. Dielectric constant is tightly controlled to 3.3 in the z direction (thickness) of the material at 10 GHz for consistent board-to-board and across-the-board circuit performance. The loss is extremely low, with a dissipation factor of 0.0030 at 10 GHz and room temperature. Circuits on the RO4835T materials can be fabricated using the same processes as for standard FR-4 epoxy/glass-based circuit materials.

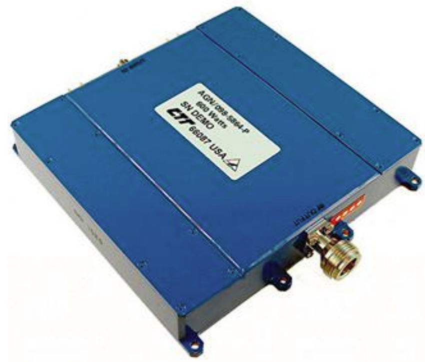
RO4450T bonding materials are meant to complement the firm's RO4000 family of laminates, providing secure bonds with low dielectric constant for multilayer designs with low loss. The spread-glass-reinforced, ceramic-filled bonding materials are available in multiple thicknesses—3, 4, and 5 mils—with corresponding dielectric constants of 3.23, 3.35, and 3.28 at 10 GHz, all held to a tolerance of ±0.05. The dissipation factor is 0.0040 or less at 10 GHz for all of the bonding material thicknesses. The coefficient of thermal expansion (TCE) is 62 ppm/°C (for the thickest material) and less for stable and secure performance over temperature.

Taconic Advanced Dielectric Div. **(Booth 504)** will offer up some of its advanced materials, including circuit laminates, prepregs, and bondplies. For circuit designers working at higher frequencies, EZ-10 woven-glass-reinforced polytetrafluoroethylene (PTFE) laminates provide stable foundations for mmWave circuits and high-speed digital circuits. Formed with nanotechnology reinforcement, these high-performance laminates feature excellent layer-to-layer consistency with very little variation in dielectric constant and minimal fiberglass content. The EZ-10 laminates are well-suited for circuit designs that combine high-speed digital and high-frequency microwave/mmWave circuits. The material was developed as an alternative to FR-4 for the most difficult 30-to-40-layer digital circuit designs.

PROVIDING A BOOST

2019 IMS attendees in search of the latest solid-state GaN power amplifiers will find a wide assortment at Empower RF Systems **(Booth 659).** From compact modules to fully equipped, rack-mount system amplifiers, these rugged amplifiers built on high-power GaN-on-SiC semiconductor technology deliver as much CW and pulsed power as possible from such small housings. For example, model BBM5K8CKT is a compact module rated for at least 100 W CW output power from 2500 to 6000 MHz, with typical output power of 125 W. It provides 60-dB typical small-signal gain. The Class AB linear amplifier features built-in control and monitoring, with protection functions to ensure high availability.

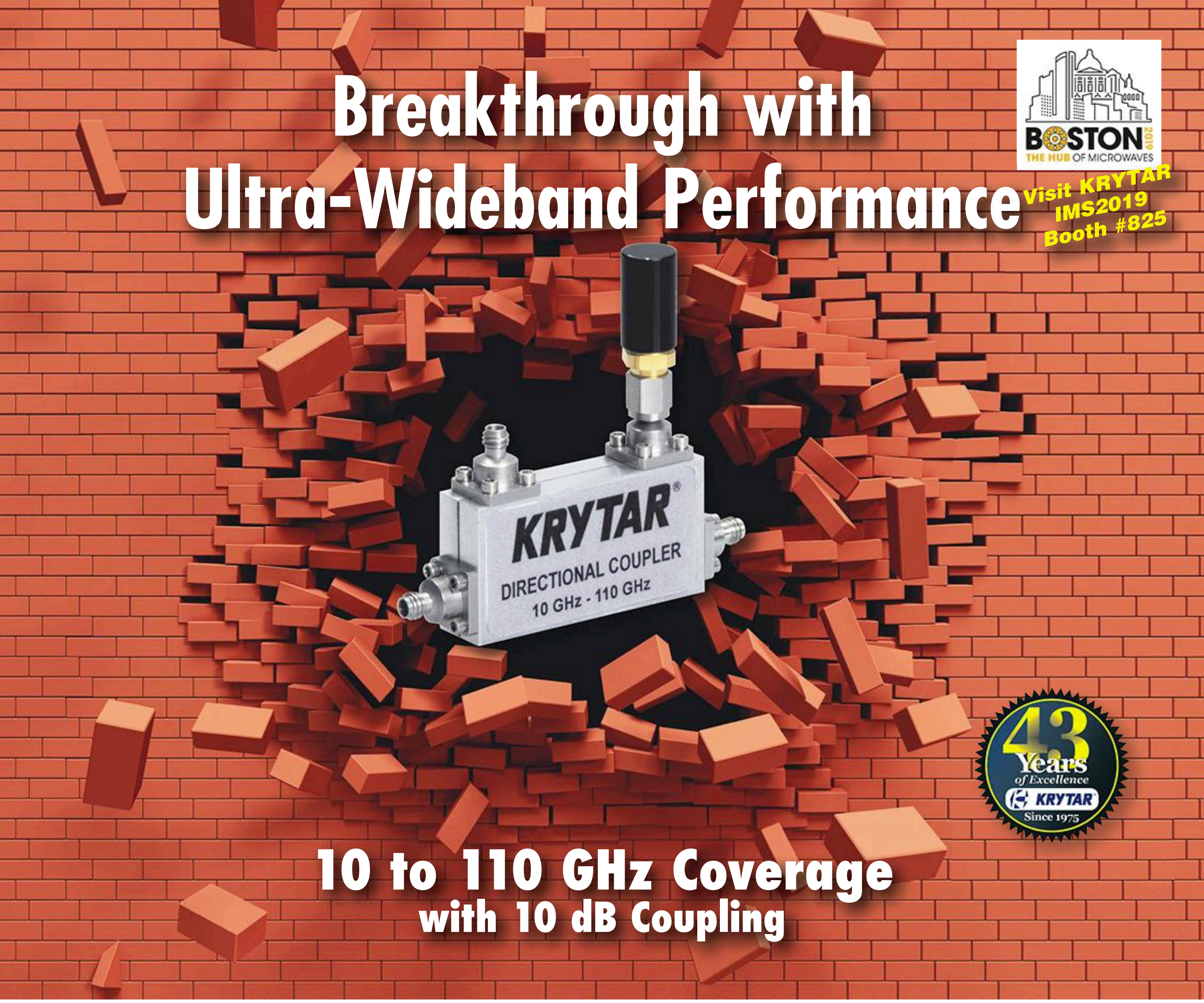
On a larger scale, model SKU 2221 is a full rack-mounted amplifier system teaming multiple GaN devices to reach at least 8 kW peak pulsed output power from 9 to 10 GHz. It includes EMI filters for shielding, fans for cooling, and has a built-in control and monitoring system, with protection functions. Designed for operation from 180- to 260-Vac power supplies, the amplifier system has an embedded web server that allows network-managed monitoring and control by connection to a local area network (LAN). Ideal for industrial, test, and military radar applications, the amplifier system is rated for maximum pulse width of 500 µs at 20% maximum duty cycle and 400-kHz maximum pulse repetition frequency (PRF). The amplifier covers its 1-GHz bandwidth with 70-dB minimum power gain and power gain flatness of ±1 dB.



10. This compact amplifier is designed for X-band synthetic aperture radar (SAR) applications such as in UAVs. *(Courtesy of CTT)*

CTT Inc. **(Booth 1061),** a veteran exhibitor at IMS shows, will be at the 2019 IMS with its model AGN/098-5864-P X-band power amplifier for synthetic aperture radar (SAR) applications. The robust amplifier *(Fig. 10)* provides more than 600 W output power at 9.5 GHz when operating with pulse signals at 10% duty cycle. The amplifier, which is housed in a compact package measuring 6.17 × 6.60 × 0.82 in., is a good lightweight fit for many UAV applications.

Similarly, dB Control **(Booth 1416)** will provide examples of its many different power amplifiers, from compact modules to larger systems. The firm will show the recently introduced model dB-3774B pulsed microwave power module (MPM) for amplification applications from 6 to 18 GHz. It provides 1 kW peak output power at 5% maximum duty cycle in a package weighing 18 lbs. and measuring 7 × 3 × 18 in. The amplifier module is a good fit for radar jamming and other electronic-warfare applications. It's based on "old school" vacuum-tube technology, with a conduction-cooled miniature traveling-wave tube as the active device and a solid-state amplifier for gain.



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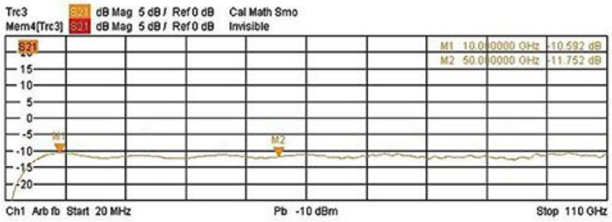

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California Eastern Labs **(CEL, Booth 231)** will be at the 2019 IMS with a collection of its RF/microwave switches and high-performance amplifier ICs, including its recently introduced model CA3509M4 low-noise-amplifier (LNA) IC. Ideal for global navigation satellite systems (GNSS), satellite radio systems, and microwave communications links at L- to S-band frequencies, the LNA IC is supplied in a flat-lead, four-pin package. It has a typical noise figure of 0.4 dB at 1575 MHz when running on 15 mA at +3 Vdc. The typical gain is 17 dB at that same frequency, with +4.5 dBm typical input third-order intercept point and +12-dBm typical output power at 1-dB compression.

Kratos Microwave Electronics Div. (the former General Microwave) will arrive at the 2019 IMS **(Booth 617)** with a small sample of its diverse product lines for commercial and military applications. These include integrated microwave assemblies (IMAs), frequency-converter assemblies, transmit/receive modules, switched filter banks, and detector log-video amplifiers (DLVAs).

For system designers in need of high pulsed gain, Kratos' SPA-X1-400 is one example of many SSPAs for pulsed microwave applications. With a maximum bandwidth of 400 MHz from 8.5 to 10.9 GHz, the amplifier module generates 100 W average power and 400 W peak output power when operating with pulse widths from 0.2 to 60 μs at maximum duty cycle of 25% and PRF of 1 to 600 kHz. The SSPA module measures 11.0 × 5.5 × 2.9 in. (280 × 140 × 75 mm) and is designed for operating temperatures from −40 to +85°C. The former Herley Industries will also be exhibiting at the 2019 IMS as part of the Kratos exhibition area.

Agile Microwave Technology **(Booth 1442)**, which recently moved to a larger facility in Cary, N.C., will provide examples of its high-performance, cost-effective components, such as compact high-power amplifiers for frequencies from 0.1 through 30.0 GHz. The amplifiers are based on GaN and GaAs semiconductor technologies and provide output levels to 100 W CW and 150 W pulsed power. The rugged amplifiers, which are available in broadband and narrowband versions, can also be supplied in many different linearity and efficiency configurations, including Class A, Class AB, Class C, Class D, and Class E.

QuinStar Technology **(Booth 327)** will be unveiling some new products and prototypes, along with some recent additions to its mmWave lineup of active and passive components, such as its model QPP-94043335-00 W-band dual-model solid-state amplifier *(Fig. 11)* for pulsed and CW use. The GaAs-based MMIC amplifier operates at W-band frequencies from 92 to 96 GHz with 2 W saturated output power under pulsed conditions. Suitable for radar and test applications, the amplifier is available with and without a heatsink.

11. This GaAs-MMIC amplifier is designed for pulsed and CW signals at W-band frequencies from 92 to 96 GHz. *(Courtesy of QuinStar Technology)*

SEEKING SEMICONDUCTORS

For semiconductor and chip manufacturers, MRSI Systems **(Booth 686)** will make the short trip to Boston to show its MRSI-HVM3 family of die-bonding systems. Providing the speed to serve die-bonding requirements for rapidly emerging, high-volume markets such as 5G and automotive radar systems, these die bonders offer zero-time tool changes between working on different dice, as well as better than 3-μm accuracy. The die-bonding system has been developed for specific applications, including chip-on-carrier (CoC), chip-on-submount (CoS), and chip-on-baseplate (CoB) assembly using eutectic and/or epoxy stamping die bonding.

Skyworks Solutions **(Booth 424)** will be on hand with some of its many subsystem and component solutions for 5G systems, including its recently introduced miniature waveguide circulators. The small sizes of these circulators make them well-suited for size-sensitive applications, such as in 5G massive multiple-input, multiple-output (MIMO) antenna and small-cell applications.

As an example, model SKYFR-001657 is a single-junction circulator for use from 3400 to 3600 MHz. Supplied in a RoHS-compliant, compact surface-mount package, the circulator handles as much as 15 W average power and 30 W peak power. The 50-Ω circulator exhibits typical insertion loss of just 0.25 dB and has an operating temperature range of −40 to +105°C. The circulator is a good fit for protecting power amplifiers (PAs) from damage from reflected power. Skyworks will also have a sampling of its many PAs and LNAs for wireless applications, such as in 5G infrastructure systems.

Analog Devices **(Booth 918)** will be close to home in the Boston Convention Center for the 2019 IMS, with many of its high-performance ICs on display, including its new model ADF5610 wideband frequency synthesizer with integrated VCO. With a frequency range of 57 MHz to 14.6 GHz, the device operates in fractional-N and integer-N frequency-synthesizer modes. It contains a 24-b fractional modulus that helps the synthesizer achieve outstanding performance, with typical phase noise of −115 dBc/Hz offset 100 kHz from a 7.3-GHz carrier and integrated RMS jitter of less than 40 fs. The source provides +5 dBm output power and maintains frequency lock over a temperature range of −40 to +85°C.

Another long-term leading local semiconductor supplier, MACOM

(Booth 532), will show off a number of its recent developments in support of continued 4G Long Term Evolution (LTE) wireless base stations and emerging 5G base stations. It will exhibit some of its many RF/microwave and optical solutions for 5G communications, including high-speed switches, amplifiers based on GaN and GaAs semiconductor technologies, and antennas that employ coherent beamforming to create highly focused beams to connect wireless users to base stations.

Custom MMIC **(Booth 1350)** will be ready to explain the use of its high-performance GaAs MMIC amplifiers to visitors at the 2019 IMS, including its model CMD275 low-phase-noise-amplifier die with a frequency range of dc to 26.5 GHz. Well-suited for military, space, and communications applications, the broadband 50-Ω amplifier die provides 16-dB gain at 10 GHz, with noise figure of 5.5 dB and saturated output power of +20.5 dBm. The low-phase-noise performance refers to single-sideband (SSB) phase noise of –165 dBc/Hz offset 10 kHz from a 10-GHz carrier.

For narrower-bandwidth requirements, the model CMD283 LNA GaAs MMIC die that's impedance-matched to 50 Ω for ease of use. It provides 27-dB gain across a frequency range of 2 to 6 GHz with low 0.6-dB noise figure and +16-dBm output power at 1-dB compression. Targeted at EW and communications systems, the LNA is fully passivated for increased reliability and moisture protection. At higher frequencies, the model CMD293 medium-power driver amplifier covers 20 to 45 GHz for communications and military applications. It provides 20 dB gain at 30 GHz with a typical noise figure of 6 dB. The output power at 1-dB compression at 30 GHz is +31.5 dBm. As with the other two amplifier dice, the CMD293 is impedance-matched to 50 Ω. It integrates a temperature-compensated power-detection circuit for added convenience.

Representatives from Xilinx **(Booth 194)** will explain how the company has been able to extend its Zynq UltraScale+ Radio Frequency (RF) System-on-Chip (SoC) portfolio with devices for the full frequency range below 6 GHz. The single-chip SoCs support direct RF sampling to 5 Gsamples/s with 14-b analog-to-digital converters (ADCs) and 10-Gsamples/s with 14-b digital-to-analog converters (DACs). It features 20% reduction in power consumption compared to earlier attempts to provide sub-6-GHz radio coverage for such applications as 5G wireless communications systems and phased-array radars.

SOFTWARE SOLUTIONS

Sonnet Software **(Booth 430)** will be on hand at the 2019 IMS exhibition to describe the best uses of its planar

electromagnetic (EM) electronic-design-automation (EDA) software for modeling chips and ICs, low-temperature-cofired-ceramic (LTCC) components, and PCB designs. Sonnet's design and analysis software is used to model IC layouts even to submicron levels and has been applied to a wide range of semiconductor technologies, including GaN, GaAs, indium-phosphide (InP), and silicon-germanium (SiGe) circuits.

For designers working with LTCC, the Sonnet Professional Suites software tools provide the capabilities to model the most complex LTCC circuit designs, with large numbers of active and passive devices, ports, and dielectric layers. For PCB designers, the planar EM software provides an efficient means of modeling and analyzing circuit, device, and component characteristics such as loss and coupling on many different transmission-line technologies. These include microstrip, stripline, and coplanar waveguide, and many different types of dielectric circuit materials.

The software has enough processing power to handle multilayer PCB designs even when different circuit materials are used with deviations in material characteristics, such as dielectric constant with temperature. For designers looking to perform EM analysis on a smaller computer, the staff at Sonnet Software will also be happy to discuss the benefits of its Sonnet Lite software.

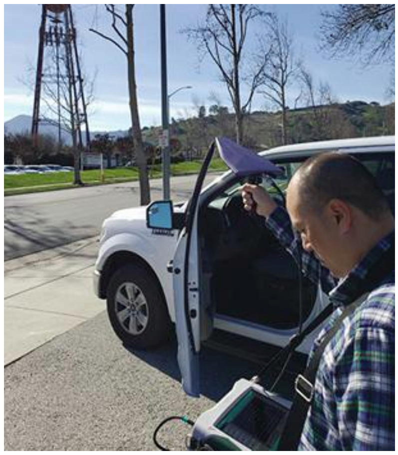
MathWorks **(Booth 1336)** will bring much more than its software to the 2019 IMS exhibition, providing four two-hour technical sessions called "Industry Workshops" for attendees interested in learning more about 5G, automotive radar, and how to apply MATLAB software to the analysis of those systems. The topics for the four workshops are "Hybrid Beamforming for 5G Systems," "Introduction to the 5G NR Physical Layer Standard," "Antenna, Array Design and Prototyping Using MATLAB," and "Automotive Radar IQ Data Simulation for Performance Analysis." These two-hour sessions will include presentations, demonstrations, and interaction with attendees.

Remcom **(Booth 1012)** will demonstrate its assortment of EM simulation software programs, including its Wavefarer radar simulator for modeling automotive radar systems to 100 GHz and beyond. The software employs near-field propagation analysis to calculate scattering from different target surfaces and multipath interactions with ground reflections. It also allows users to perform dynamic analyses to study scenarios with movements of radar sensors, target vehicles, and other scatterers in the modeled environment. Users can import radiation patterns from measured or simulated antennas to analyze many different operating environments for automotive radar systems.

MEASURING ADVANCES

For those seeking new test solutions, the 2019 IMS will provide more than its share, with many of the leading suppliers of RF/microwave measurement instruments on the exhibition floor, literally from A to Z. Among the many test solutions at its exhibition display **(Booth 542)**, Anritsu Co. **(Booth 542)** will show its recently introduced Field Master Pro portable spectrum analyzers with frequency ranges of 9 kHz to 9 GHz, 9 kHz to 14 GHz, 9 kHz to 20 GHz, 9 kHz to 26 GHz, 9 kHz to 32 GHz, 9 kHz to 44 GHz, and 9 kHz to 54 GHz. Visitors to the IMS exhibition will want to play with these model MS2090A spectrum analyzers to see what signals can be detected on the show floor.

The analyzers are small and light enough for easy transport in the field *(Fig. 12)*, but they show signals clearly on a 10.1-in. diagonal color touchscreen display. They can run for more than 2 h on battery power and reach "into the noise" to see low-level signals with a displayed average noise level (DANL) of −164 dBm when working with a preamplifier. With a third-order intercept (TOI) of +20 dBm, the spectrum analyzers can also detect and display any large signals in their range.



12. The Field Master Pro portable spectrum analyzers are ideal for measurements in the field. *(Courtesy of Anritsu Co.)*

Berkeley Nucleonics **(Booth 1214)** will offer demonstrations of several of its high-performance test instruments, including its model 855B multichannel RF/microwave signal generators. Available in different formats with as many as eight channels, these test signal sources cover frequency ranges from 300 kHz to 6.2, 12.5, 20.0, and 40.0 GHz, with tuning resolution as fine as 1 Hz (and 0.001 Hz as an option) and frequency switching speeds as fast as 25 µs. These low-noise signal generators provide power levels from −90 to +27 dBm. The model 855B is supplied in a standard 19-in. 1U rack-mountable module format for as many as four channels and a 3U rack-mountable format for as many as eight channels.

Standard model 855B signal generators feature low phase noise of −87 dBc/Hz offset 10 Hz from a 1-GHz carrier,

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–115 dBc/Hz offset 1 kHz from the same carrier, and –140 dBc/Hz offset 100 kHz from a 1-GHz carrier. Standard units make it possible to set the phase relationship between signal channels in 0.1-deg. increments over a phase range of 0 to 360 deg., and an option is available for phase-coherent output signals. Standard control interfaces include USB, LAN, and GPIB.

13. The model 50PSA-101-XX programmable phase-shifter assembly has a phase range of 0 to 358.6 deg. in 1.4-deg. steps for center frequencies from 1.5 to 3.0 GHz. *(Courtesy of JFW Industries)*

For those in need of signal phase control for testing and system-level applications, JFW Industries **(Booth 607)** will be demonstrating its model 50PSA-101-XX programmable phase-shifter assembly with a phase range of 0 to 358.6 deg. in 1.4-deg. steps. Packed into a 2RU-high, 19-in. rack-mountable enclosure, the phase shifter's center frequency can be selected from 1.5 to 3.0 GHz. The assembly *(Fig. 13)* is available with as many as eight individually programmable phase shifters.

Although known for its high-power components, Werlatone **(Booth 961)** also supplies handy digital power meters for remote and local measurements of high RF/microwave power levels at frequencies to about 5 GHz. For example, model WPM11505 is a digital power meter for use from 800 to 2500 MHz. It can measure CW power levels to 1500 W with accuracy that's within ±1% of a customer-calibrated standard at preselected frequencies and within ±5% over a multi-octave bandwidth.

For temperature monitoring, the compact WPM11505 includes one sensor within the instrument for internal measurements and one sensor for placement by a user for external measurements. It's equipped with female 7/16 coaxial connectors and can be used at operating temperatures from –55 to +75°C. The digital power meter can be operated with a Microsoft Windows-compatible, PC-based graphical user interface (GUI) and includes RS-232, RS-485, and TCP/IP interfaces. A RoHS-compliant version is also available.

For those in need of an affordable vector network analyzer (VNA), Copper Mountain Technologies **(Booth 1160)** will be on hand with its M Series two-port VNAs *(Fig. 14)* covering frequency ranges of 300 kHz to 6.5 GHz (model M5065), 300 kHz to 8.5 GHz (model M5090), and 300 kHz to 18 GHz (model M5180). The compact VNAs are compatible with S2VNA software running on Windows or Linux operating system (OS) for displaying results on a PC screen. The analyzers boast a minimum dynamic range of 125 dB and typical measurement time of only 70 μs.

14. The M Series of two-port VNAs provides measurement ranges from 300 kHz to 18 GHz. *(Courtesy of Copper Mountain Technologies)*

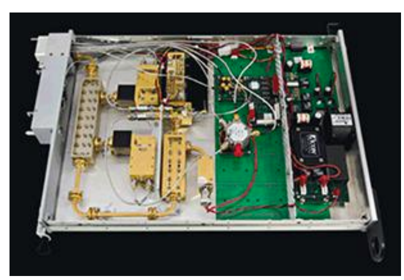
Visitors interested in just how much measurement power can be packed into a "headless" spectrum analyzer (without a display screen) can learn more about the SM200A from Signal Hound **(Booth 123).** Also suitable for use as a monitoring receiver, the real-time spectrum analyzer tunes from 100 kHz to 20 GHz with 110-dB dynamic range. It's capable of sweep speeds as fast as 1 THz/s for a 1-MHz resolution bandwidth, 160-GHz/s for a 10-kHz resolution bandwidth, and 18 GHz/s for a 1-kHz resolution bandwidth.

15. Model SM200A is a real-time spectrum analyzer with 110-dB dynamic range from 100 kHz to 20 GHz that can be used as a monitoring receiver. *(Courtesy of Signal Hound)*

Resolution bandwidths can be set from 0.1 Hz (across a 200-kHz span) to 3 MHz (across any span).

The SM200A's displayed average noise level is –156 dBm from 100 kHz to 700 MHz, –160 dBm from 0.7 to 2.7 GHz, –158 dBm from 2.7 to 4.5 GHz, and –149 dBm from 15 to 20 GHz. The powerful little analyzer *(Fig. 15)* measures just 10.2 × 7.2 × 2.8 in. (259 × 183 × 71 mm) and weighs 9.13 lbs with active cooling, with an additional 1.43 lbs for the ac power module and ac power cord.

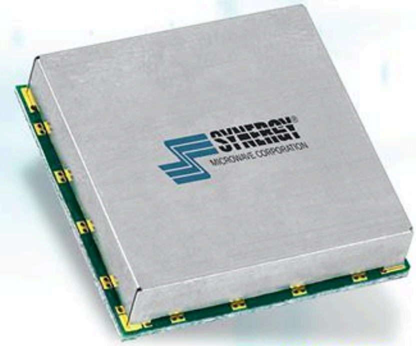
Roos Instruments **(Booth 880)** will show its many modular measurement solutions, including the Cassini 16 modular test systems and the RI8564 test set *(Fig. 16)* to bring the capabilities of the Cassini source and test receivers into the 75- to 81-GHz frequency range for testing automotive radar systems. Roos will be showing many instruments and systems aimed at performing measurements on automotive safety systems. The RI8564 is installed into



16. The RI8564 test set enhances the capabilities of a modular test set for mmWave measurements through 81 GHz. *(Courtesy of Roos Instruments)*

Amazingly Low Phase Noise

SAW VCO's



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HFSO640-5	640	0.5 - 12	+5 VDC @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-150
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142
HFSO914R8-5	914.8	0.5 - 12	+5 VDC @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-137
MSO1000-3	1000	0.5 - 14	+3 VDC @ 35 mA	-138
HFSO1200-5	1200	0.5 - 12	+5 VDC @ 100 mA	-140
HFSO1600-5	1600	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO1600-5L	1600	0.5 - 12	+5 VDC @ 100 mA	-133
HFSO2000-5	2000	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO2000-5L	2000	0.5 - 12	+5 VDC @ 100 mA	-133

** Package dimension varies by model. (0.3" x 0.3" to 0.75" x 0.75")*

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Cassini, providing frequency translation and signal conditioning for phase and power measurements S-parameter measurements, and distortion testing at mmWave frequencies.

Multiple-purpose testers capable of doing signal analysis and EMC testing within one compact housing will be one of the attractions at Elite RF LLC **(Booth 888)**. The company's S-Series multipurpose RF test systems are suitable for design and production testing as an alternative to more expensive test systems. Instruments such as the model SPA1241 *(Fig. 17)*, with maximum frequency of 12.4 GHz, provide ease of use by means of a front-panel 7-in. display screen. The instruments can also be connected to larger monitors for improved visibility. The firm is also expected to have an assortment of its LNAs and PAs for narrowband and wideband applications on display at the 2019 IEEE IMS exhibition.

17. Compact multipurpose testers like that shown can perform signal analysis and EMC testing at microwave frequencies. *(Courtesy of Elite RF LLC)*

GGB Industries **(Booth 762)** continues to attract engineers to its IMS booth year after year for one of the true marvels of the high-frequency industry, the Picoprobe Model 35 high-frequency probe. With full dc capability, frequency range of dc to 26 GHz, and rise times to 14 ps, this is a powerful complement to a high-speed digital oscilloscope for probing high-speed and high-frequency circuits as well as ICs. The probe tips can be replaced by a user, and an assortment of different tips are available. The probe features an operating voltage range of –6 to +6 Vdc. It only requires a single probe point for its high (2%) linearity.

This article is but a brief preview of the massive amount of innovative technology and products that will pack into the Boston Convention and Exhibition Center this first week of June 2019. For visitors interested in RF/microwave technology of any kind, from consumer and commercial applications such as wireless communications in smart buildings and cities to self-driving autonomous vehicles of the future guided by 77-GHz radars, attending the conference and exhibition will be a week well spent. The general trend is for "higher frequencies," and many presenters and companies will be highlighting their capabilities at mmWave frequencies from about 24 GHz to 100 GHz and beyond. That's where the bandwidth is available and where the future of this industry lies. mw

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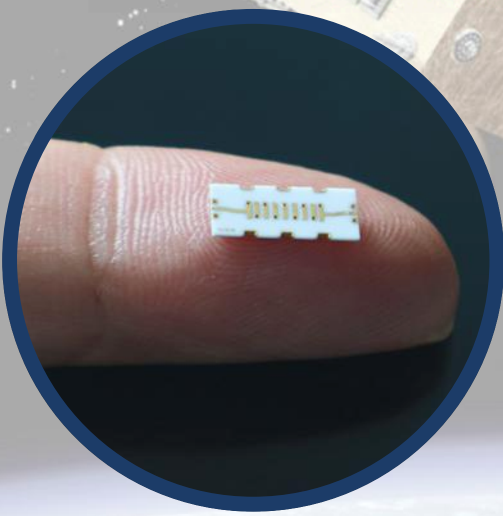

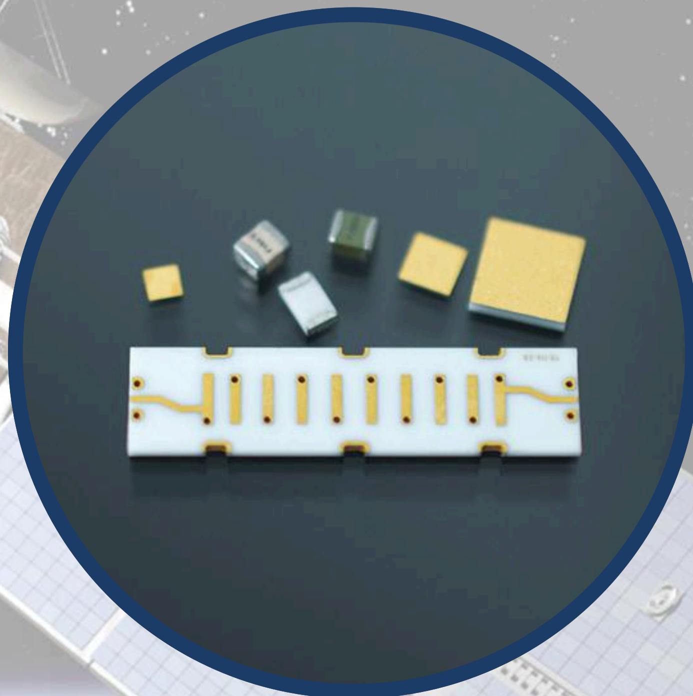

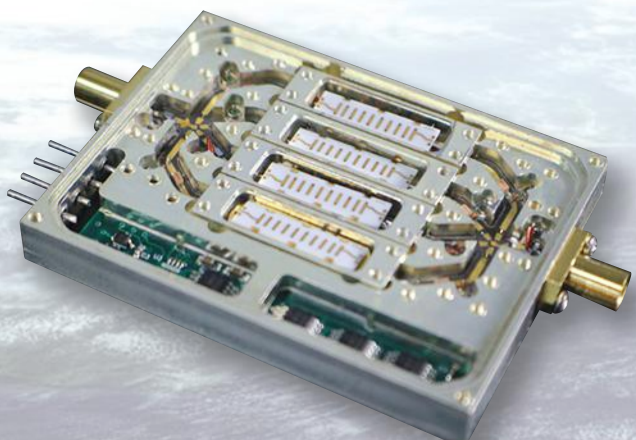

FEATURES

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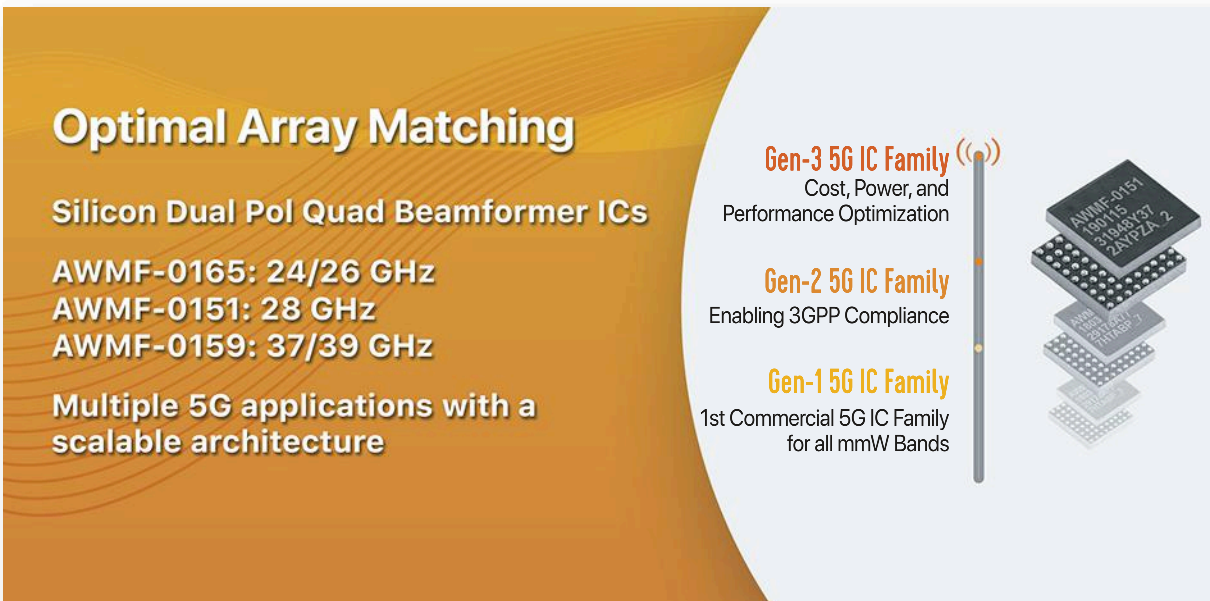

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CHRIS DeMARTINO | Technology Editor

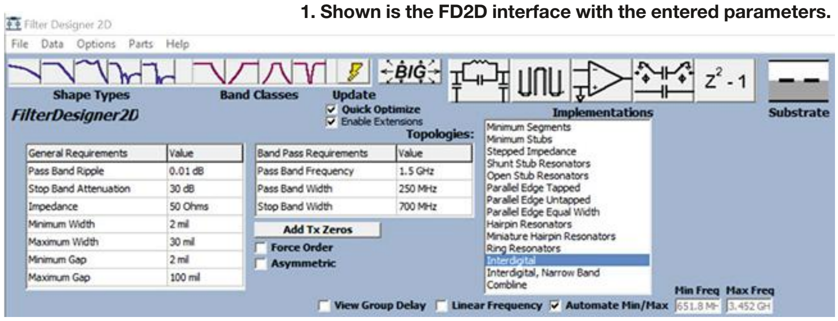
Software Tools
Bring a Unique Approach to Filter Design

A novel filter design workflow leverages an easy-to-use filter synthesis tool as well as optimization based on coupling matrix extraction.

No question, the task of designing high-frequency filters can be made much easier by taking advantage of the capabilities of today's design software tools. Whatever the filter, whether lumped-element, distributed, cavity, or some other kind, simulation software is readily available to help do the job at hand. One such software tool is CST Studio Suite, a product of Dassault Systèmes *(www.3ds.com)*. CST Studio Suite is a 3D electromagnetic (EM) analysis software package intended for designing, analyzing, and optimizing EM components and systems.

The CST Studio Suite contains two tools intended to facilitate the filter design process: Filter Designer 2D (FD2D) and Filter Designer 3D (FD3D). The FD2D tool, based on Nuhertz Technologies' *(www.nuhertz.com)* software, can be employed for the design of lumped-element and distributed filters and more. With FD2D, designers can synthesize filters based on a set of parameters.

FD3D is a synthesis tool for bandpass filters and diplexers. It features a unique coupling-matrix-extraction capability for any type of filter that employs coupled resonators. In addition, diplexers with coupled resonators are supported, provided that the common port connects to the channels via a star or resonator junction. Coupling matrix extraction allows for fast tuning of filter designs, helping designers quickly achieve performance goals. The FD3D tool is integrated into CST Studio Suite's built-in optimizers.



1. Shown is the FD2D interface with the entered parameters.

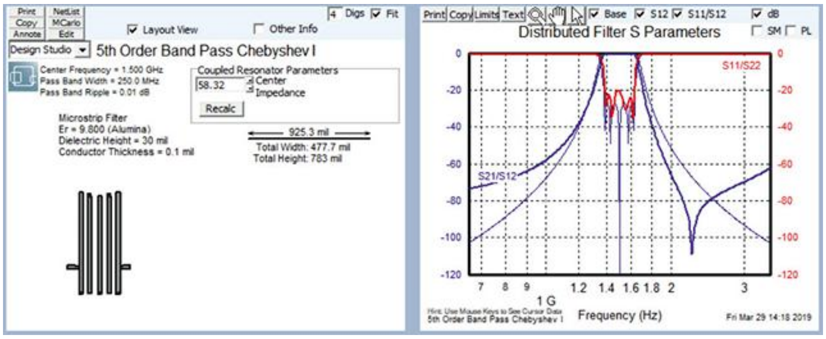
This article presents the design process of a microstrip interdigital filter using CST Studio Suite in combination with FD2D and FD3D. The process can be summarized in two steps. The first step involves using FD2D to synthesize the filter based on a set of parameters followed by the creation of a filter schematic. The schematic is then optimized with the help of FD3D.

A schematic-level (i.e., circuit-level) simulation is typically only part of the process when designing filters for use at high frequencies. Designers will likely want to perform an EM analysis as well. Hence, the second step of the design process involves performing an EM analysis of the 3D simulation model of the optimized circuit schematic. By taking advantage of FD3D, the 3D simulation model can subsequently be optimized to achieve the desired performance goals.

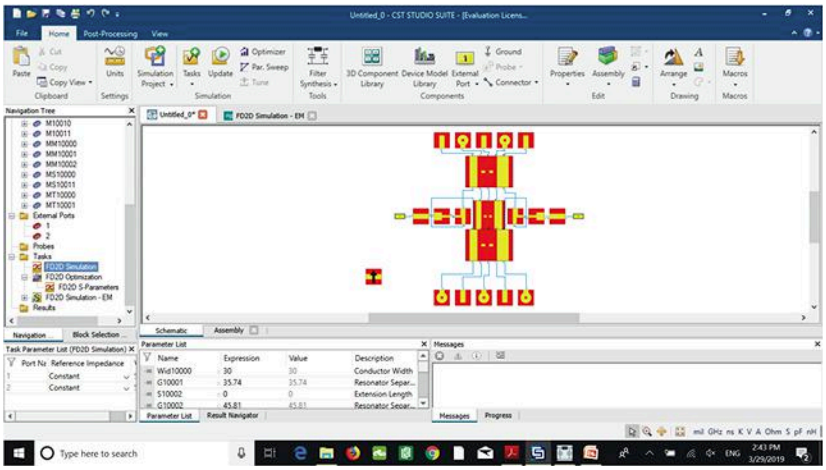
BEGINNING THE PROCESS

As stated, the first step in the design process involves using FD2D to synthesize the filter. After a filter is created in FD2D, it can be directly exported to CST Studio Suite. Once exported, filters can be quickly analyzed and optimized with circuit simulation methods.

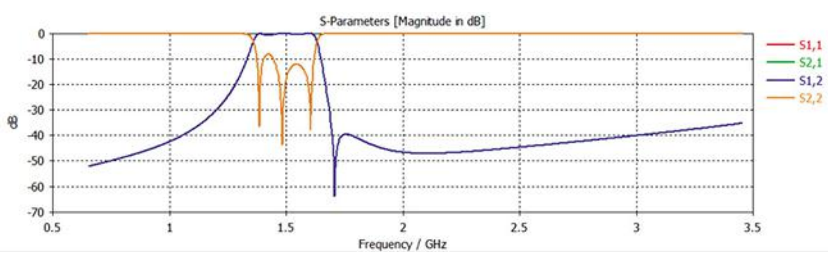
One can get started from the splash page by clicking the *Circuits & Systems* dropdown and then selecting *Schematic*. Once a new schematic is open, FD2D can be opened by clicking *Filter Synthesis* in the ribbon bar and then selecting *Filter Designer 2D*.



2. S-parameters are generated in FD2D based on the parameters specified.



3. After exporting the filter from FD2D, a filter schematic is generated in CST Studio Suite.



4. These are the S-parameter plots from the initial schematic simulation.

Figure 1 shows the top portion of the FD2D user interface. The example presented here is a microstrip interdigital bandpass filter with a center frequency of 1.5 GHz. FD2D allows users to select several *Shape Types*. Here, *Chebyshev I* is selected. In addition, the *Pass Band Width* is specified to be 250 MHz, while the *Stop Band Width* is set to 700 MHz. Furthermore, the substrate for this filter is 30-mil-thick alumina. The rest of the parameters can be seen in *Figure 1*. It should be noted that the *Enable Extensions* checkbox is checked to enable resonator length extensions for optimization.

Figure 2 reveals the bottom portion of the FD2D user interface, with the S-parameters of the filter shown on the right. The thin traces represent an ideal response, while the darker traces depict more realistic S-parameters that account for parasitic effects.

Now, the filter can be exported to CST Studio Suite in just seconds by clicking the CST Design Studio icon, shown at the top left corner of *Figure 2*. *Figure 3* reveals the generated filter schematic in CST Studio Suite. As shown, the filter consists of various blocks that represent the microstrip interdigital filter elements.

A circuit analysis can be executed by right-clicking *FD2D Simulation* in the navigation tree and then clicking *Update*. *Figure 4* shows the resulting S-parameter plots, which are clearly unsatisfactory. Hence, optimization is required.

AN INTRODUCTION TO FD3D

Before continuing, it's helpful to first explain FD3D in some detail. As mentioned, FD3D features what's known as coupling matrix extraction, which involves importing the S-parameters of a filter. Once the S-parameters are imported, a coupling matrix can be quickly extracted for that specific response.

When utilizing coupling matrix extraction for filter optimization, the extracted coupling matrix is compared to a synthesized coupling matrix. This synthesized coupling matrix corresponds to the desired filter performance. By comparing the extracted coupling matrix with the ideal synthesized one, problematic areas in the model can be identified. In turn, the model dimensions are changed accordingly. This cycle is repeated until the filter is tuned to a state in which it achieves an acceptable level of performance.

Coupling matrix extraction offers several benefits. For one, an optimization based on coupling matrices can execute in less time than a standard optimization based on S-parameters. In addition, it can help designers locate problematic or parasitic couplings. Thanks to coupling matrix extraction, designers are able to tune the relevant parameters of the filter geometry.

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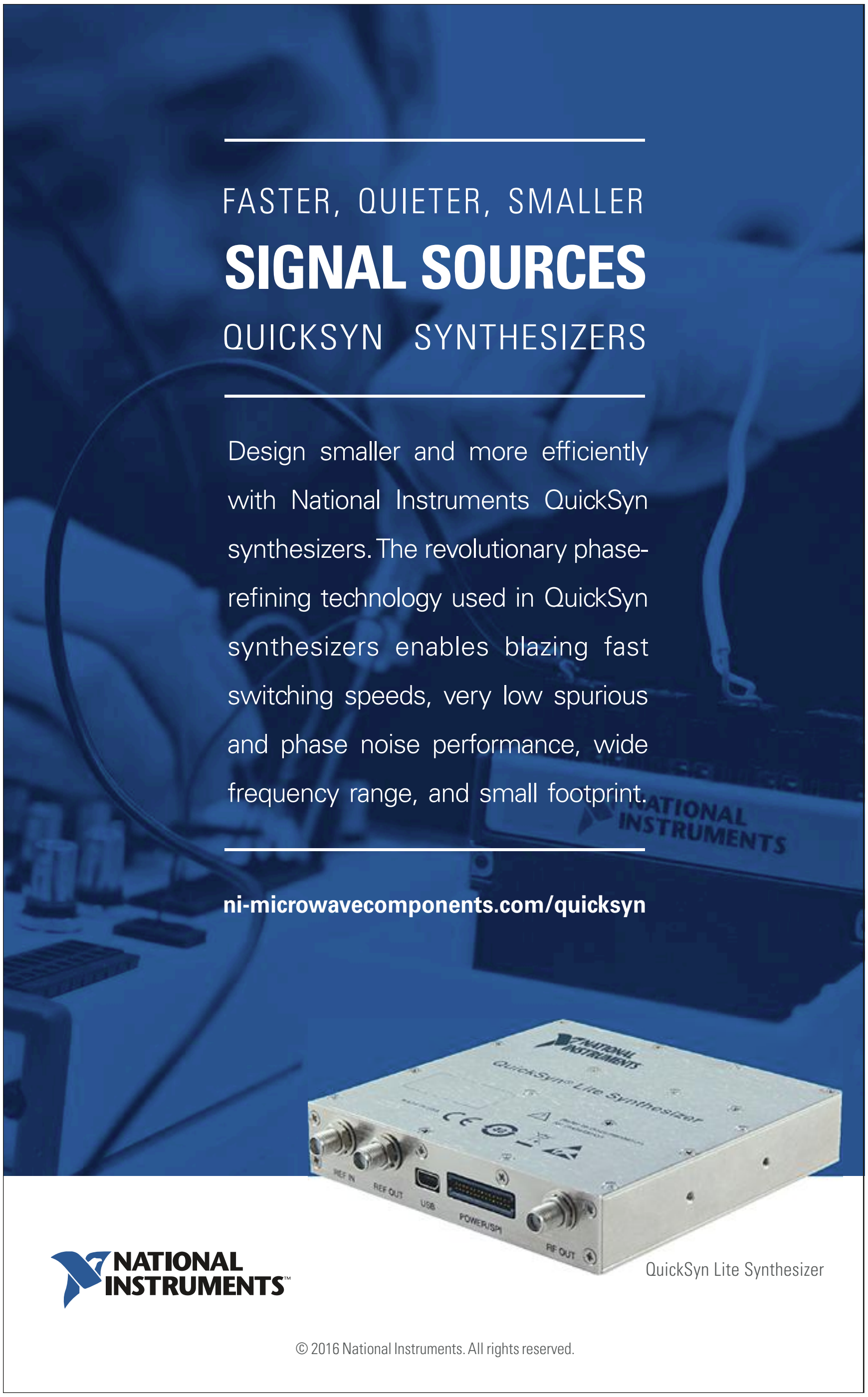
> Coupling matrix extraction offers several benefits. For one, an optimization based on coupling matrices can execute in less time than a standard optimization based on S-parameters. In addition, it can help designers locate problematic or parasitic couplings. Thanks to coupling matrix extraction, designers are able to tune the relevant parameters of the filter geometry.



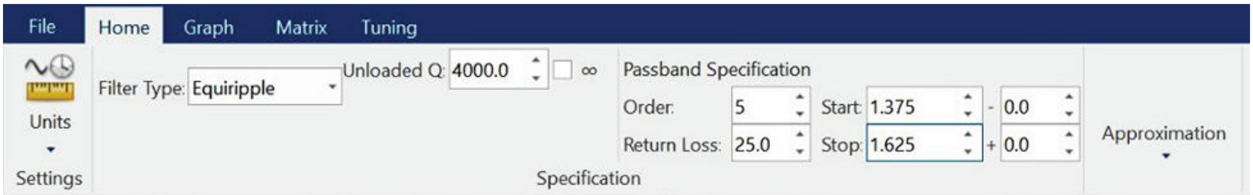
OPTIMIZING THE FILTER SCHEMATIC

Continuing with the example, the filter can now be optimized with the help of FD3D. First, to open FD3D, click *Filter Synthesis* in the ribbon bar when in the schematic view and then select *Filter Designer 3D*. Upon opening FD3D, users can enter the passband specifications, which determine the optimization goals. For the passband specifications in this example, *Order* is set to 5, *Return Loss* is set to 25, *Start* (frequency in GHz) is set to 1.375, and *Stop* (frequency in GHz) is set to 1.625 *(Fig. 5)*.

FD3D also gives users the option to specify transmission zeros. However, no transmission zeros will be added in this case, since an inline filter is being designed (a transmission zero is present, but that's due to the uncontrollable cross-coupling in the interdigital layout).

Clicking the *Matrix* tab reveals the different topologies that can be employed to realize the specified filter *(Fig. 6)*. Here, a fifth-order mainline coupling topology is selected. *Figure 6* also displays the coupling matrix that's automatically synthesized based on the specifications and topology.

Before closing FD3D, save the FD3D file. After returning to CST Studio Suite, the goal is to now optimize the filter. Double-clicking *FD2D Optimization* in the navigation tree prompts users to specify the optimization settings and goals *(Fig. 7)*. To obtain the desired performance, the selected parameters shown in *Figure 7* will be tuned. These parameters include *G10001* and *G10002*, which denote the resonator separations. *Len10000* represents the conductor



5. FD3D allows users to define the passband specifications for a bandpass filter.

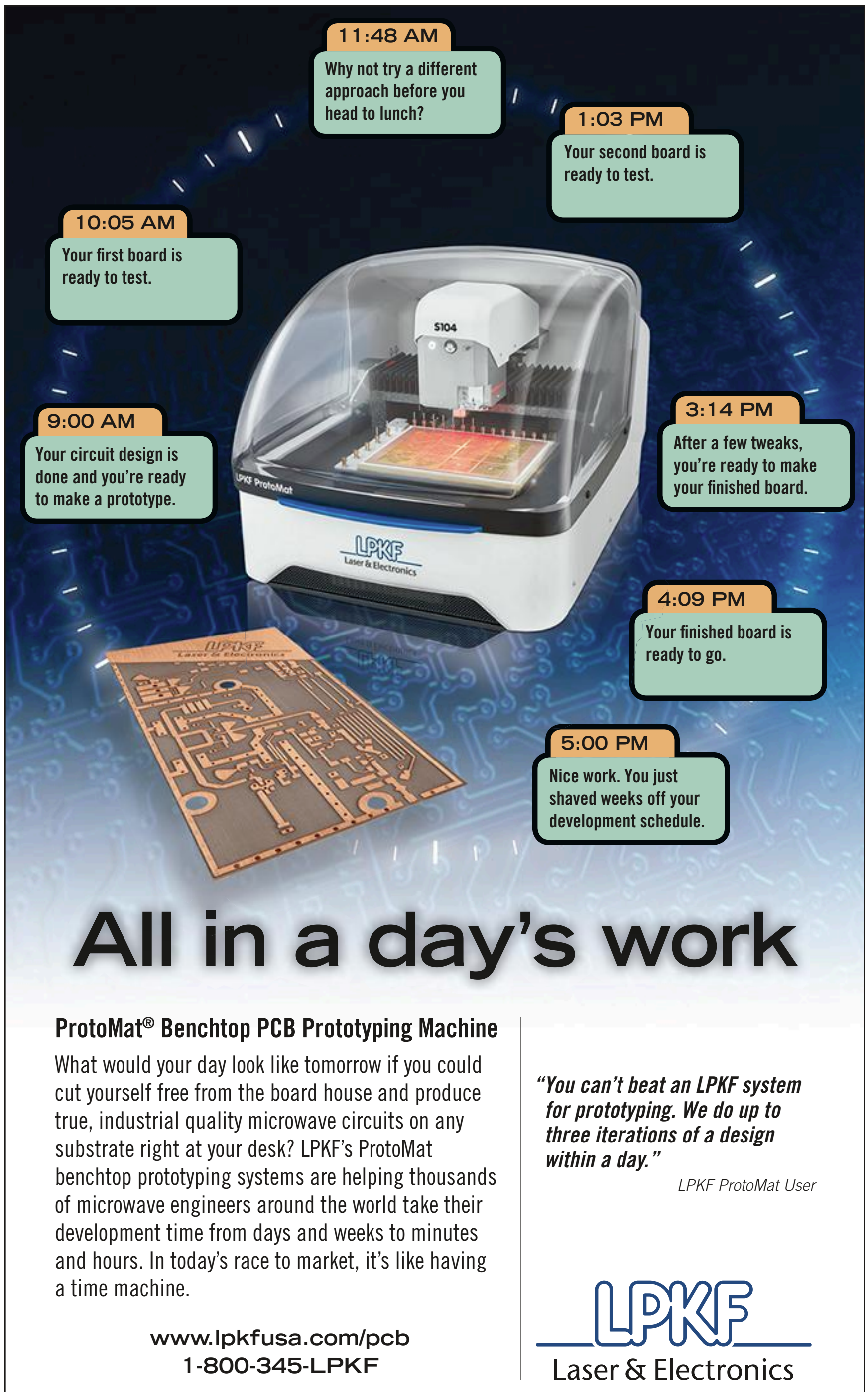
lengths, while *Lext10000* denotes the end extensions. *S10002* and *S10003* indicate the extension lengths, and *Tap10000* represents the tap position.

The optimization goals can be specified by clicking the *Goals* tab *(Fig. 8)*. After selecting *Remove All* to delete all pre-defined goals, *Filter Designer 3D* is then selected as the *Goal type*. By making this selection, it will execute an FD3D-based optimization rather than a standard version. Clicking *Add New Goal* automatically opens FD3D once again.

Once FD3D is open, the previously saved FD3D file can be imported by selecting *File>Import*. It's important to now specify the matrix-extraction settings in FD3D, which can be accomplished by clicking the *Matrix* tab and then selecting *Matrix Extraction*. *Figure 9* shows the settings used in this example. Checking the *Limit Extraction Range* checkbox limits the frequency range and the amplitude for the samples utilized for extraction. The *Parasitic Extraction* checkbox is also selected so that the software can take into account parasitic transmission effects like the unintended cross-couplings that cause the high-side transmission zero in this interdigital configuration.

The next step is to apply FD3D to the project by clicking *File>Apply*. Closing FD3D and returning to CST Studio Suite reveals that the parameters from FD3D have been applied to the optimization goals *(Fig. 10)*. Clicking *Start* will begin the optimization.

After the optimization is complete, the new S-parameter plots of the filter can be viewed by clicking *S-Parameters* under *FD2D Optimization* in the



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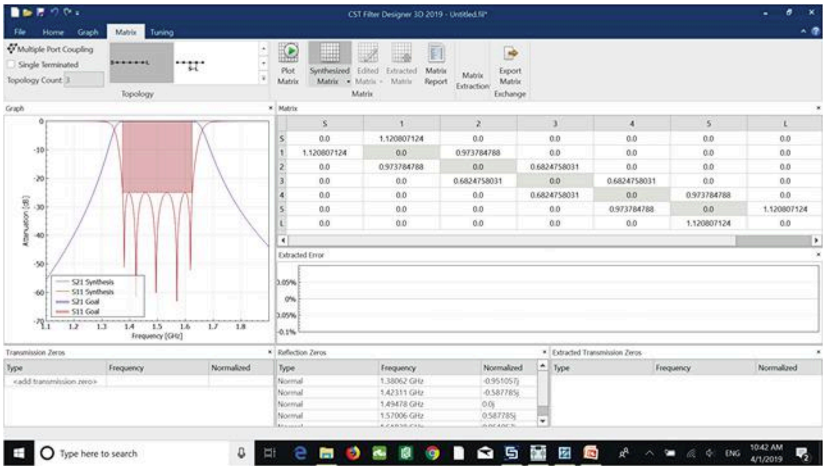
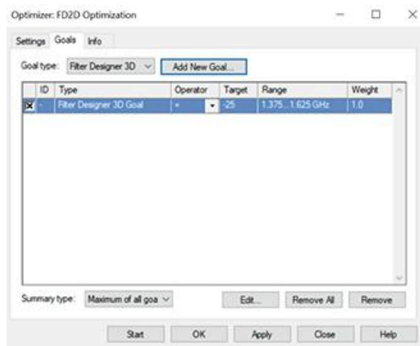
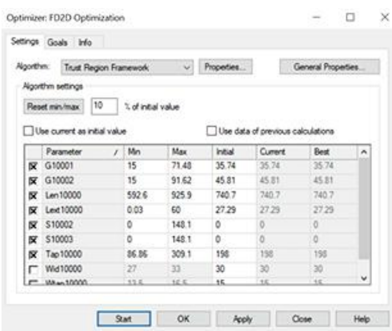


6. With FD3D, designers are able to select different topologies that can be implemented to achieve the specified performance.

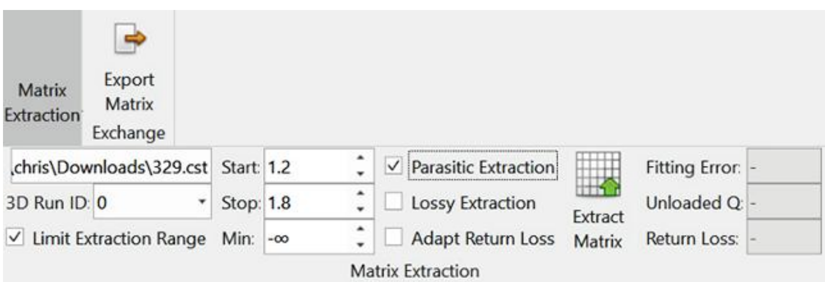


10. The specifications defined in FD3D are now applied to the optimization goals.



7. The optimization settings reveal the parameters that will be tuned to meet the design goals.

8. FD3D must be specified when setting the optimization goals.



9. The settings for the matrix extraction include the start and stop frequency and more.

navigation tree *(Fig. 11)*. Since the new S-parameters reveal dramatically improved performance, the first step of the design process is now complete.

SIMULATION OF THE 3D MODEL

The filter schematic has been optimized to achieve acceptable S-parameter simulation results. Now it's time to begin the second step of the design process: Perform an EM analysis of the 3D model of the filter. Since the filter schematic has been optimized, a 3D model based on the schematic should be a good starting point for the EM analysis.

One additional step is required before simulating the 3D model. It's necessary to merge all metallic microstrip filter elements on the top layer, as the filter is automatically generated with various microstrip components that are joined together. Merging these metallic elements will remove unnecessary faces in the model that are undesirable for the meshing.

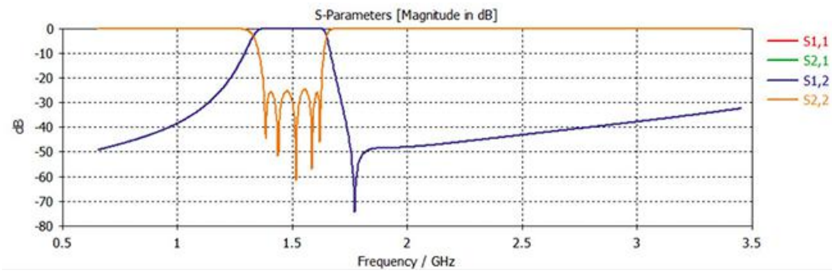
Merging the metallic elements can be carried out by selecting all of the microstrip components, which are found under *Components* in the navigation tree *(Fig. 12)*. Next, by clicking *Boolean* in the ribbon bar and then selecting *Add*, the components are able to be merged.

The 3D model can now be simulated. Selecting *Setup Solver* from the ribbon bar reveals the frequency-domain solver parameters. *Figure 13* shows the settings implemented in this example. Clicking *Start* begins the simulation.

Figure 14 illustrates the resulting S-parameter plots of the 3D EM simulation. The filter clearly does not achieve the desired goals—the performance at the high end of the specified passband is not acceptable. Therefore, optimization is required once again.

THE FINAL STEP: OPTIMIZING THE 3D MODEL

At this stage, "face constraint parameters" will be added before optimizing the 3D model. While such parameters



11. The S-parameter plots from the optimized schematic simulation reveal a significant improvement.

are not required for optimization, using them makes it possible to calculate sensitivities that speed up the simulation. The different face constraint parameters, which will serve as the tunable filter parameters, correspond to the resonator lengths and the amount of separation between resonators.

To create the face constraint parameters that will define the tunable resonator lengths in this example, follow these steps:

1. Select *Picks* from the ribbon bar followed by *Pick Face* (or simply hit the 'f' the shortcut key). Next, click the end face of the open-ended side of the first resonator *(Fig. 15).*
2. Click the *Local Modification* dropdown in the ribbon bar followed by *Define Face Constraints.*
3. Select Y as the *Principal plane normal (Fig. 16).* In addition, clicking *Parametrize* allows users to enter a parameter name.
4. Repeat steps 1 to 3 for all other resonators.

Once the face constraint parameters that correspond to all of the resonator lengths are defined, the next step is to create the face constraint parameters that will define the tunable amount of separation between resonators. This can be accomplished with the following steps:

1. Select the *Pick Points* dropdown followed by *Pick Edge Center* (or simply hit the 'm' shortcut key) to select the top edge of the first resonator that's adjacent to the second resonator. Use the P*ick Edge Center* function again to select the top edge of the second resonator that's adjacent to the first resonator *(Fig. 17).*
2. Next, select *Mean Last Two Points* (also located under the *Pick*

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NW-PA-11C01A	225 - 2400	40	15	3.00 x 2.00 x 0.65
NW-PA-13G05A	800 - 2000	45	50	4.50 x 3.50 x 0.61
NW-PA-15D05A	800 - 2500	44	20	4.50 x 3.50 x 0.61
NW-PA-12B01A	1000 - 2500	42	20	3.00 x 2.00 x 0.65
NW-PA-12B01A-D30	1000 - 2500	12	20	3.00 x 2.00 x 0.65
NW-PA-12A03A	1000 - 2500	37	5	1.80 x 1.80 x 0.50
NW-PA-12A03A-D30	1000 - 2500	7	5	1.80 x 1.80 x 0.50
NW-PA-12A01A	1000 - 2500	40	4	3.00 x 2.00 x 0.65
NW-PA-LS-100-A01	1600 - 2500	20	100	6.50 x 4.50 x 1.00
NW-PA-12D05A	1700 - 2400	45	35	4.50 x 3.50 x 0.61
NW-PA-05E05A	2000 - 2600	44	30	4.50 x 3.50 x 0.61
NW-PA-C-10-R01	4400 - 5100	10	10	3.57 x 2.57 x 0.50
NW-PA-C-20-R01	4400 - 4900	43	20	4.50 x 3.50 x 0.61

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NW-BA-12B04A	1000 - 2500	35	10	3.00 x 2.00 x 1.16
NW-BA-12C04A	1000 - 2500	35	15	3.00 x 2.00 x 1.16
NW-BA-C-10-RX01	4400 - 5100	10	10	3.57 x 2.57 x 0.50
NW-BA-C-20-RX01	4400 - 4900	43	20	5.50 x 4.50 x 0.71

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HILNA-V1	50 - 1000	20	32	3.15 x 2.50 x 1.18
HILNA-G2V1	50 - 1000	40	31	3.15 x 2.50 x 1.18
HILNA-LS	1000 - 3000	50	33	2.50 x 1.75 x 0.75
HILNA-GPS	1200 - 1600	32	30	3.15 x 2.50 x 1.18
HILNA-CX	5000 - 10000	35	21	1.77 x 1.52 x 0.45

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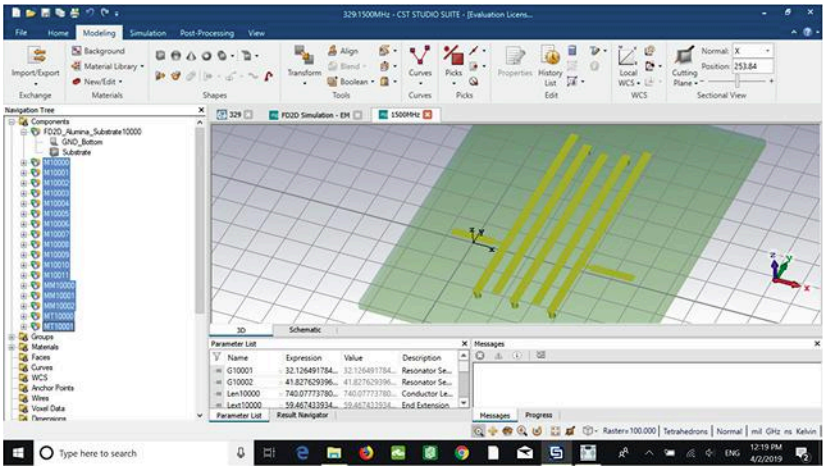
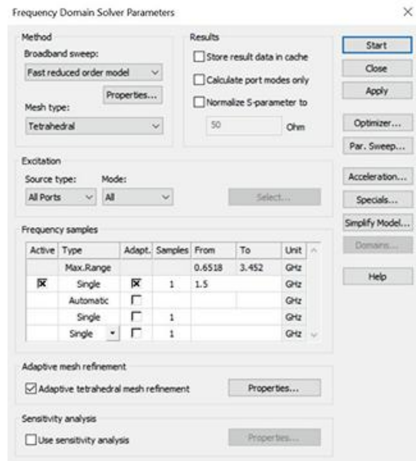
Points dropdown), which will result in the creation of a single point located between the two resonators.

3. Use the *Pick Face* function ('f' shortcut key) to select the inside face of the first resonator that's facing the point *(Fig. 18).*
4. Click the *Local Modification* drop-down in the ribbon bar followed by *Define Face Constraints.*
5. Select *Set distance to point (Fig. 16, again).* Click *Parametrize* to enter a name for the parameter.
6. Next, repeat steps 1 and 2 and then use the *Pick Face* function ('f' shortcut key) to select the inside face of the second resonator that's facing the point.
7. Repeat steps 4 and 5.



12. Merging the metallic filter elements is a necessary step in this example.



13. The frequency-domain solver parameters include the frequency settings and more.

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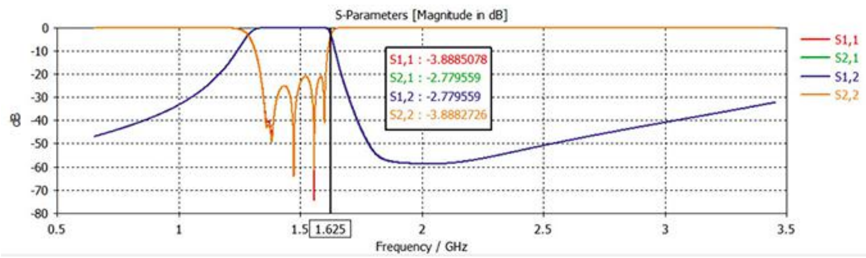
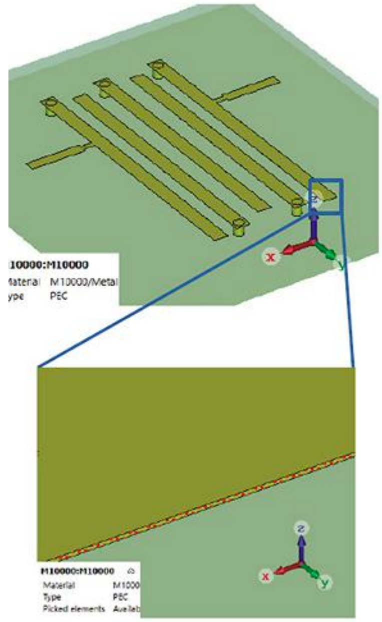
These seven steps should be repeated to create the face constraint parameters for the remaining areas of separation between resonators. Furthermore, clicking the *Local Modification* dropdown followed by *Show Face Constraints* allows users to view all the face constraint parameters.

Now that all face constraint parameters have been defined, the optimization process can begin. After selecting *Setup Solver* from the ribbon bar, check the *Use sensitivity analysis* checkbox to allow for a more efficient optimization *(Fig. 13, again)*. Selecting this option will activate the corresponding *Properties* button, which can be clicked to ensure that all created face constraint parameters are selected for the sensitivity analysis.

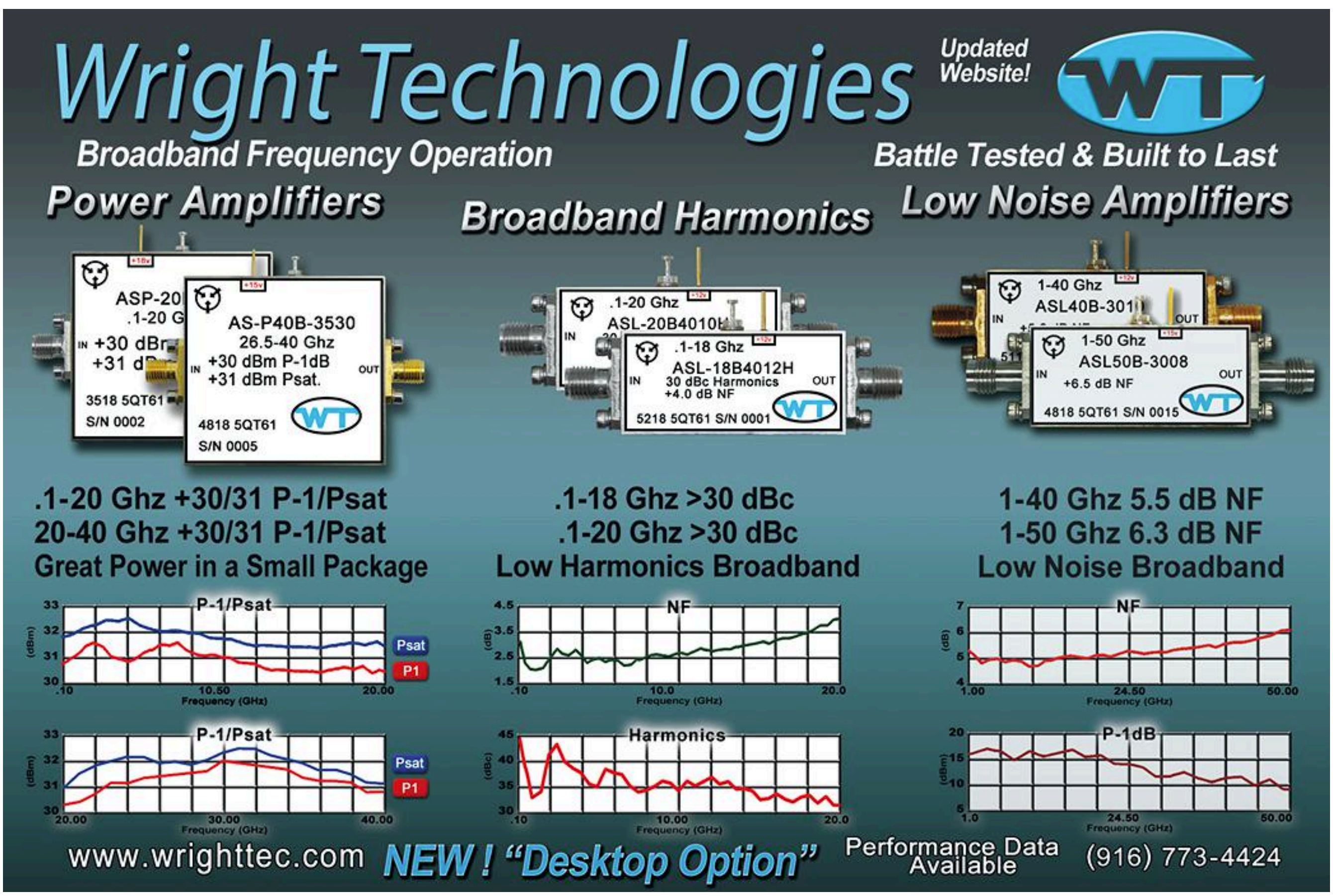
Now, to configure the optimization in a similar manner as before, click the *Optimizer* button (also found in the ribbon bar). The main difference here is that the newly created face constraint parameters must be selected for optimi-



14. The S-parameter results from the initial EM simulation demonstrate that the filter does not meet the performance goals. Denoted are all four S-parameter values at 1.625 GHz.



15. In this example, creating a face constraint parameter to define a tunable resonator length began by selecting the end face of the resonator's open-ended side.

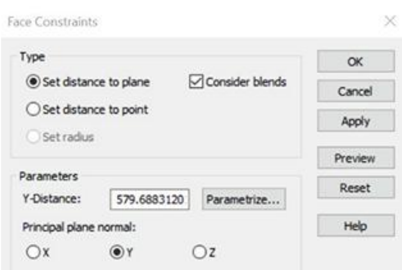


zation rather than the parameters used previously to optimize the filter schematic. In addition, the *Properties* button can be selected to specify the *Max. number of evaluations*, *Domain accuracy*, and *Finite difference*. These parameters are set to 80, 0.01, and 0.01, respectively. In addition, clicking the *General Properties* button allows users to activate the *move mesh* feature for the optimization process, enabling a faster convergence. When optimizing narrowband filters, the *move mesh* feature plays an important role in terms of achieving convergence.

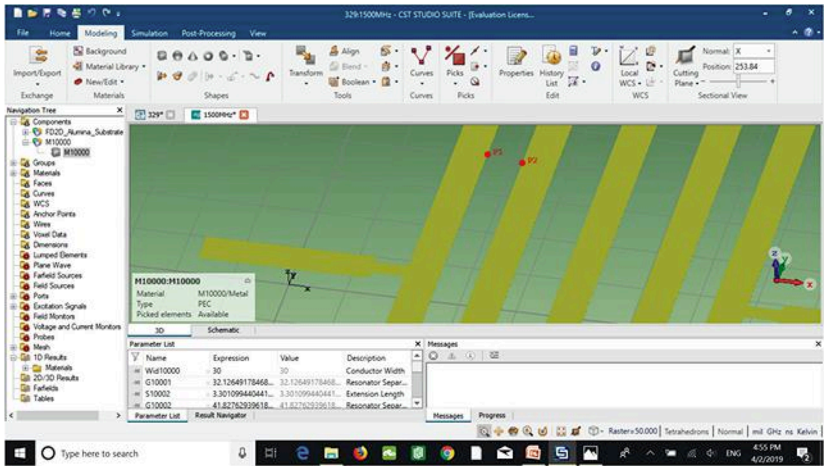
The same process of defining the optimization goals can be carried out by clicking the *Goals* tab *(Fig. 8, again)*. With *Filter Designer 3D* again selected as the *Goal type*, one can select *Remove All* to delete all pre-defined goals and then click *Add New Goal* to automatically open FD3D once more.

The same process of importing the previously created FD3D file must be performed. *Figure 19* shows the matrix-extraction settings that will be used this time. In addition to the *Parasitic Extraction* checkbox, both *Lossy Extraction* and *Adapt Return Loss* are selected. When *Lossy Extraction* is enabled, the software takes into account loss when performing the extraction.

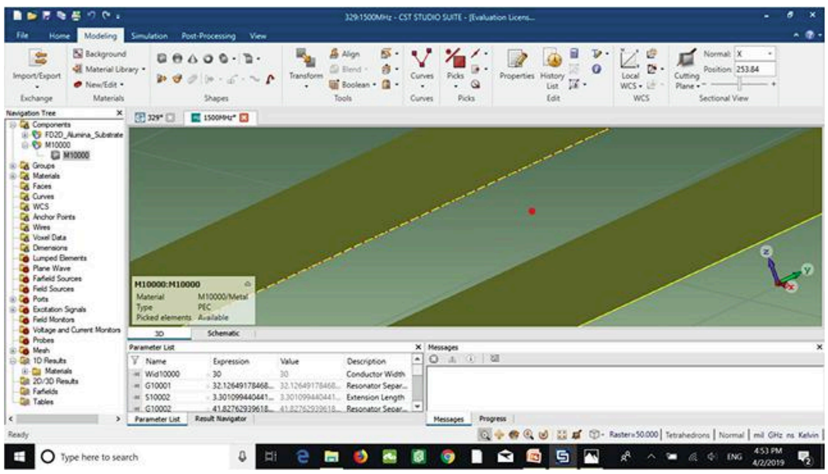
Activating the *Adapt Return Loss* function allows the software to adapt the return loss of the synthesized comparison matrix so that it matches the extracted return loss. This feature should be used when the input/output couplings are not controllable. In this case, since face constraint parameters were not created to correspond to the input/output feed-line positions, these positions cannot be controlled. Alternatively, face constraint parameters could have been created to correspond to the input/output feed-line positions.



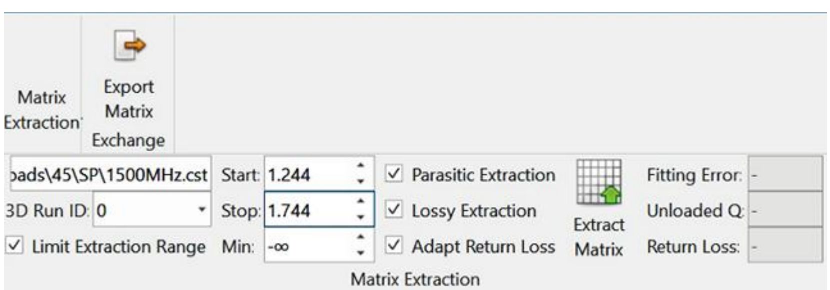
16. When defining face constraints, users can specify whether the distance should be set with respect to a plane or a point.



17. In this case, creating face constraint parameters to define an area of separation between resonators began by placing a point on the top edge of both adjacent resonators.



18. Here, the inside face of one resonator is selected. A face constraint parameter will be defined with respect to the point shown to ultimately define the tunable amount of separation between both resonators pictured.



19. These are the matrix extraction settings used for the EM optimization.

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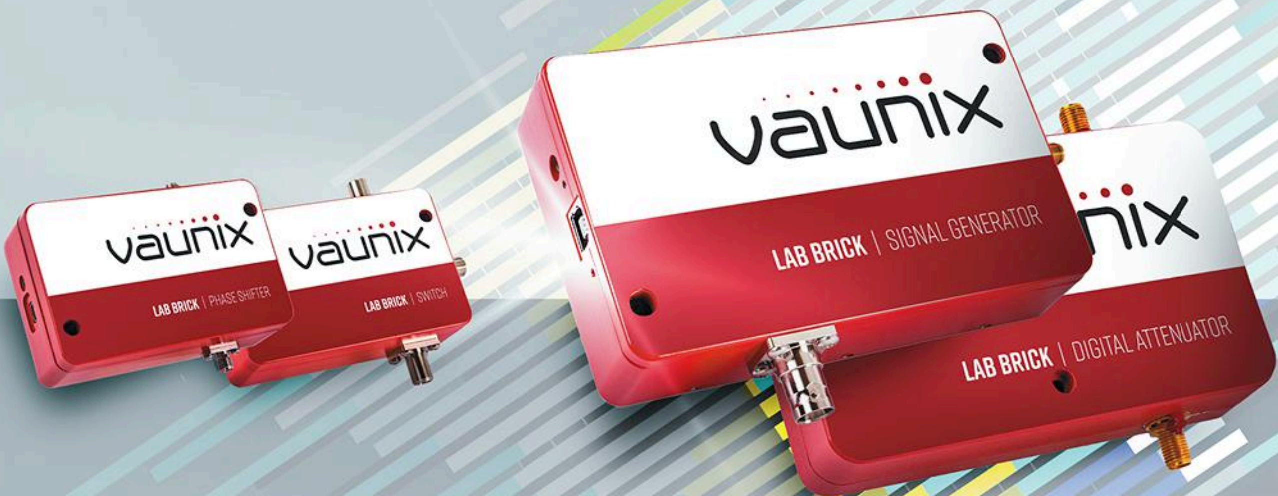

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Gain (dB)	54
AC-to-RF efficiency at rated power (%)	57
Noise floor in transmit-disable mode (dBm/Hz)	-173
Harmonic suppression (dBc)	-10 second order -28 third order -60 with filter
Spurious rejection (dBc)	<-70
Third-order IMD (dBm)	+75
Input/output return loss (dB)	-22/-16
Phase flatness (±2 MHz BW) (deg)	<1
Maximum duty cycle (%)	100
Maximum VSWR	2:1, 30:1 with foldback
TX/RX isolation (option)(dB)	60
RX/TX switching time (option)(μs)	5, 2 typical
Prime power (VAC)	85 to 265
Control/Monitoring	RS-232 or RS-485, Ethernet
Altitude (ft.)	30,000
Dimensions (in. HWD)	7x19x20. Amplifier 5.25 H , power supply 1.25 H
Weight (lb.)	Amplifier (29), total (57)
Protection	Thermal overload, over/under voltage, temperature, fan
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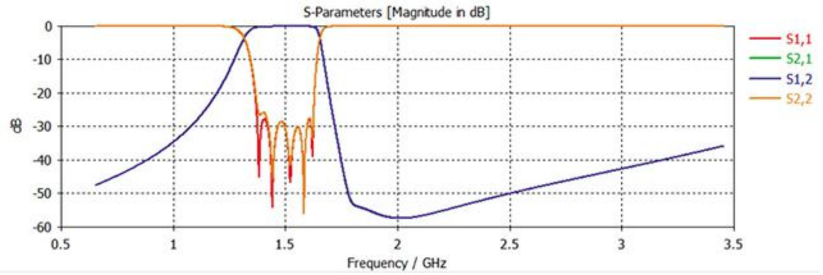
After selecting *File>Apply* and closing FD3D, return to CST Studio Suite—it shows that FD3D has been applied to the optimization goals. Clicking *Start* will begin the optimization.

Figure 20 shows the S-parameter results of the optimized 3D model. The results reveal that S_{11} is below −25 dB throughout the entire passband. The design process is now complete. Furthermore, the optimization required 23 solver runs to achieve the goal function value.

In summary, the software tools from Dassault Systèmes are a unique approach to filter design that can benefit all filter designers. This article presented one specific example, a microstrip interdigital filter. However, the tools utilized to design this filter will work with many other types, including cavity and dielectric filters. Anyone tasked with this responsibility may want to check out these tools. mw

In summary, the software tools from Dassault Systèmes are a unique approach to filter design that can benefit all filter designers. This article presented one specific example, a microstrip interdigital filter. However, the tools utilized to design this filter will work with many other types, including cavity and dielectric filters.



20. The simulated S-parameter results of the optimized 3D model reveal that the filter meets the performance goals.

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Shielded Anode PIN Diode

Breathes New Life into a 1950s Technology

A novel PIN diode concept is said to achieve 10 to 50 times better isolation than a typical PIN diode.

The RF PIN diode as we know it today was invented by J. Nishizawa in 1950. Now, almost 70 years later, a new PIN diode concept—shielded-anode PIN diode (SAPIN)—has emerged. This new PIN diode offers 10 to 50 times better "OFF" isolation thanks to the introduction of a simple electrostatic shield. An "OFF" isolation greater than 40 dB at 2 GHz and 0 Vdc is achieved from a single series device. The theory of operation will be presented here along with measurements on fabricated silicon (Si) SAPIN didoes.

PIN DIODE OPERATION

A PIN diode is built with a wide undoped intrinsic (i-region) semiconductor, usually Si or gallium arsenide (GaAs). The i-region is sandwiched between the p+ anode and the n+ cathode. Both are connected to a conducting metal like gold or aluminum *(Fig. 1)*.

In contrast to conventional diodes, the wide i-region enables the PIN diode to operate as a fast RF switch or a current-controlled linear resistor. When forward-biased, the PIN diode operates under a high-level injection condition. At low frequencies, the PIN diodes behave as a normal diode and follow the same basic equations for current (I) versus voltage (V).

At low frequencies well below the carrier lifetime τ, the charge can be swept out and the diode turns "OFF." At high frequencies, there's not enough time to sweep the carriers out of the i-region and the diodes remain turned "ON." The ac series resistance, R_s is given by:

$$R_s = \frac{W^2}{(\mu_n + \mu_p)Q}$$

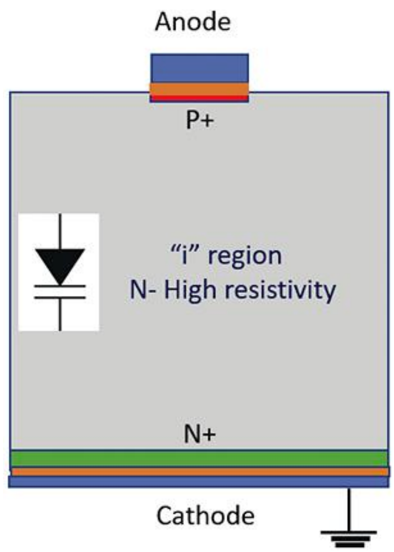
where:

τ = carrier lifetime in i-region (about 1 μs for Si, 10 ns for GaAs)

$Q = I_f\tau$

W = i-region width (about 5 μm for switches, 200 μm for CATV attenuators)

I_f = forward-bias current

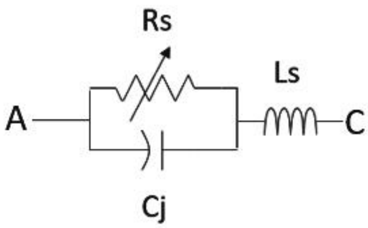


1. The anode and cathode are both connected to a conducting metal.

μ_n = electron mobility

μ_p = hole mobility

Figure 2 shows a simplified RF equivalent circuit for an RF PIN diode. The series resistance, R_s, was already given. PIN diodes for RF switching typically have an R_s of 10 Ω at 1-mA forward quiescent current. For linear attenuator applications, R_s is typically 75 Ω. The

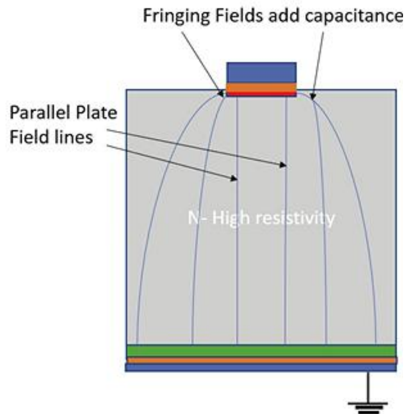


2. This is a simplified RF equivalent circuit for a PIN diode.

parasitic series inductance, L_s, represents the bond-wire and package-lead inductance. The value for L_s is usually around 1 nH.

The capacitor C_j from the anode to cathode is due to the junction and fringing capacitance within the PIN diode. This capacitance is an unwanted parasitic. In RF switches and attenuator circuits, good isolation is important yet difficult to attain. Ultimately, the best isolation is limited by the magnitude of C_j.

Under zero bias, the depletion region in a PIN diode will usually extend the whole distance across the i-region to the cathode due to the i-region's undoped nature. Under zero bias, the electrostatic field lines will extend from the anode to the cathode *(Fig. 3)*.



3. Field lines and fringing fields are shown in this illustration.

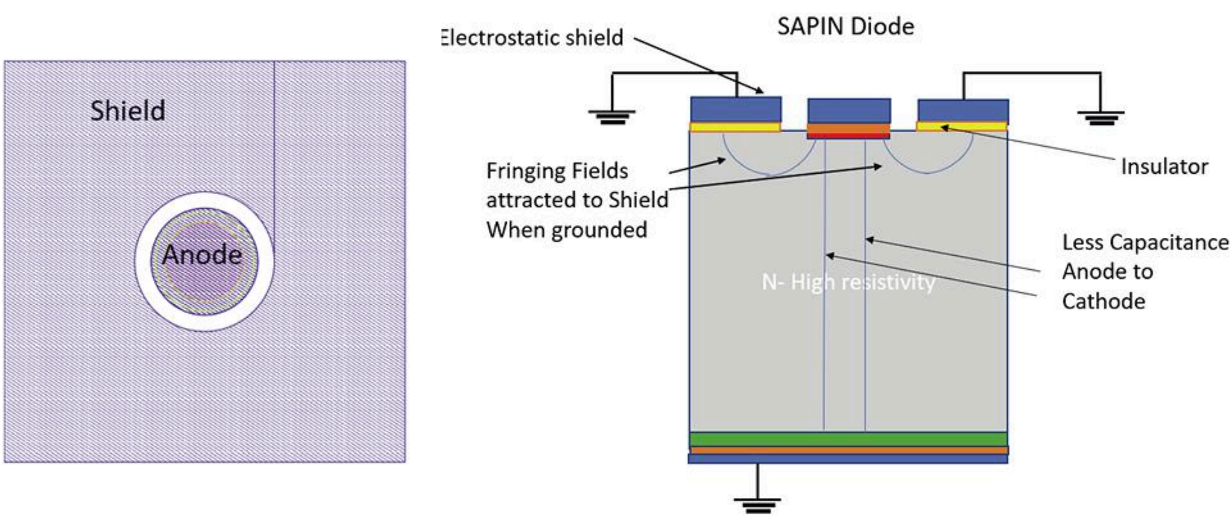
Figure 3 shows the field lines that would be considered as per the parallel-plate capacitance formula, as well as fringing field lines to the grounded cathode below. The total capacitance from the extra fringing fields can be much larger than that of the parallel-plate capacitance alone.

THE SAPIN DIODE

Figure 4 shows the top view of the SAPIN and a simplified cross-section drawing of the SAPIN diode.[1] As a normal PIN diode, the device has a p+ anode, undoped i-region, and an n+ cathode connection. (Normally the cathode is the back-side of the device for a good ground connection, but the anode and cathode can be interchangeable.)

A new shield terminal made of metal over an insulator is added around the anode, which in this case is SiO_2. This shield has little effect on the dc R_S characteristics of the PIN diode action. With 0 Vdc applied to the anode, part of the electrostatic field lines is drawn away from the cathode; instead, it's terminated on the new shield terminal.

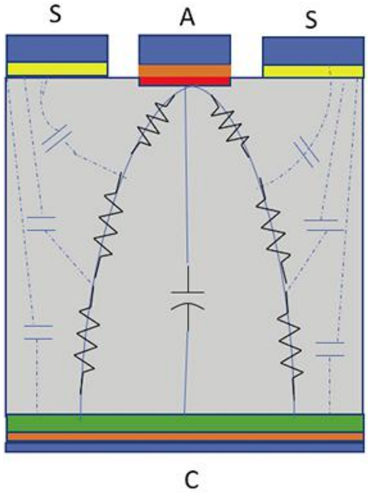
3D device simulations demonstrate that the value of C_j can be reduced by more than two to three times the total value, thereby dramatically improving the device isolation. The actual operation of the SAPIN is much more complicated than what the simplified electrostatic drawing indicates. *Figure 5* shows a SAPIN turned "ON" that's operating at low currents (approximately 10 µA to 1 mA). A simple distributed RC network has shown to be a rough model description of the SAPIN's operation. The actual operation is very difficult to model due to the distributed nature of



4. Shown are a top view of the SAPIN (left), as well as a simplified cross-section drawing (right).

the parasitics, as well as a variable carrier lifetime.

As can be determined directly from *Figure 5*, parasitic coupling will occur between the shield (S) and the anode



5. Parasitic coupling exists between the shield and the anode as well as between the shield and the cathode.

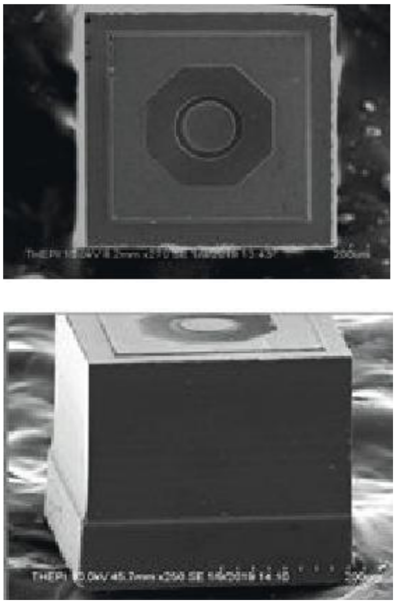
and between the shield and the cathode. Direct measurements will best allow for understanding and modeling of the actual device.

SAPIN DIODE MEASUREMENTS

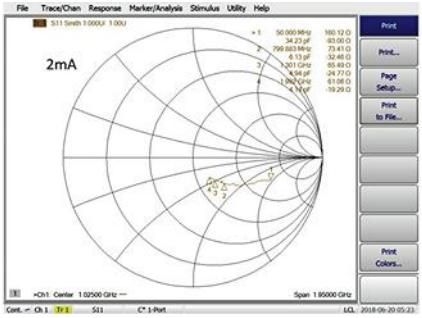
Figure 6 shows a fabricated SAPIN. The device was made using 4-in. Si wafers with resistivity greater than 3000 Ω-cm. The die size is 350 × 350 µm with the i-region thickness varied from 250 to 375 µm. These devices are geared toward RF attenuator applications.

The anode, cathode, and shield metallization are aluminum. The measured effective carrier lifetime on Si wafer and die samples was determined to be about 1.5 µs.

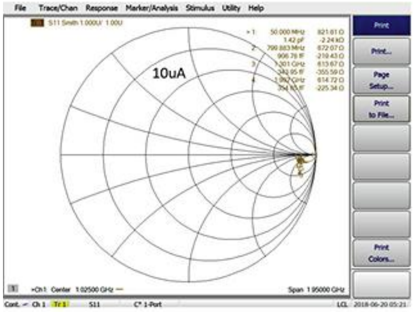
One-port (S_{11}) RF measurements were performed on the SAPIN diode between the anode, shield, and grounded cathode. The biggest concern involved the capacitive loading of the shield to anode and cathode, since the shield was also grounded. Devices were epoxied to a metal carrier, and a ground-signal (G-S) probe from GGB industries *(www.ggb.com)* was used to measure S_{11} from 50 MHz to 2 GHz.



6. Shown above is a fabricated SAPIN.



7. Shown is S_{11} with a diode current of 2 mA and shield grounded.

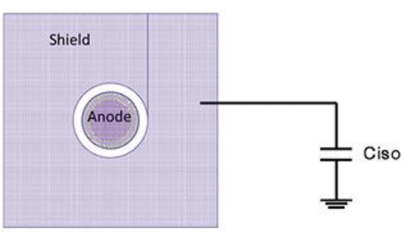


8. This is S_{11} with a forward bias of 10 µA and shield grounded.

Directly grounding the shield would be a disaster at higher currents, and the SAPIN would not be a usable device. Notice that at low currents, there's a large resistive component to the input impedance.

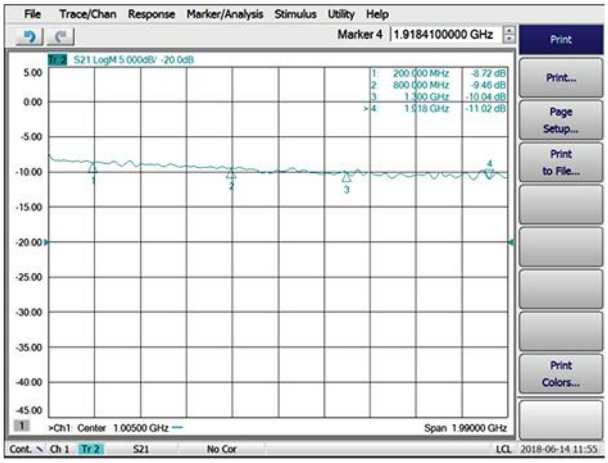
Figures 7 and *8* show S_{11} at a diode current of 2 mA, and a measured S_{11} at a forward bias of 10 μA, respectively. As can be seen, there's a dramatic difference between the equivalent input capacitances at the two operation currents. At 2 mA, C = 34 pF and 4.1 pF at 50 MHz and 2 GHz, respectively. At 10 μA, C = 1.4 pF at 50 MHz and 0.35 pF at 2 GHz. The frequency dependence of capacitance is affected by the carrier lifetime and the distributed nature of the SAPIN *(Fig. 5, again)*.

Directly grounding the shield would be a disaster at higher currents, and the SAPIN would not be a usable device. Notice that at low currents, there's a large resistive component to the input impedance. At high currents, R_S is a very small value. One aspect discussed in Ref. 1 solves the loading problem. *Figure 9* shows the solution.

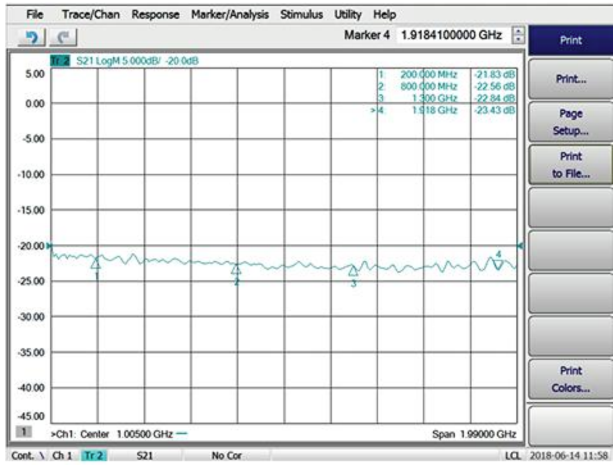


9. Here, an external capacitor is connected from the shield to ground.

A small external capacitor of about 0.3 pF, dubbed C_{iso}, can be directly connected to the shield to ground. At high currents, C_{iso} would look like a shunt



10. With the SAPIN assembled in a SOT3 package and with an external capacitance of 0.3 pF, S_{21} was measured with 1 mA of dc bias current and a calculated series resistance of about 175 Ω.

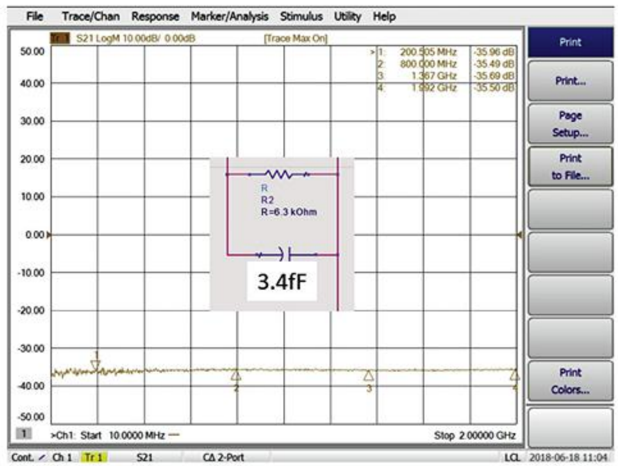


11. R_S was set to 1.25 kΩ for this measurement.

capacitor to ground, and compared to 50 Ω, would be a relatively high impedance that doesn't significantly affect the circuit. At low current, C_{iso} is in series with a small capacitance. This large series-resistance component would therefore not be detrimental to the circuit's performance. At low currents, however, C_{iso} will produce effective reduction in fringing capacitance *(Fig. 4, right)*.

For two-port measurements looking into the anode and cathode terminals, the SAPIN was assembled in a SOT3 package with an external C_{iso} of 0.3 pF. *Figure 10* shows the S_{21} measurement with 1 mA of dc bias current. The calculated series resistance is about 175 Ω.

In *Figure 11*, R_S is set to 1.25 kΩ. An R_S-value of 6.3 kΩ for a variable feedback resistor is needed for a transimped-



12. This is the measured S_{21} with R_S equal to 6.3 kΩ.

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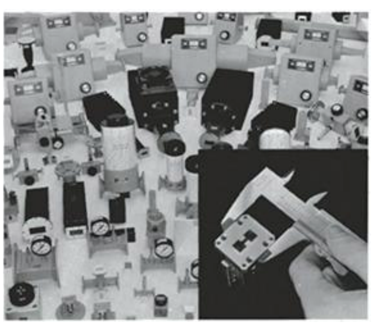

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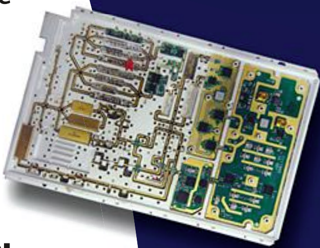

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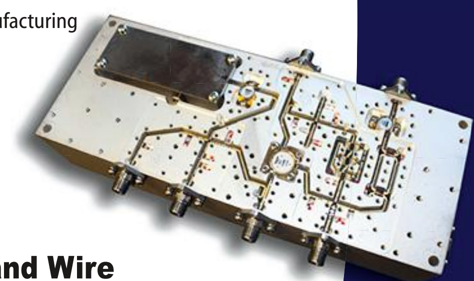

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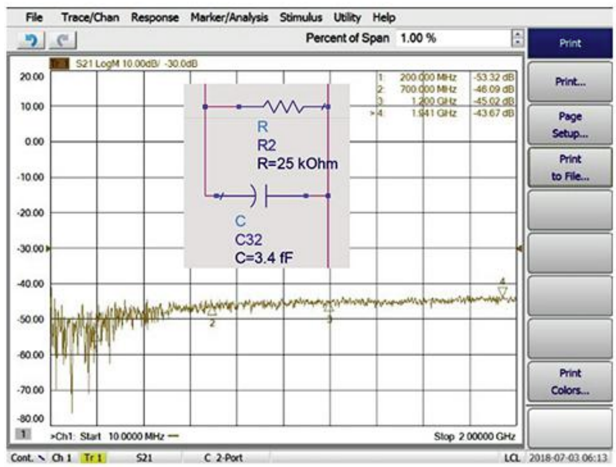
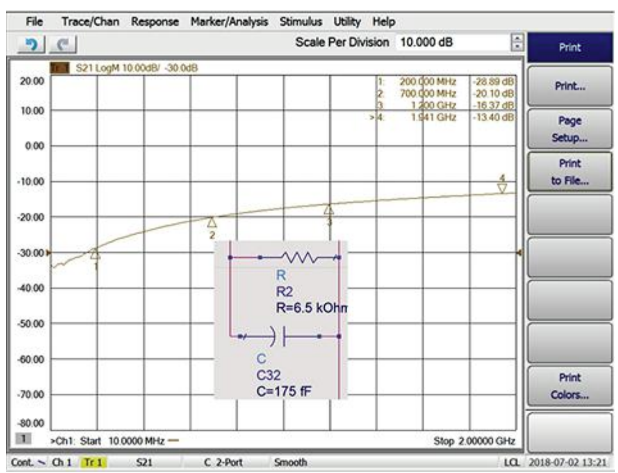
ance amplifier application.[2] *Figure 12* shows the measured S_{21} at 6.3 kΩ, along with the Advanced Design System (ADS) lumped elements for the best-fit simulation. The equivalent capacitor across the 6.3-kΩ resistor is 3.4 fF, indicating an RC 3-db frequency of 7.2 GHz.

With 0 Vdc, the device current was set to 0 mA. *Figure 13* illustrates the resulting "OFF" isolation exhibited by the SAPIN diode with best-fit resistor and capacitor values of 25 kΩ and 3.4 fF.

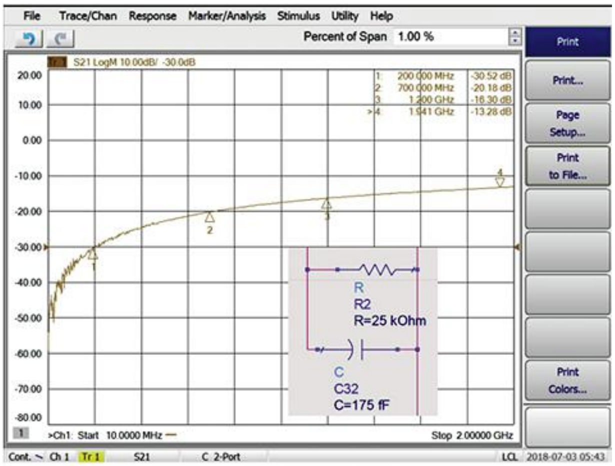
For comparison, an industry-standard SMP1307 attenuator PIN diode was measured at 6.3 kΩ. *Figure 14* shows the two-port S_{21} response that results in a best-fit RC model of 6.5 kΩ and 175 fF. The 3-db bandwidth when using this device as a resistor would only be about 144 MHz. In *Figure 15*, S_{21} is in the "OFF" isolation case with 0 Vdc and I = 0 mA. The equivalent RC lumped-element fit is 175 fF/25 kΩ.



13. Shown is the SAPIN's "OFF" isolation.



14. This is the S_{21} of an SMP1307 attenuator PIN diode with R_S equal to 6.5 kΩ.

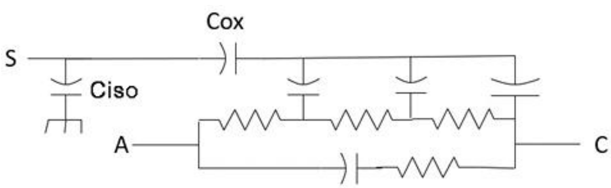


15. The SMP1307's "OFF" isolation is revealed.

CONCLUSIONS

Device simulations show a dramatic improvement in device performance with the addition of the shield—but not as much as a 50× improvement. We suspect there's additional attenuation due to the distributed nature of the SAPIN device as shown in *Figure 5*.

A lumped-element distributed circuit may help to explain the SAPIN broadband behavior *(Fig. 16)*. It can be thought of in a similar manner as the old oscilloscope probe-compensation networks. There's a voltage division with the resistances and capacitances together with the 50-Ω source and load impedances.



16. This circuit representation may provide insight into the SAPIN's broadband performance.

Work needs to be done to further understand the exact details of the device operation. In addition, future work will look to integrate the compensation capacitor C_{iso} into the Cox capacitor between the shield electrode and silicon surface. As it stands now for oxide thickness t_{ox} of about 800 A, the value of Cox is in the range of 100 pF. Simplifying the capacitors will allow the shield to be directly grounded. mw

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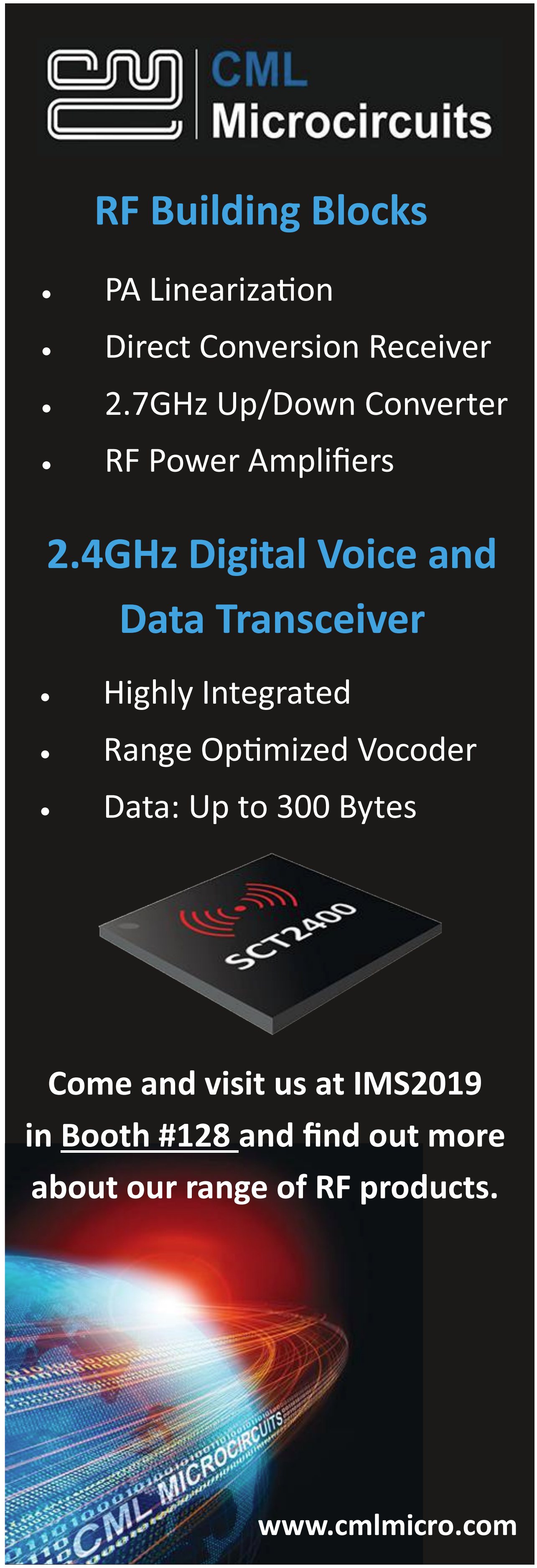
2. R Bayruns and T Laverick, *"Automatic gain-control transimpedance amplifier,"* US Patent 5646573 and US 5602510.



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Breathable E-Textile Proven for RF Wearable Apps

This novel technology allows for the creation of conductive tracks on fabric, making it a potential solution for a wide range of wearables.

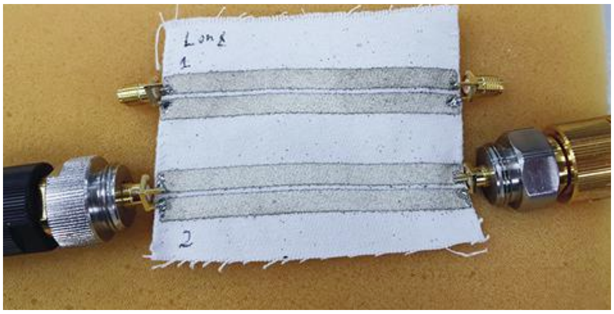
In the RF world, a significant effort has been made to develop high-performance substrates to reduce losses and extend frequencies. While many high-performance substrate options are now on the market, most can be classified as rigid, or at best, semi-flexible. In fact, in this high-performance race, many have overlooked all of the markets in which extreme performance and high frequencies were not required. Rather, these markets would have benefitted from new mechanically compliant substrates.

In this era when technology is becoming smaller and cheaper, more are looking to wearable technology as a predominant field of interest for markets ranging from medical to military to fitness. Conventional manufacturing technology that uses "rigid" components requires a great deal of effort to miniaturize the overall component. However, this kind of approach doesn't lend itself to RF applications in which the overall geometry depends on the frequency and imposes certain limitations that cannot be easily overcome.

In fact, many of the wearable devices that require wireless communications are large and bulky, limiting the freedom of movement, or at least the comfort, of the user. Here, we want to illustrate how a technology that allows for the creation of conductive tracks on fabric can provide both freedom of space and design while maintaining comfort and flexibility for the final user.

Pireta's (*www.pireta.co.uk*) technology process, which makes it possible to create conductive tracks and patterns on textiles, is suitable for both natural and synthetic fibers. This proprietary process involves five steps: cleaning, sensitizing, seed layer printing, electroless coating, and passivation. These are all immersion processes except for the seed layer printing, which allows for the geometrical freedom in creating the desired pattern.

Designed to be scalable, this process is amenable to large-scale production, sharing some processing steps with roll-to-roll digital printing. The fabric is coated with metal at the fiber level, making it conductive without losing its inherent properties like handle, drape, stretch, and breathability.

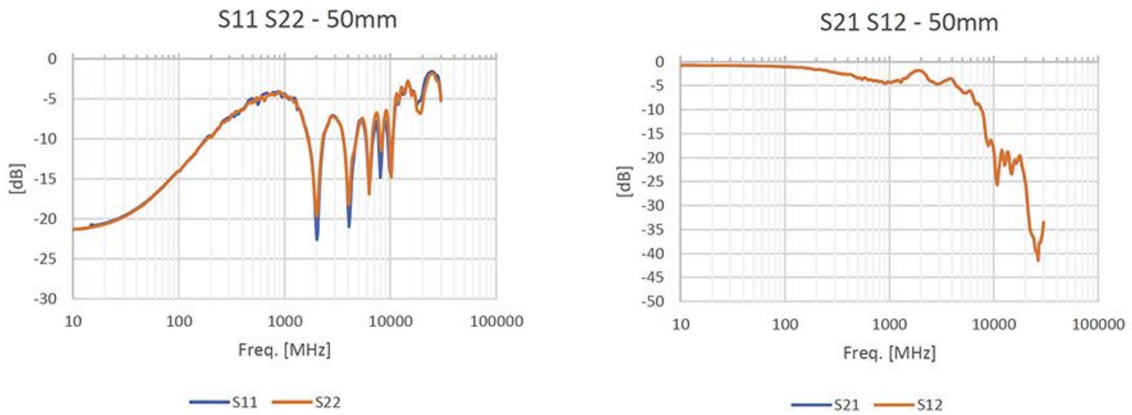


1. The 80-mm transmission lines with SMA connectors are connected to the vector-network-analyzer cables.

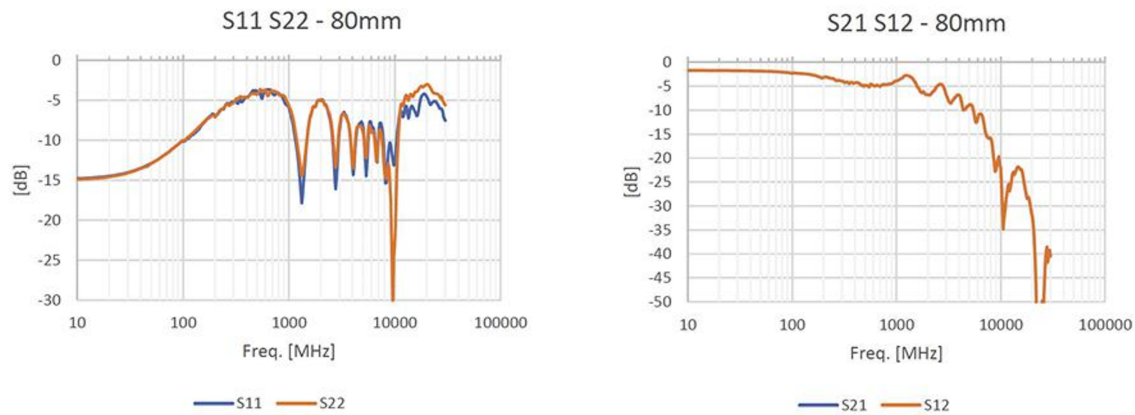
One of the fundamental structures involved with evaluating the suitability of a process for RF applications is transmission lines. Thus, short transmission-line sections were fabricated on cotton drill fabric using the Pireta process.

The transmission lines consisted of two 5-mm wide tracks with 2 mm of separation between them. Two different versions were fabricated, one with two 50-mm-long transmission lines and another with two 80-mm-long transmission lines. This kind of transmission line, known as a coplanar strip, is the electromagnetic (EM) counterpart of a coplanar waveguide.[1] They were manufactured by the deposition of a silver seed layer using the Pireta process, followed by copper electroless plating and finally a silver layer passivation.

After fabrication, geometrical measurements were taken again, and the track width was found to be 5.5 mm with a gap of 1.7 mm. Subsequently, the piece of fabric was hemmed, allowing the SMA female coaxial connectors to be soldered to the ends (*Fig. 1*). As this technology uniformly coats the fibers with metal, the fabric surface is suitable for soldering using common lead or lead-free solder, depending only on the fabric's tolerance to high temperatures.



2. These are the S-parameters for the 50-mm-long line.



3. The S-parameters for the 80-mm-long line are plotted.

VNA MEASUREMENTS

Measurements were carried out at the National Physical Laboratory (*www.npl.co.uk*) using a Keysight (*www.keysight.com*) PNA-X vector network analyzer (VNA). The test frequency was varied between 10 MHz and 10 GHz. The cables connected to the VNA used precision 3.5-mm connectors, which are rated up to 33 GHz.[2] (SMA connectors are commonly used up to approximately 12 GHz, although they can be used at higher frequencies.)[3] A short-open-load-thru (SOLT) calibration was carried out before performing the measurements.[4] The measurement results (i.e., S-parameters) for one of the 50-mm-long lines and one of the 80-mm-long lines are shown in *Figures 2* and *3*, respectively.

For both lines, the values of the reflection parameters (S_{11} and S_{22}) reveal relatively poor matching above 100 MHz. Due to the resolution limitations of the printing process, and this being a preliminary test, the impedance of the lines was deliberately not optimized. However, it's feasible that implementing an impedance transformer could solve this matching problem. Furthermore, in both cases, S_{11} and S_{22} are almost identical at each frequency, suggesting that the soldering process for the SMA connectors has good repeatability.

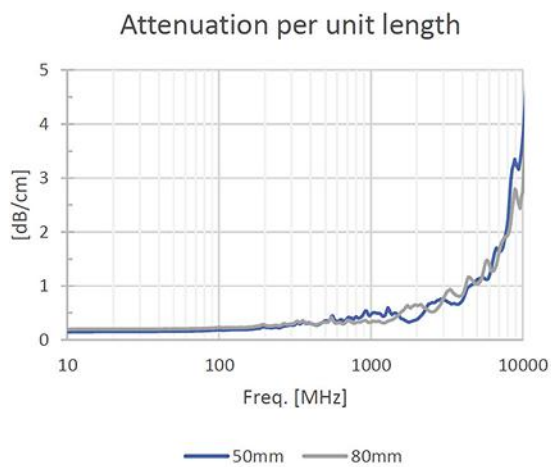
	MHz				GHz		
S21 (dB)	10	50	100	500	1	2	3
50 mm – line 1	−0.75	−0.85	−1.07	−3.5	−4.18	−2.13	−4.70
50 mm – line 2	−1.08	−1.16	−1.40	−3.75	−4.35	−2.53	−5.96
80 mm – line 1	−1.70	−1.86	−2.26	−4.81	−3.88	−6.80	−8.27
80 mm – line 2	−1.90	−2.07	−2.44	−5.07	−4.02	−6.30	−8.50

S_{21} measurements were taken at specific frequencies for the four lines.

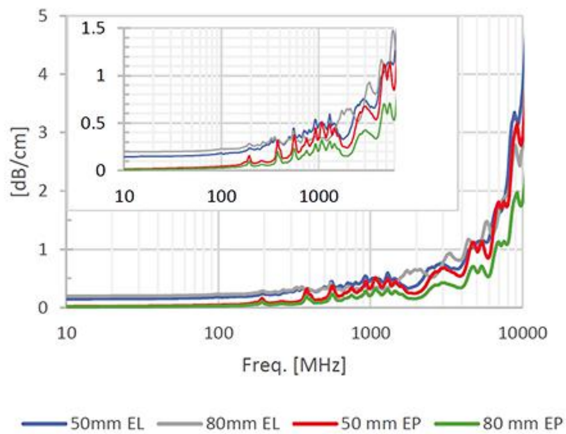
The transmission parameters (S_{12} and S_{21}) for both lines show acceptable performance up to 2 GHz and possibly beyond, once the design has been optimized to reduce the mismatch from the VNA test port connectors. The transmission losses, summarized in terms of S_{21} at specific frequencies for all four lines, are shown in the *table*.

Using the formula below:[5]

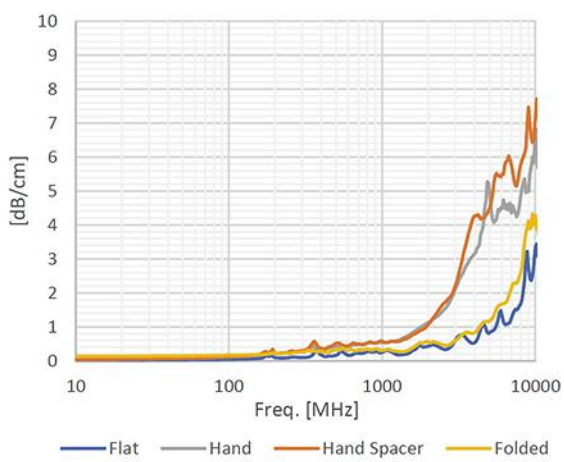
$$\alpha'_d = -\frac{10}{l}\mathrm{Log}\left(\frac{|s_{21}|^2}{1-|s_{11}|^2}\right)$$



4. Calculated attenuation per unit length is given for the 50- and the 80-mm-long lines.



5. An attenuation per unit length comparison between the electroless (EL) and the electroplated (EP) 50- and 80-mm lines was performed.



6. Attenuation is revealed in the cases of contact with human tissue (fingers), with a spacer between the tissue, and with the printed fabric folded between the transmission line and the tissue.

In this era when technology is becoming smaller and cheaper, more are looking to wearable technology as a predominant field of interest for markets ranging from medical to military to fitness. Conventional manufacturing technology that uses "rigid" components requires a great deal of effort to miniaturize the overall component.

It's possible to calculate α'_d (i.e., the attenuation per unit length after correcting for the mismatch loss) for the two lines. The results illustrated in *Figure 4* show very low attenuation per unit length for electrically short sections of line, i.e., approximately 0.20 dB/cm from 10 MHz to 100 MHz and 0.32 dB/cm at around 1 GHz.

INCREASE IN METALLIZATION

To improve the performance of these RF transmission lines, a new set of lines was manufactured. This time, a copper electroplating step was added after the passivation step to reduce the ohmic losses. These lines had a similar external appearance as the previously manufactured lines, with a marginal increase in stiffness.

Figure 5 shows the measured attenuation per unit length for both the set of transmission lines manufactured using the standard Pireta electroless (EL) process and the new set of lines fabricated with an extra layer of electroplated (EP) copper. Design and testing parameters were kept the same to allow for a direct comparison between the results. The electroplating parameters were 50 mA/cm^2 for 10 minutes.

The results show a significant improvement over the frequency range of 10 to 100 MHz. Above 100 MHz, the losses gradually start to increase. Nonetheless, the results continue revealing a 0.2 dB/cm improvement in comparison to the electroless lines, resulting in a loss per unit length of 0.3 dB/cm at 1 GHz.

It's believed that this increase in loss is due to inevitable geometrical imperfections in the lines, the rough edges of the printed features caused by the weaving pattern, and the roughness of the fabric itself. It's logical to assume that a better design and a finer fabric would improve the results. The suitability of the Pireta technology depends on the requirements of the application. By copper electroplating, the usable frequency can be extended to at least 1 GHz.

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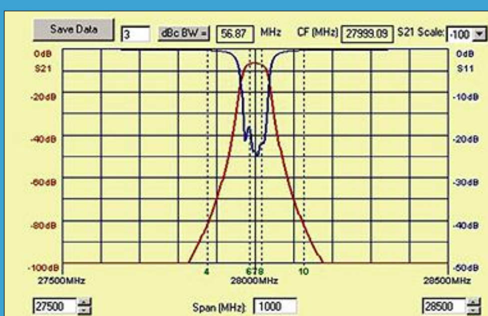
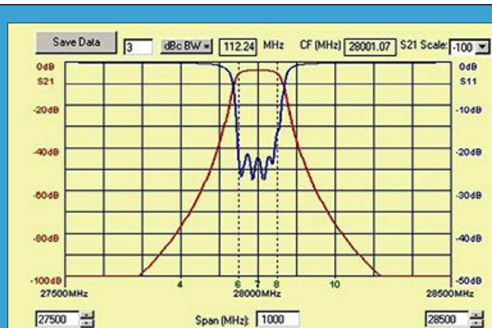
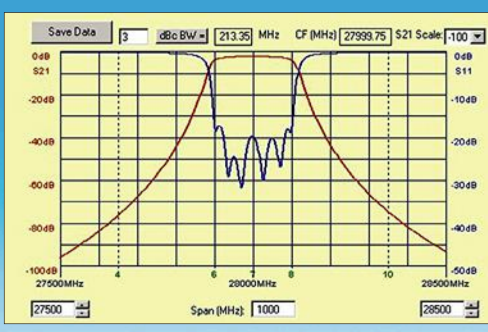


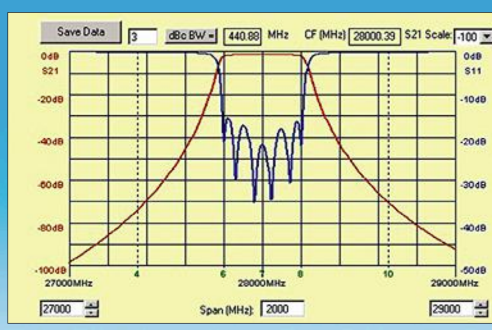
50 MHz



100 MHz



200 MHz



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TISSUE PROXIMITY

For the Pireta technology to be usable on clothing, it must be suitable for use when in contact with skin. It's to be expected that the body, being a lossy medium, would degrade the performance of the transmission lines. This can be seen in *Figure 6*, when three fingers were placed directly under the transmission lines (*Fig. 7a*).

Similar degradation in performance was observed when an insulating layer was interposed between the fingers and the lines (*Fig. 7b*). However, if another layer of conductive fabric is placed underneath the lines, the performance remains approximately the same (*Fig. 7c*). This demonstrates that, given the right design, the human body's effect on performance can almost be removed.

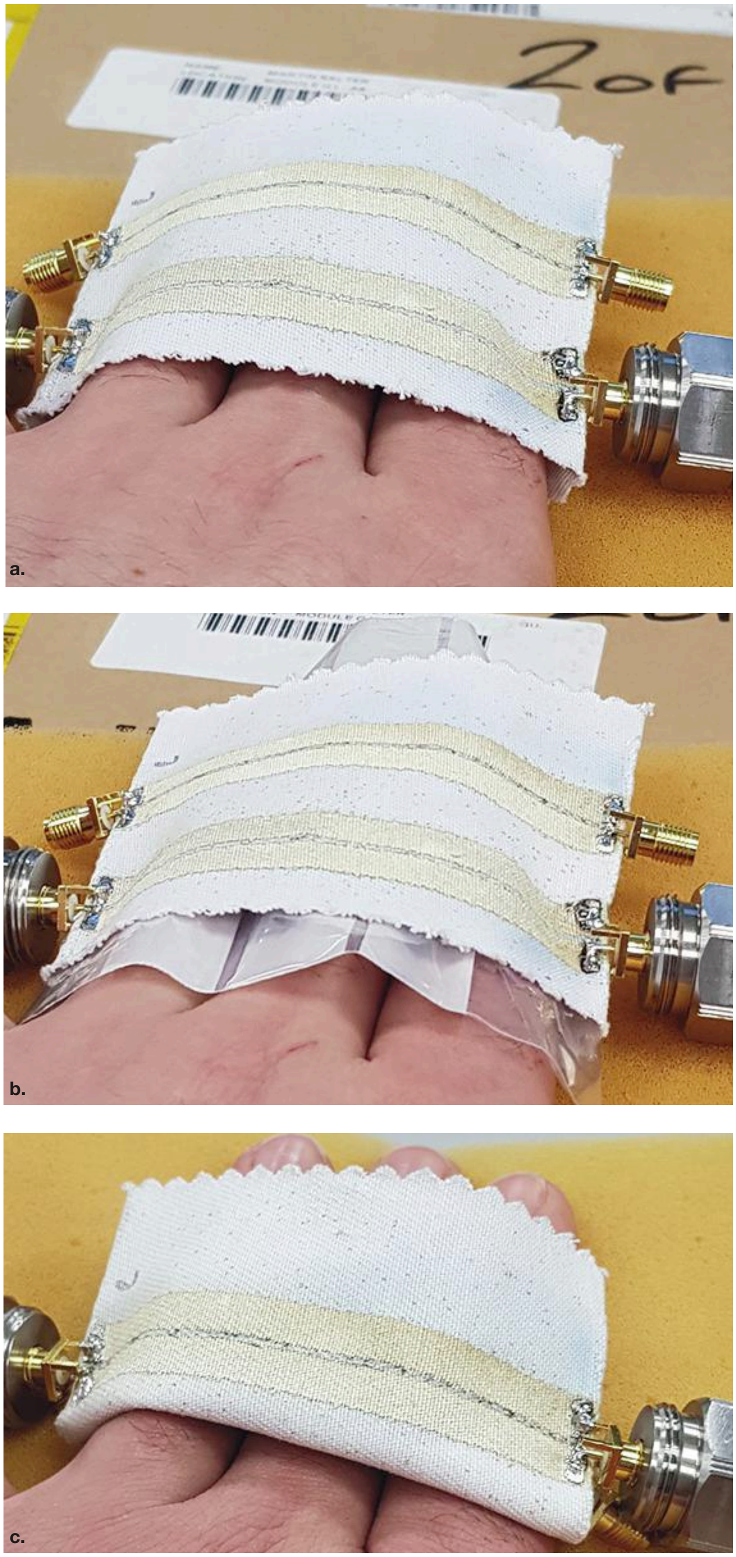
NON-FLAT FABRIC

Finally, the lines were tested under different distortion conditions of the fabric substrate (i.e., flat, U-bend, wiggle, misaligned, and twisted) (*Fig. 8*). *Figure 9* shows the results for all of these test conditions. There's very little variation in the measured performance as a result of these different test conditions, with only slightly larger losses in the wiggle configuration. This may be due to the formation of coupling between different sections of the line, as suggested by the shift in the observed peaks for these transmission lines.

RESULTS AND FUTURE WORK

The reported results show the feasibility of a process to produce transmission lines on fabric for RF applications to at least 1 GHz and perhaps beyond. This corresponds to the radio communications range of frequencies (AM: 0.3 to 3 MHz, FM: 30 to 300 MHz), RFID (3 to 30 MHz), and wireless communications (Wi-Fi/Bluetooth: 2.4 GHz, satellite radio: 1.4/2.3 GHz). With the possibility of removing the effect of human tissue on the performance of these transmission lines, this approach could be used for wearable RF applications. This is further supported by the observed resilience to fabric distortion, which had very little effect on the measured loss in the lines.

Future steps will include optimizing the planar structure to improve the reflection losses. In addition, the dielectric constant of the fabric substrate, the thickness of the conductive lines, and the non-uniform current path compared with conventional solid metal track lines will all be considered.



7. The 80-mm transmission lines were tested with a hand underneath (a), an insulation layer between the hand and the lines (b), and another line folded underneath and a hand below (c). *(See Figure 6 for the results).*

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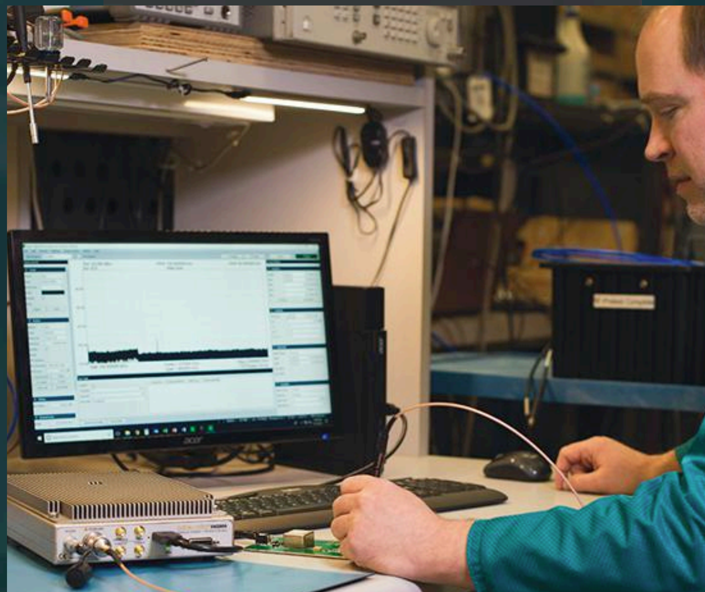

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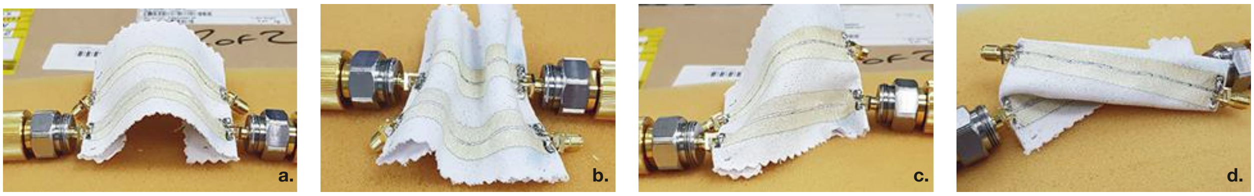
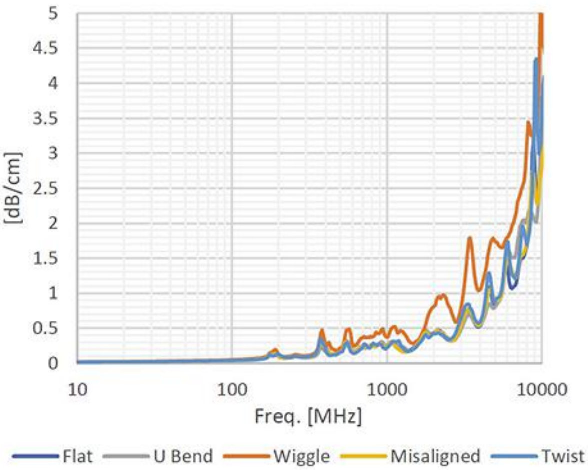


8. Four different test conditions were applied to the fabric transmission lines: U-bend (a), wiggle (b), misaligned (c), and 180° twist (d).



9. This is the measured attenuation per unit length for all five test conditions: flat, U-bend, wiggle, misaligned, and twist.

CONCLUSIONS

It's been demonstrated that the Pireta technology, though still in its infancy, can deliver an e-textile technology that meets the RF requirements of many telecommunications applications, including the sub-6-GHz end of the 5G spectrum. At the same time, the technology does not affect the textile characteristics of the handle, drape, and breathability. This exciting combination of properties offers important opportunities in many application areas and potentially opens doors to new product developments. mw

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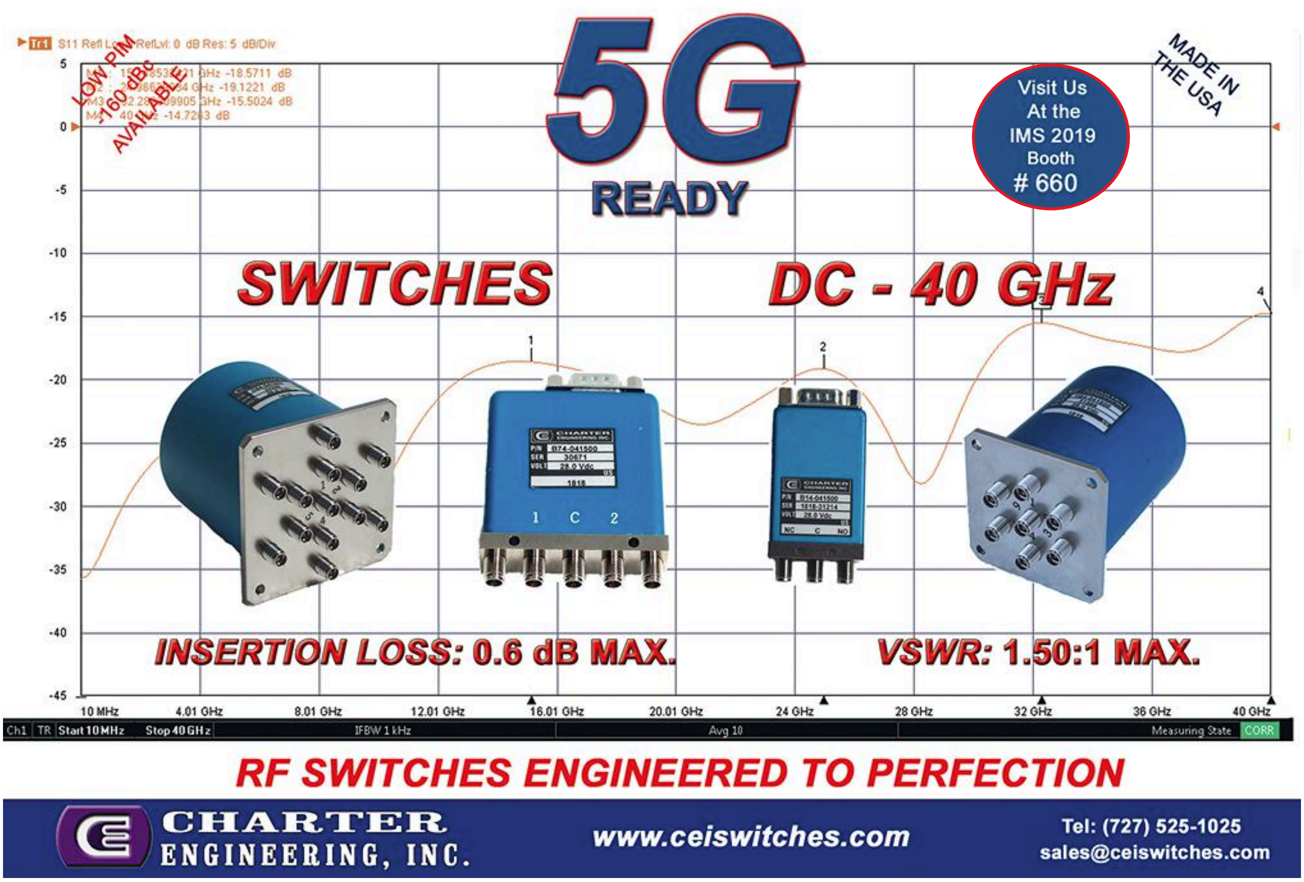

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A Practical Design Approach to Custom mmWave SMT Packages

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

After many years of research and development, electrical engineers, physicists, mathematicians, and scientists have come to realize the benefits of operating communications systems at higher frequencies. Some of the most notable advances stemming from this research include smaller circuit implementations for the same functionality, improved antenna gain for a given antenna size, and dramatic increases in data-carrying capacity. However, numerous challenges remain in implementing high-frequency circuits under real-world constraints. Among the non-trivial problems, packaging is one that stands out.

It's critical that packages for RF components allow for the integration of multiple circuital technologies while achieving the best possible balance of performance and cost for a given application. Nevertheless, traditional packaging techniques have proven incapable of translating the same performance typically seen below X-band into the millimeter-wave (mmWave) range due to embedded parasitics and other inherent technological constraints. These limitations have led the design community to leverage the latest packaging technologies, novel design methodologies, and advanced CAD tools to develop cost-effective, scalable packaging solutions for high-frequency markets and applications.

These new packaging techniques are now moving away from performance-degrading implementations, such as molding compounds and long wire-bonding structures, to achieve outstanding performance beyond 55 GHz. In light of these developments, this article explores some of the key concepts that underlie the development of commercially viable packaging solutions for mmWave components (patent pending).

INTRODUCTION

Global mobile data usage is expected to grow from 11.2 petabytes/month in 2017 to 48.3 petabytes/month in 2021. 5G has emerged as a strong proposal to increase mobile data capacity by a factor of 1000 and support the expected data consumption of seven billion people and seven trillion devices. All of this would happen while still retaining energy efficiency and maintaining near-zero downtime.[1]

The advent of 5G has brought about an increase in development of integrated circuits (ICs) to meet the requirements for high-frequency applications. The need also arises for the development of cost-effective packages that not only protect the ICs, but are also capable of maintaining good electrical performance across wide operational frequency bands.

Current surface-mount quad-flat no-leads (QFN) packages are not suitable for packaging devices at mmWave frequencies. Parasitic elements encountered in the signal path—for example, discontinuities in the vertical transition from the printed circuit board (PCB) to the top side of the QFN and from the wire bond to the IC—are negligible at lower frequencies. However, such discontinuities become relevant once the physical dimensions of the elements become a fraction of the wavelength.

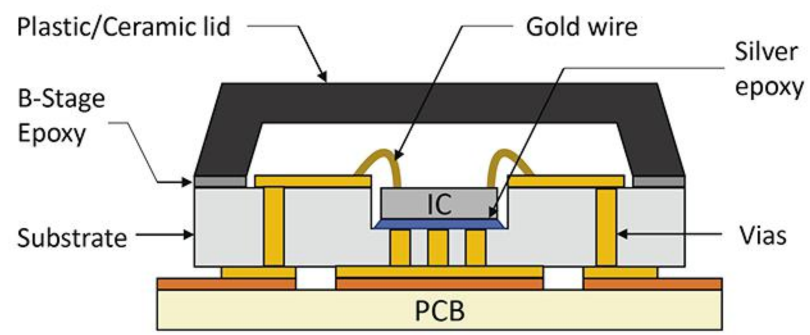
Another drawback associated with QFN packages is their reliance on overmolding. This not only increases electrical loss at higher frequencies, but also makes it impossible to package die featuring air bridges. Moreover, QFN packages are incapable of accommodating flip-chip devices due to their standardized nature.

Many solutions have emerged to address these challenges. Air-cavity QFN packages allow for ICs with air bridges, but they still lack a well-matched transition at high frequencies. Micro-Coax structures allow for high-frequency operation but require specialized assembly processes.[2] Custom packaging solutions can compensate for parasitic effects and allow for air-cavity implementation.[3] Fully-custom solutions are most viable when incorporated into a rapid, low-risk design strategy as well as a highly automated assembly process.

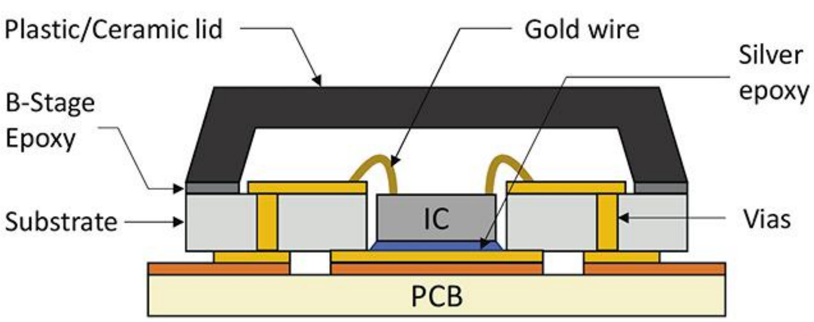
Modern RF applications have stringent requirements for components beyond electrical specifications. Dense assemblies, high operating powers, and the need for robust, reliable systems place heavy demands on monolithic-microwave-integrated-circuit (MMIC) package designers in terms of balancing electrical performance with desirable thermal and mechanical characteristics.

Since design features that benefit one aspect of performance may detract from the requirements of others, tradeoffs are often necessary. For example, a tradeoff intended to improve electrical performance at the expense of heat dissipation may produce little benefit due to a temperature rise on conductors and semiconductors. It's therefore critical for designers to understand the simultaneous effects of design choices on the different aspects of a device's performance.

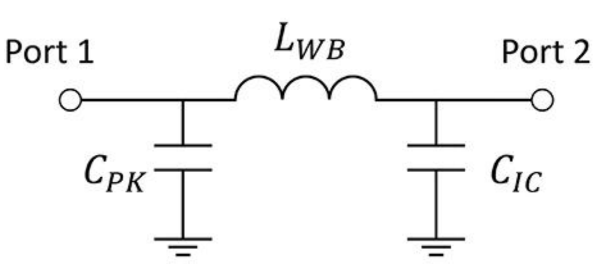
In this article, we present the development of custom surface-mount packages with good electrical performance from dc to 50 GHz, accounting for the PCB, the surface-mount package, and the IC (patent pending). What follows is a discussion of the package's components and design. After that, the article dives into the tradeoff between customization and standardization of design features in the context of performance and cost goals. Measured performance of a broadband MMIC attenuator die in both custom organic and low-temperature co-fired ceramics (LTCC) packages are shown. Also discussed are the benefits of a multi-physics simulation workflow employed in the design of these packages.



1. This is the schematical cross-section of a ceramic package.



2. An organic package's schematical cross-section is shown.



3. Here's a lumped-element representation of the gold wire interconnect between the package pad (C_{PK}), the gold wire (L_{WB}), and the IC pad (C_{IC}).

DESIGN ELEMENTS

Structure

Schematical cross-section diagrams of the ceramic and organic packages with the PCB are shown in *Figures 1 and 2*, respectively. The description that follows is common to both. The IC is attached to the pocket inside the substrate using conductive epoxy. This implementation minimizes the length of the gold wire bonds. The gold wire connects the RF pads of the IC to the RF pads of the package, forming a lowpass network in which the wire bond is represented as a lumped series inductance, L_{WB}, and the pads are represented as C_{PK} and C_{IC} *(Fig. 3)*.

Proper tuning of this matching network is critical for an accurate impedance match and good wideband electrical performance. The package's RF pad is followed by a microstrip line with 50-Ω characteristic impedance, and a matched vertical transition down to the bottom pad. The bottom pad of the package is made to have a 50-Ω characteristic impedance in a grounded-coplanar-waveguide (GCPW) configuration. The package is soldered to the PCB, which employs GCPW with a 50-Ω characteristic impedance. A plastic or ceramic lid is attached to the package with a non-conductive B-staged epoxy.

Materials

Material and technology selection play a big role in the performance of a package. Selecting the right materials will depend on the application requirements, such as hermeticity, maximum operating frequency, package size, package weight, first- and second-level interconnects, thermal management constraints, and tolerable insertion loss of interconnects.[4]

In both the LTCC and organic substrate packages, the selection of substrate material must account for the dielectric constant and loss tangent needed to achieve the desired RF performance. The substrate also determines the package topology and the compatibility with the other materials.

The two substrates explored here are LTCC and organic substrate. The LTCC package consists of a ceramic monolithic structure with a cavity formed in the top tape layers of the substrate *(Fig. 1, again)*. The exposed top face of the pocket features a continuous metallization that's connected to the bottom ground pad through multiple vias. Being a stiffer material, it's easier to wire bond.

In the case of the organic package, the pocket is created by removing a portion of the substrate and exposing the bottom metallization *(Fig. 2, again)*. This allows for better RF grounding and thermal resistance.

In both packages, the conductor materials and finishes are selected to achieve good RF performance and to accommodate industry-standard assembly processes. The metal conductor on the LTCC package is typically silver with an electroless-nickel-immersion-gold (ENIG) surface finish. The plating protects the underlying silver from oxidation and must have properties compatible with soldering and wire-bonding processes.

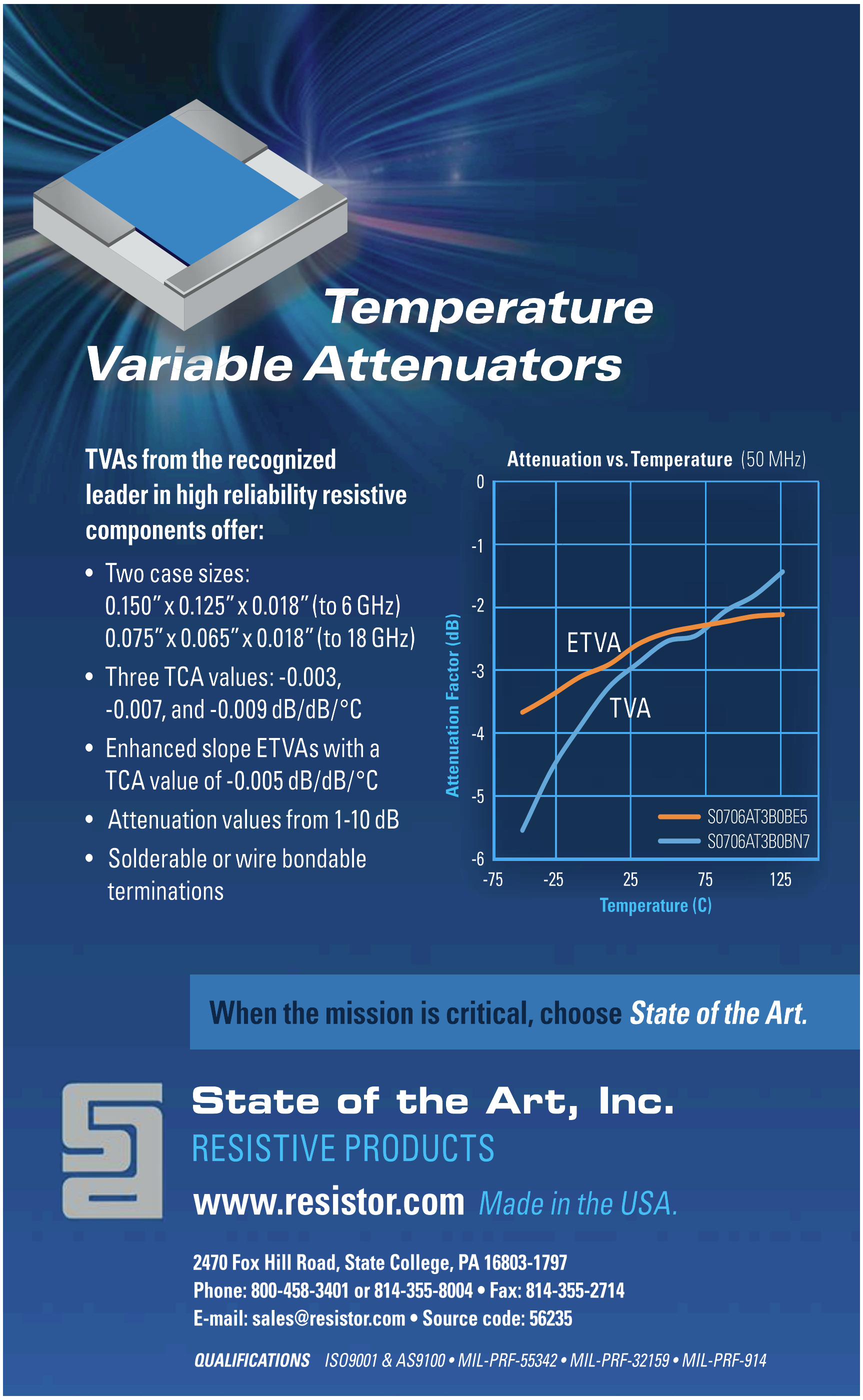
The organic package employs copper conductors and may feature any of several different surface finishes. The choice of surface finish may be a critical matter in high-frequency applications, as both surface roughness and electrical conductivity have significant effects on insertion losses.[5, 6]

Selection of the conductive epoxy used to mount the MMIC die has a significant impact on the total thermal resistance of the package. As the main point of contact between the die and the package, the epoxy facilitates most of the die's heat dissipation.

Simulation Workflow

During the design phase of this project, the electrical, thermal, and mechanical performance of the LTCC and organic packages were analyzed using a multi-physics simulation workflow. The simulation workflow employed multiple simulators that were operated sequentially, with each simulator's results being used as part of the next simulator's setup.

While more complex than a workflow involving separate electrical, thermal, and mechanical simulation tasks, a true multi-physics simulation workflow gives design engineers a holistic view of a design's performance.



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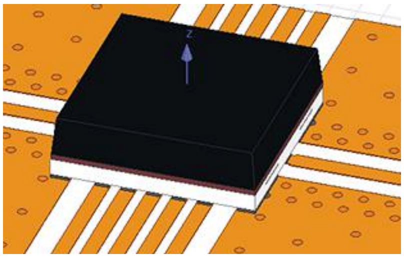
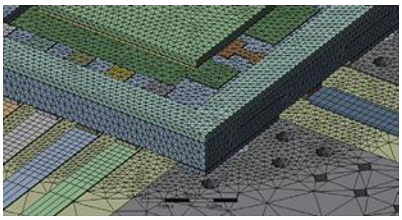
The specific simulation workflow is as follows:

1. A full 3D finite-element electromagnetic (EM) simulation is performed on a simplified version of the design's geometry *(Fig. 4)*. The simulation yields S-parameter data and a spatial distribution of power dissipation within the design.
2. A full 3D finite-element thermal simulation is run on the EM simulation's model, augmented to include geometry relevant to thermal and mechanical (but not electrical) performance. As shown in *Figure 5*, effort was made to accurately model critical regions of simulation geometry, such as hollow and solder-filled plated through-holes (PTHs). The simulation employs the power dissipation computed from the EM simulation and yields a temperature distribution within the model's geometry.
3. A full 3D finite-element mechanical simulation is run on the full model geometry, employing the spatial temperature distribution as part of its setup. The simulation yields mechanical strains and stresses within the model geometry.
4. If desired, the above process may be iterated until convergence criteria are met, feeding the temperature rise information and model geometry deformation into the electrical simulator for the next pass. In practice, a single pass is often sufficient to achieve outstanding agreement between simulation results and physical measurements.

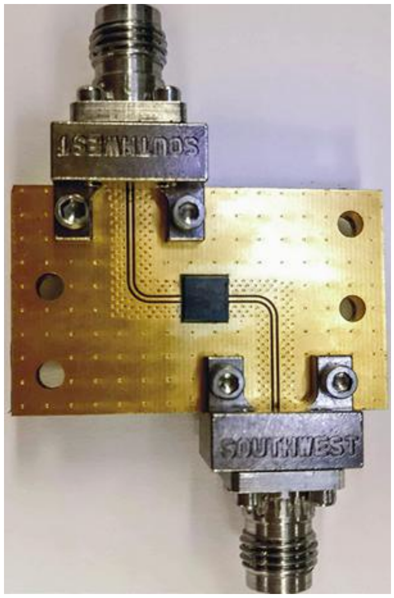
While more complex than a workflow involving separate electrical, thermal, and mechanical simulation tasks, a true multi-physics simulation workflow gives design engineers a holistic view of a design's performance. For example, a traditional thermal simulation of a

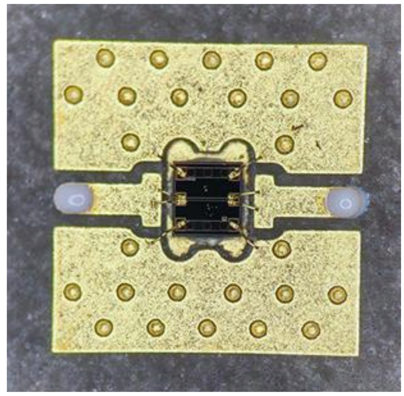


4. The electromagnetic simulation model of the LTCC package included only the design elements relevant to electrical performance.



5. This is a close-up of the geometry and mesh employed in thermal and mechanical simulations of the LTCC package with package lid hidden. Note that the model includes solder, die-attach epoxy, and both hollow and solder-filled plated through-holes.





6. The IC in an organic package (with lid) is shown here on an evaluation board (left). A close-up of the package without the lid shows the flip-chip die atop package substrate (right).

microstrip conductor may involve a uniformly distributed heat source applied to the conductor's volume or faces. Such an approach discards valuable information about localized heat generation, since current densities at mmWave frequencies are nonuniform. A multi-physics simulation approach implicitly captures this effect and others without needing attention from the designer.

The ability of a multi-physics simulation to automatically account for conditions too complex to manually set up is especially valuable for LTCC designs. As LTCC designs consist of a monolithic ceramic structure with complex internal conductor geometry, thermal images of the exterior of such a device may not fully reveal its internal thermal behavior.

Because the electrical, thermal, and mechanical aspects of a design's performance are often linked (due to temperature-dependent electrical resistivities, thermal expansion, etc.), such a simulation workflow makes it possible to best understand the impact of design decisions on interrelated aspects of performance. The workflow has been qualified through multiple projects involving several technologies and achieves simulation results in very close agreement with performance measurements. As with other portions of Mini-Circuits' established LTCC process, it's subject to continual evaluation and improvement.

CUSTOMIZATION VS. STANDARDIZATION

Although the QFN package has been an industry workhorse for both active and passive electronic components up to V-band frequencies, its highly standardized nature makes it a suboptimal solution for some applications.[7] As applications march toward mmWave frequencies, packaging technologies must adapt to widely varying industry needs.

While a one-size-fits-all solution may fit all applications equally poorly, a fully custom solution yielding outstanding results may be cost- and time-prohibitive. To develop a rapid, cost-effective packaging solution that still offers outstanding application flexibility, it was desirable to combine industry-standard processes and tunable design features into a customizable package template.

Taking a "templated" approach to package design allows for the reuse of proven design elements, reducing the effort and risk incurred by solutions that require starting from scratch. Facilities for adaptation to an application's specific electrical, thermal, mechanical, and environmental needs are provided while minimizing or eliminating the need for extensive qualification of new designs.

QFN packages are typically available in a granular range of standardized sizes (3 × 3 mm, 4 × 4 mm, etc.), while a MMIC die may be any size and aspect ratio. A die that's slightly too large to fit one standard QFN-package size must instead use the next size up, necessitating long wire bonds with correspondingly large parasitic inductances. The package itself offers little facility to compensate for these parasitics, a task relegated instead to conductor geometry on the PCB and die. Furthermore, QFN packages employ a plastic encapsulant that envelops the leadframe, die, and wire bonds.

Delicate structures on the MMIC die, like air bridges, are incompatible with such an encapsulation process. Even in the absence of incompatible MMIC features, the encapsulant may detune or degrade the performance of sensitive electronics simply by proximity. Finally, the terminals of the QFN package are highly standardized with little flexibility of the pad sizes and geometries. For some applications, the electrical parasitics associated with the fixed transition geometry may be unacceptable.

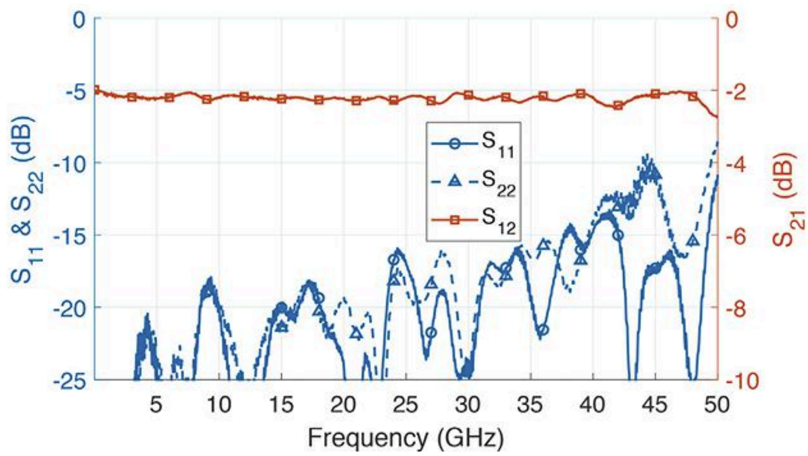
Mini-Circuits' custom LTCC and organic substrate packages address the above limitations, offering solutions with sufficient flexibility to meet the needs of a wide variety of applications. In these packages, the die inhabits a pocket atop the substrate *(Figs. 1 and 2, again)*. The pocket's dimensions are specified according to the customer's die so that wire-bond pads can be brought as close to the die as possible, minimizing bond-wire length and inductance.

Therefore, the LTCC and organic substrate packages offer greater flexibility with regard to MMIC die sizes, even though they are currently available in the same sizes as standard QFN packages (3 × 3 mm, 4 × 4 mm, and 5 × 5 mm). A plastic lid is affixed over the die and wire bonds with a B-staged epoxy compound, maintaining an air gap above the die and wire bonds and achieving a semi-hermetic seal. Using an air gap rather than an encapsulant permits the packaging of delicate MMIC structures and minimizes degradation of electrical performance.

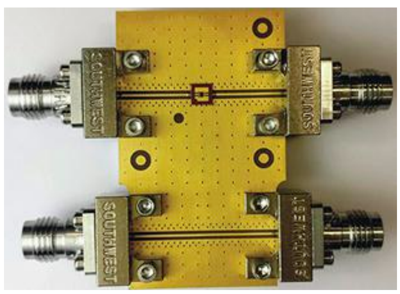
Unlike QFN packages, the LTCC and organic substrate packages offer the flexibility needed to best suit a wide variety of applications. The package structure contains tunable elements that electrically compensate for the parasitics associated with the transitions from the PCB to the package and from the package to the MMIC die. Furthermore, since the package features printed conductors rather than a solid leadframe, the footprints of the LTCC and organic substrate packages can be customized with minimal tooling cost.

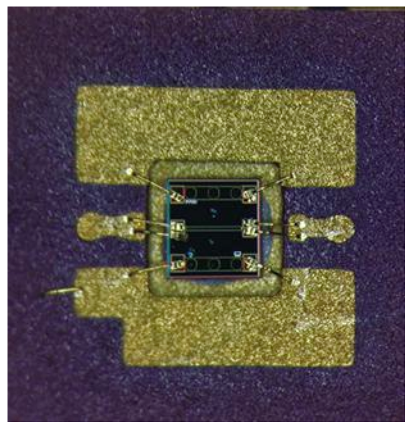
EXAMPLES

To validate the design and to measure the performance of the organic and LTCC packages, multiple packages were designed, fabricated, and tested. The packages were assembled and soldered on 5-mil Taconic TLY-5 evaluation PCBs with 50-Ω GCPW traces. Southwest Microwave *(www.southwestmicrowave.com)* 2.4-mm edge-launch connectors were used to interface the PCBs with the vector network analyzer (VNA). A standard short-open-load-

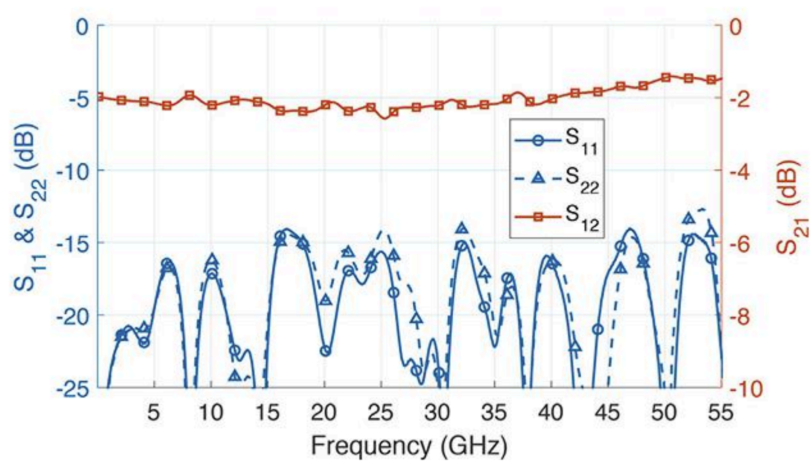


7. These are the measurement results of a 2-dB attenuator on organic package.





8. Here, the IC is in an LTCC package on an evaluation board (left). A close-up of the package without the lid shows the die and wire bonds (right).



9. The plots reveal measurement results of a 2-dB attenuator on LTCC package.

thru (SOLT) calibration was performed up to 55 GHz, up to the reference plane of the connectors. The insertion-loss measurements for each package are normalized by subtracting the losses of the PCB thru-line.

MMIC 2-dB Attenuator on Organic Package

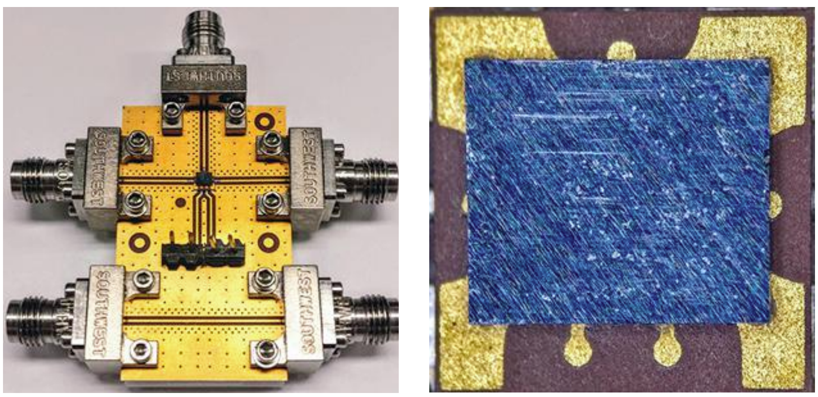
A 2-dB MMIC attenuator is mounted and wire-bonded on top of an organic package. *Figure 6* shows the package mounted on top of the PCB, as well as a close-up of the package without the lid, depicting the die and the wire bonds. *Figure 7* shows the measured data of the device. The S_{21} trace reveals a very flat response of –2 dB up to 48 GHz. A good return loss is also observed for the entire frequency bandwidth.

MMIC 2-dB Attenuator on Ceramic Package

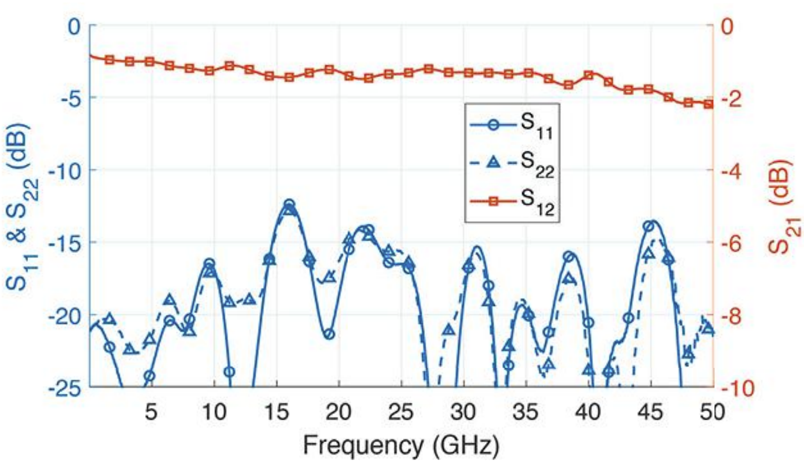
A 2-dB MMIC attenuator is mounted and wire-bonded on top of a ceramic package. *Figure 8* shows the package mounted on top of the PCB, as well as a close-up of the package without the lid, illustrating the die and the wire bonds. *Figure 9* shows the measured data of the device. The S_{21} trace reveals a very flat response of –2 dB up to 55 GHz. A good return loss is also observed for the entire frequency bandwidth.

Flip-Chip SPDT Switch on Ceramic Package

A flip-chip single-pole, double-throw (SPDT) switch is mounted on top of a ceramic package. *Figure 10* shows the package mounted on top of the PCB, as well as a close-up of the package with the exposed flip-chip die. *Figure 11* reveals the measured data of the device with the RF2 channel active. A good return loss is observed over the entire bandwidth.



10. Shown is the packaged IC on evaluation board (left). One can view a close-up of the package without the lid, showing die and wire bonds (right).



11. Measurement results indicate good return loss for the SPDT flip-chip switch with RF2 channel active.

CONCLUSION

Packages employing both LTCC and organic substrate materials have been developed (patent pending). Outstanding electrical performance of both packaging technologies was demonstrated up to 55 GHz. Both packaging methodologies accommodate a wide variety of application-specific needs, including impedance matching, variable die sizes, and a wide range of I/O pad counts, signal types (dc or RF), and PCB geometries. By combining standardized and adjustable features into a tunable package template, Mini-Circuits' approach to packaging achieves desirable electrical performance and broad applicability while minimizing turnaround time, cost, and risk. mw

ACKNOWLEDGEMENTS

The authors would like to thank Mini-Circuits for providing the resources needed to conduct the research and develop the innovations presented in this article.

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defense electronics

A Special Section to INFORMA'S DESIGN ENGINEERING & SOURCING GROUP MAY 2019

Latest IR Binoculars Include Sniper Function

JACK BROWNE | Technical Contributor

SNIPERS NOW HAVE a new tool for long-distance targeting: the latest version of the JIM Compact multifunction infrared (IR) binoculars. Developed by Safran Electronics & Defense *(www.safran-electronics-defense.com)* in partnership with the French Commandment of Special Operations (COS), the "Long Range Sniper" (TELD) function is integrated into the IR binoculars to enhance a sniper's capabilities.

TThe TELD function operates by measuring the distance to a target and its speed of motion, and then calculating the flight time of the bullet according to a firing table for the weapon and ammunition used in an application *(Fig. 1)*. The binoculars will

1. The JIM Compact IR binoculars measure the distance to a target as well as the motion of the target and calculate a bullet's flight time to improve sniper effectiveness. *(Courtesy of Safran Electronics & Defense)*

2. The compact IR binoculars weigh only 2 kg and even include wireless communications capabilities. *(Courtesy of Safran Electronics & Defense)*

(Continued on page 92)

Compact UAS Goes Distance with Tether

MOBILITY AND AGILITY in the field are as important for intelligence, surveillance, and reconnaissance (ISR) as for actual battle, and the latest addition to the Indago portfolio of unmanned aerial systems (UAS) from Lockheed Martin provides speed where needed. The tethered Indago UAS can collect information from a distance, operating with or without the tether for power. With the tether, the distance is limited by the physical link, although the operating time is greatly extended for uninterruptible missions. Without the tether, the flying time is about 50 to 70 minutes on battery power.

The Indago UAS drone *(see figure on page 92)* features folding rotors, enabling the UAS to be fit into a backpack for ease of transport. It weighs less than 5 lbs. and can be folded to a size with a longest dimension of 12 in. According to Michael Carlson, Business Development Manager for Indago, "When it comes to unmanned systems and capability, size does matter. We want to make something as important as force and facility protection as simple and effective as possible—the tethered Indago can do that."

(Continued on page 92)

JACK BROWNE | Technical Contributor

Are Modern Battlefields Becoming Like Video Games?

TECHNOLOGY PLAYS A large part in the modern military, for all branches, with electromagnetic (EM), optical, and even infrared (IR) energy being harnessed for defensive and offensive purposes on the battlefield. On top of that, the U.S. Army and other branches have made no secrets of their use of computer video games as a way to develop future soldiers interested in showing their skills with technology-based weapons, such as unmanned aerial vehicles (UAVs or drones) and robotics-based systems, on the battlefield and for counter-terrorism operations.

Many military-flavored video games, including "Modern Warrior 2," "Call of Duty," and "Tom Clancy's Rainbow Six," have served to recruit their share of young soldiers and helped steer them toward enlistment in the armed forces. However, as in those video games, when does the technology take over and the reality of the battlefield become too "virtual?"

Much of modern warfare has turned into defense against terrorist operations and attacks being performed by secretive troops who have adopted military actions that result from time spent on video games. Many of the military video games present realistic scenarios and invite players to defend and attack against extremely difficult conditions.

At the same time, in the real world, military systems are being upgraded with modern electronic capabilities such as highly accurate long-range radar systems, terrestrial and satellite-based communications systems, advanced electronic-warfare (EW) systems, and drone-based surveillance systems. Ironically, the video controllers for many of these systems, such as surveillance drones, are not far removed from the screens appearing for military video games.

Future battlefields will more closely resemble the screens of those many popular military video games, filled with laser weapons and UAVs and robotic warriors. And, therefore, future soldiers will likely feel that they have been going through training since childhood.

As in commercial and industrial environments, the amount of data in military settings, from the growing number of sensors, will be enormous and much more than any commander can handle without extensive computing power and support.

In a way, the time spent on all those military video games is beneficial training, helping to prepare future troops for battlefields that look more like science fiction than reality. de

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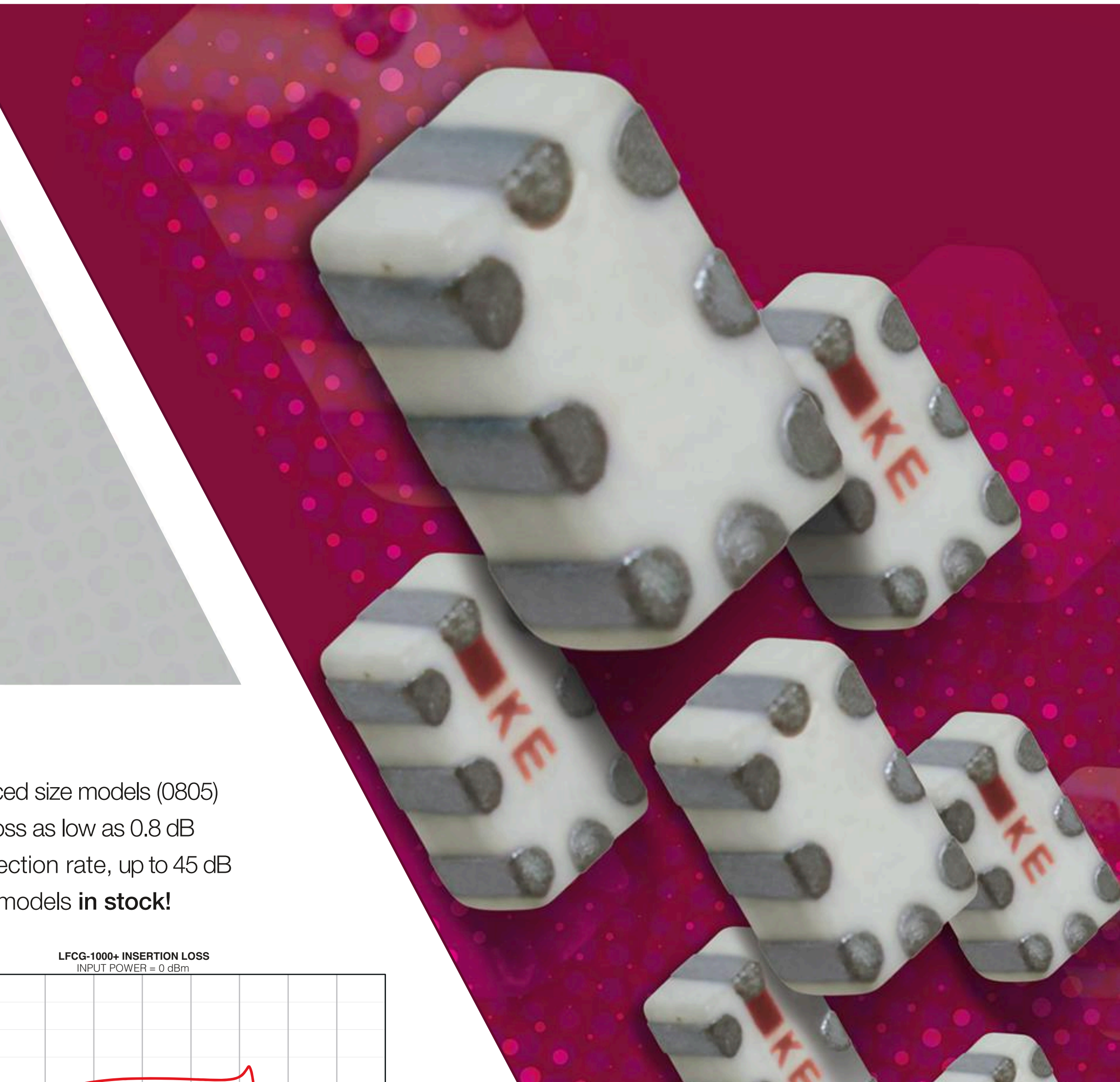

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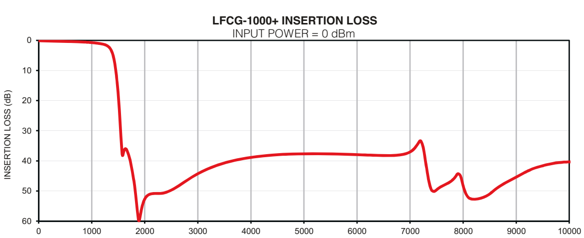

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Latest IR Binoculars Include Sniper Function

(Continued from page 89)

display in its sights any corrections necessary to the angle of fire. This function can increase the probability of a first-round hit on moving targets and reduce the possibility of collateral damage.

The novel IR binoculars *(Fig. 2)* weigh less than 2 kg with battery for ease of transport and use in both day- and night-time operations. Designed to meet size, weight, and power (SWaP) requirements, the IR binoculars are also equipped with wireless communications capabilities, including Bluetooth and Wi-Fi.

The portable binoculars pack a tremendous amount of functionality into a compact package, including a high-resolution cooled IR channel, a television channel, a laser pointer, a laser range finder, a low-level light (LLL) channel, a digital magnetic compass, and a Global Positioning System (GPS) receiver. The JIM Compact IR binoculars are currently used by more than nine NATO military forces. The multifunction IR binoculars were recently on display at the Special Operations Forces Innovation Network Seminar (SOFINS) event April 2-4 in Camp de Souge, France. de

Compact UAS Goes Distance with Tether

(Continued from page 89)

The tethered Indago incorporates electro-optical imaging capable of reading a vehicle license plate from 1000 ft. It also includes thermal IR imaging for night-time operations. de

The Indago UAS is now available in a tethered version for uninterruptible tactical missions. The UAS features a collapsible rotor that allows it to be folded for ease of transport. *(Courtesy of Lockheed Martin)*

MAKING HIGH-ENERGY LASER WEAPONS MORE TRANSPORTABLE

OPTICAL AND ELECTROMAGNETIC (EM) energy in many forms have been key components for the modern battlefield. In that vein, the U.S. Army has devoted its High Energy Laser (HEL) Tactical Vehicle Demonstrator (TVD) program to try to develop a 100-kW laser system that defends against incoming missiles and drone aircraft. An important part of the development program, which involves Raytheon Co., Lockheed Martin, and many other leading defense contractors, is making the laser compact and energy-efficient enough to be readily transported on tactical all-terrain vehicles. In its current state, the HEL system is deployed on a six-wheel truck, which is considered too cumbersome for tactical missions. By modifying and redesigning the laser systems, the goal is to make it deployable on standard tactical vehicles *(see figure)*.

The U. S. Army's High Energy Laser (HEL) Tactical Vehicle Demonstrator (TVD) program is devoted to making more compact weaponized lasers. *(Courtesy of Lockheed Martin, www.lockheedmartin.com)*

In addition to its laser components, the HEL TVD includes a communications, command, and control (C3) subsystem for receiving targeting instructions from a base camp or from headquarters. The U.S. Army is planning to perform a demonstration of available HEL TVD technology against a range of targets during fiscal year (FY) 2022. As a backup, the military service is also working on a lower-power version of the laser system, at 50 kW, called the Maneuver Short Range Air Defense (M-SHORAD) system. It's being designed for installation on a Stryker combat vehicle.

The Army's FY 2020 budget request for $262.1 million in funding for 44 M-SHORAD systems covers the upgrade for that number of Stryker combat vehicles. With the growing number of air-based threats, including missiles and unmanned aerial vehicles (UAVs), this use of directed-energy weapons has been posed by the Army as a more cost-effective defense, in terms of cost per shot. ■

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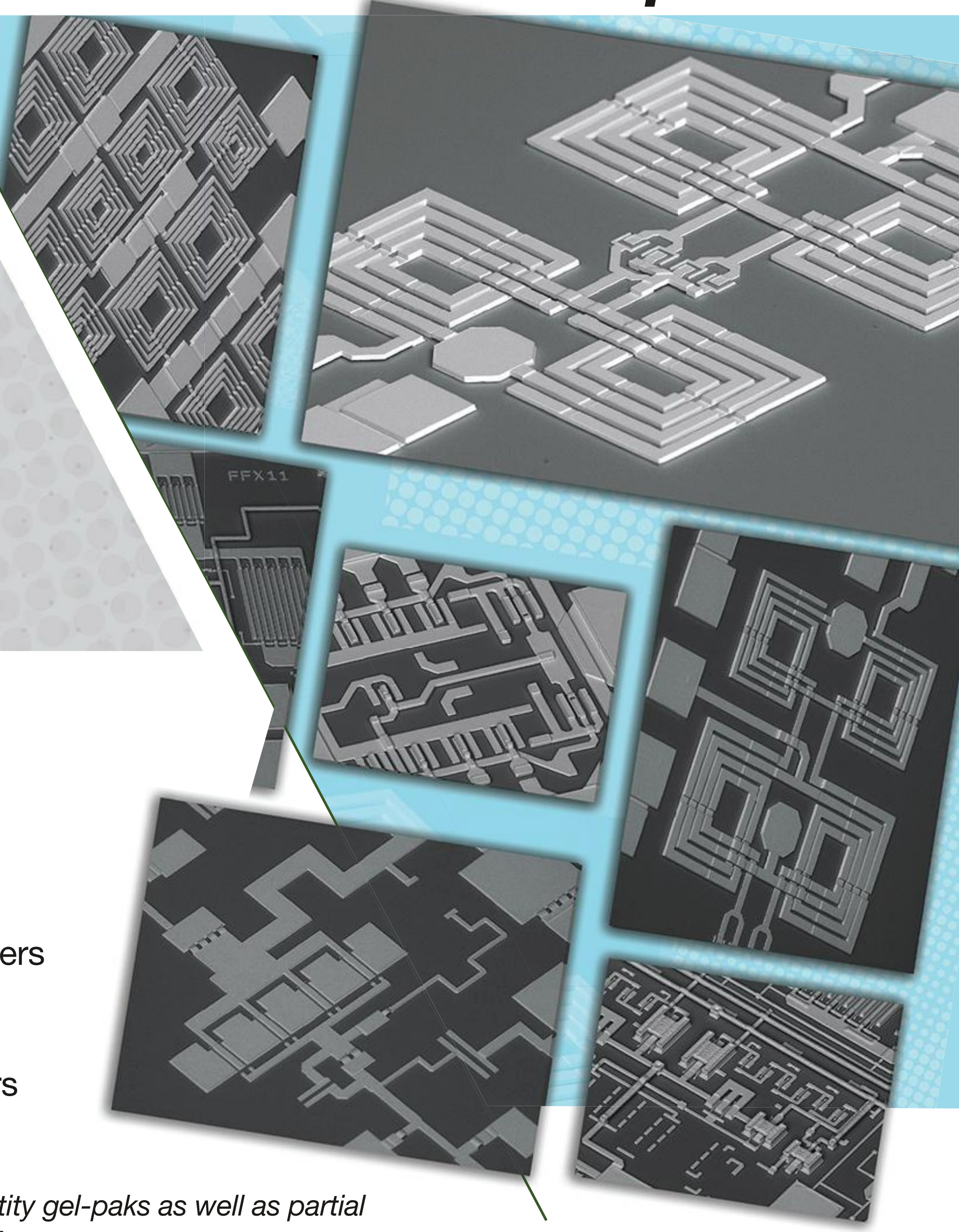

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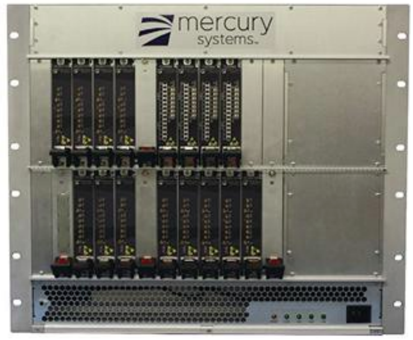
Mercury Acquires Athena Group and Syntonic Microwave

MERCURY SYSTEMS INC. *(www.mrcy.com)* significantly added to its positions in security and RF/microwave technologies with the recent acquisitions of The Athena Group and Syntonic Microwave LLC. These were all-cash transactions totaling $46 million and subject to net working capital and net debt adjustments. The deals, funded by means of Mercury's existing revolving credit facility, are not expected to have a material impact on the firm's financial results for the full fiscal year of 2019.

The Athena Group is a privately held company based in Gainesville, Fla. It's a leading provider of cryptographic and countermeasure intellectual property (IP) for securing defense computing systems. The Athena Group is a leader in differential-power-analysis (DPA) technology and offers a variety of sophisticated security-based technologies meeting Department of Defense (DoD) requirements. Solutions from the Athena group make full use of field-programmable-gate-array (FPGA) and application-specific-integrated-circuit (ASIC) devices to solve the most difficult security challenges and provide defense-based IP for AI, mobile communications, and cloud computing.

Located across the country in Campbell, Calif., Syntonic Microwave is a provider of frequency synthesizers, phase-coherent tuners, and microwave frequency converters for signal-intelligence (SIGINT) and electronic-intelligence (ELINT) applications. The company's microwave hardware covers frequency ranges to 40 GHz with instantaneous bandwidths as wide as 2 GHz. The systems and subsystems are designed in modular fashion, allowing for rapid adaptation and prototyping according to the requirements of emerging applications, to meet the needs of next-generation electronic-warfare (EW) applications.

"The acquisitions of Athena and Syntonic represent continued milestones for our market and content expansion strategy," said Mark Aslett, Mercury's President and Chief Executive Officer (CEO) "Mercury has a long history of collaboration with Athena in protecting critical Defense systems deployed across surface, subsurface, ground, and airborne platforms. Athena's technologies expand our BuiltSECURE security IP portfolio and extend our leadership in secure embedded computing, positioning us well to capitalize on DoD program protection security requirements for domestic and foreign military sales."

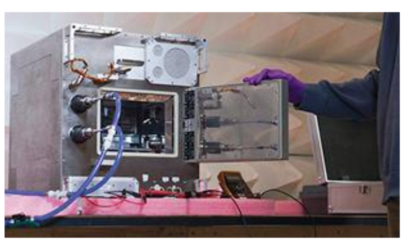


This coherent receiver system is an example of the engineering at Mercury Systems, which recently acquired The Athena Group and Syntonic Microwave LLC. *(Courtesy of Mercury Systems)*

Aslett added, "Similarly, we believe Syntonic's deep domain expertise in agile RF technology will expand and enhance our position as the preeminent supplier of high-performance, SWaP-optimized EW subsystems while enabling us to further penetrate the SIGINT and ELINT markets with additional Mercury content. The acquisition of Syntonic gives our defense Prime customers and government agencies access to highly differentiated sensor processing capability, thereby advancing our national interests through domination of the electromagnetic spectrum." ■

Advanced Printer Reuses 3D Parts on Space Station

TRANSPORTED ONBOARD a Cygus spacecraft from Northrop Grumman *(www.northropgrumman.com)* to the International Space Station (ISS) in November, the Refabricator is a different type of 3D printer that can turn waste plastic and previously printed 3D parts into 3D printer filament or 3D printing ink for reuse. Well-suited for resource-limited applications such as within the ISS, the Refabricator 3D printer provides the means to reuse materials many times to create new tools and components. The system (see figure) is designed and manufactured by Tethers Unlimited Inc. (TUI, *www.tethers.com*) of Seattle, Wash.


The Refabricator is a unique 3D printer that can form new parts and components while working with used parts and reused materials. *(Courtesy of NASA)*

The Refabricator was used as part of a recent demonstration to evaluate the quality of parts manufactured with reused materials. It was produced for NASA as part of a Small Business Innovation Research contract to TUI and completed final flight certification testing at NASA's Marshall Space Flight Center in Huntsville, Ala. Refabricator was launched from NASA's Wallops Flight Facility on Virginia's Eastern Shore. NASA feels the remanufacturing technology could prove invaluable for future deep-space exploration, including missions to the Moon and Mars. ■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JACK BROWNE | Technical Contributor

Routing High-Frequency Mission-Critical Signals

Cables and connectors are vital to military electronics systems, where real-time performance takes on greater meaning, and recent advances are now taking them to higher frequencies.

COAXIAL CABLES and connectors are important components in any electronic system, but in mission-critical systems, lives can depend on them and the signal information they carry. While they can be thought simply as the means to get signals from one point to another, a poor fit or undue stress on a coaxial interconnection can result in system performance degradation. Understanding how different coaxial cables and connectors work can not only help improve their parts in a system, but in the test equipment used to evaluate the system.

Cables and connectors have come a long way in terms of frequency, tracking the movement upward into the millimeter-wave (mmWave) range as with many other passive components. Broadband cables and connectors were once considered for use from dc to 18 GHz, but such cable assemblies are now considered standard equipment in defense electronic systems.

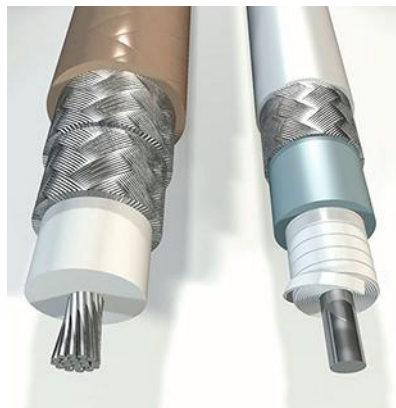
Connectors are starting points for moving signals from one component to the next. Improving capabilities to machine the shrinking interface dimensions of coaxial connectors has made it possible to reach well into the mmWave frequency range. they have progressed steadily upward in frequency since the introduction of the 2.92-mm 40-GHz K connector in 1985, followed by the 50-GHz, 2.4-mm connector; the 65-GHz, 1.85-mm connector; and the 1.00-mm, 110-GHz connector. Most recently, Anritsu *(www.anritsu.com)* introduced a D-band connector with 0.8-mm interface dimensions for test applications to 110 GHz.

Development of semirigid and flexible coaxial cables typically follows the introduction of smaller coaxial connectors. For system designers at mmWave frequencies, the question is often whether available coaxial cable assemblies can match the electrical performance of the waveguide currently used at those frequencies, especially in terms of insertion loss and power-handling capabilities.

Cables can also exhibit performance differences over time that typically do not occur with rectangular waveguide, such as changes in amplitude and phase due to cable flexure (in flexible cables). Such characteristics must be considered when specifying coaxial cables and connectors for military and aerospace system designs.

Cable suppliers are constantly seeking to improve the performance of their coaxial cables. Take the recent introduction of GORE Optimized RG400 Coaxial Cable by W.L. Gore *(www.gore.com)*, which would serve a replacement for the literally miles of low-frequency RG400 flexible cables in military aircraft. The upgraded version *(Fig. 1)* of the cable is 60% lighter and 30% smaller than the legacy cable, while providing enhanced performance through 3 GHz.

The new cable has an outer diameter of 3.5 mm and weight of 26 g/m, for significant savings in space and weight in aircraft interconnections. The insertion loss is extremely low, only 0.17 dB/m at 200 MHz, 0.25 dB/m at 1000 MHz, and 0.80 dB/m at 3000 MHz, while the power-handling capability is quite high, 1100 W at 50 MHz, 450 W at 400 MHz, and 150 W at 3 GHz. The 50-Ω



1. RF400 coaxial cables, widely used in defense electronics systems, were recently upgraded into the GORE Optimized RG400 Coaxial Cable that's smaller and lighter, and has better performance, than the original. *(Courtesy of W. L. Gore & Associates)*

cables exhibit a maximum velocity of propagation of 75% and an operating temperature range of −65 to +200°C. Environmental protection is achieved with a fluorinated ethylene propylene (FEP) outer jacket

Perhaps of most importance when it comes to the long-term reliability of aircraft high-frequency interconnections, the optimized RG400 cables can be bent into tight spaces: They have a maximum dynamic bend radius of 100 mm (3.94 in.) for repeatable bends without damage and a maximum static bend radius of 35 mm (1.38 in.) for permanent bends in system installations. The cables, which meet or exceed MIL-C-7 electrical requirements, can be terminated with a variety of coaxial connectors, including SMA, BNC, and Type N connectors. The outer jacket of the

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KEEPING IN PHASE

Due to the use of signal phase as a key parameter in many defense electronic systems, phase stability is an important characteristic for high-frequency coaxial cables. Phase tracking is yet another phase-based parameter for cables, to evaluate how closely cables of the same length maintain the same phase at the same frequency during changes in temperature.

Coaxial cables can be subjected to a great deal of bending during installation, use, and maintenance, and are subject to changes in phase as a result of the bending. This may degrade the performance of phased-array radars and other systems depending on stable phase.

For multiple-channel installations where different channels are compared, the stability of the electrical cable length with flexure, temperature, vibration, and other environmental conditions is another important performance parameter for defense electronics systems. W.L. Gore employs its proprietary expanded-polytetrafluoroethylene (ePTFE) cable dielectric material as a key component in its coaxial cables to maintain stable phase and electrical length under changing environmental conditions.

Installation within aircraft systems can take its toll on coaxial cable assemblies, with all of the routing, bending, and flexing that the cables go through. GORE-FLIGHT 6 Series and Standard Series microwave cable assemblies from Gore were developed to withstand such punishment, for applications from dc to 18 GHz.

Suitable for use in missile warning systems, airborne electronic-countermeasures (ECM) systems, and radar systems, these 50-Ω cables have low loss, with typical insertion loss of 0.198 dB/ft. at 18 GHz for 6 Series cables and 0.342 dB/ft. for Standard Series cables. A velocity of propagation of 86% ensures minimal signal delays through the cables. The cables undergo extensive testing, including wear testing to simulate the abrasions from aircraft installations *(Fig. 2)*, as a way of understanding how they will perform under realistic operating conditions.

DEALING WITH POWER

For many EW and radar systems, power-handling capability is an important performance parameter. It's an area where coaxial cables and connectors usually fall short compared to the capabilities of waveguide flanges and trans-

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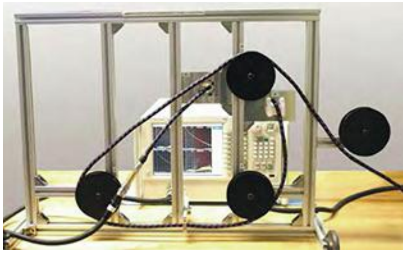

2. Many cable suppliers subject their cable and connector assemblies to rigorous testing to more closely simulate real-world conditions, such as this test system that duplicates the installation of coaxial cables into airframes. *(Courtesy of W. L. Gore & Associates)*

mission lines. RG400 50-Ω coaxial cables from Winchester Interconnect *(www.winconn.com)* for example, are formed with silver-plated copper-clad steel center conductor and PTFE dielectric to achieve a maximum cutoff frequency of 12.4 GHz. They handle as much as 1470 W signal power at 100 MHz, 430 W at 1 GHz, and 100 W at 11 GHz, and offer a minimum bend radius of 1 in. with a velocity of propagation of 69.5%.

For even higher-power applications, the same company's line of Tru-Win high-power coaxial cables provide power-handling capabilities in the kilowatt range at microwave frequencies (with the proper coaxial connectors). For example, the TRU-350 coaxial cable is rated for maximum power of 22.5 kW at 50 MHz, 4 kW at 1 GHz, and 8.88 kW at 18 GHz. The firm supports its cables with many M39012-qualified coaxial connectors, including for type C, N, TNC, BNC, and SMA interfaces.

Some firms, such as Mini-Circuits *(www.minicircuits.com)*, simplify the task of specifying coaxial cable assemblies for system or test applications through 50 GHz by providing an online "cable creator" type tool. Visitors can select a type of cable (flexible, semirigid, armored), its length, the types of input and output connectors, and the connector gender (male or female). A number of companies, such as Pasternack Enterprises *(www.pasternack.com)*, offer similar tools, such as Pasternack's "The Cable Creator," which is backed by search engines and filters for custom cable creation services and a listing of test services through 65 GHz.

For military and aerospace purposes, many suppliers offer phase-stable versions of cables with low loss and reasonable power-handling capabilities. Using their online tools, cable assemblies can be ordered with a choice of connectors and at desired lengths, in many cases for shipment by the manufacturer the same day. de

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Clock Oscillators Keep Time in MIL Systems

Various forms of crystal oscillators provide the signal generation and timing precision essential to the synchronization of many subsystems within military/aerospace systems.

HIGH-FREQUENCY CRYSTALS and crystal oscillators (XOs) must survive operating environments from the ground to deep space, providing timing signals in different forms and frequencies to maintain the accuracy of myriad electronic systems from communications through electronic warfare (EW) and radar. These XOs can be specified in a range of package styles to fit the mechanical and electrical requirements of a defense-based application. A quick review of the key performance specifications and a sampling of available oscillator types can help in choosing a clock XO when the time is right.

XOs are available with many different output types, including single-ended and differential waveform types. Single-ended clock signals can be routed on a printed circuit board (PCB) by a single-path transmission line (such as microstrip or stripline). Differential clock signals require a pair of transmission-line paths to channel the complementary differential signals. Single-ended clocks feature simpler circuit designs, while differential clock oscillators offer the suppression of power-supply noise and control of electromagnetic interference (EMI) that comes from the use of balanced lines.

Single-ended oscillator types include sources with sine waves and clipped sine waves, square waves, complementary metal-oxide semiconductor (CMOS) signals, high-speed CMOS (HCMOS) signals, low-voltage CMOS (LVCMOS) signals, and transistor-to-transistor-logic (TTL) signals. Among the differential output types are emitter-coupled-logic (ECL) signals, positive-emitter-coupled-logic (PECL) signals, low-voltage PECL (LVPECL) signals, current-mode logic (CML), low-voltage differential signaling (LVDS), and high-speed current-steering logic (HCSL).

As the names may indicate, the clock outputs differ in power consumption and speed as well as noise levels. In addition to standard clock oscillators, which generate a fundamental-frequency or overtone-frequency output from a crystal resonator, hybrid crystal oscillators integrate additional functions as needed, such as amplifiers, noise-suppression filters, and phase-locked loops (PLLs), to provide high-performance clock outputs in compact housings for applications where space is tight.

In the frequency domain, the spectral purity of different crystal oscillators is usually compared by their single-sideband (SSB) phase noise. In the time domain, for timing applications, the SSB phase noise basically equated to the phase jitter.

Jitter is a measure of the timing consistency of an oscillator's signal waveform edges, essentially whether all rise times of the rising edges are equal and whether all fall times of the falling waveform edges are equal and occur at the same time. Low jitter refers to little or no deviations in an oscillator's signal waveform edges and is, of course, preferable for most systems. High jitter can degrade system performance, such as causing a rise in the bit error rate (BER) of serial data transmissions.

OSCILLATOR VARIETIES

Three types of XOs achieve different levels of stability by controlling thermal effects. Standard XOs offer good stability without additional circuitry. Temperature-compensated XOs (TCXOs) achieve somewhat higher frequency stability at a cost of greater complexity, higher power consumption, and slightly larger package size.

Oven-controlled crystal oscillators (OCXOs) are typically the most stable

Modern clock and hybrid clock oscillators are housed in compact packages with a variety of output signal formats. *(Courtesy of CTS Corp., www.ctscorp.com)*

form of XO, but they are larger and consume more power than XOs and TCXOs. When some adjustment in oscillator frequency is needed, voltage-controlled crystal oscillators (VCXOs) are another form of XO that provides a small amount of tuning around the center frequency by means of an applied tuning voltage.

When sorting through any catalog of XOs, TCXOs, or OCXOs in search of the right fit for a clock oscillator application, output frequency, output signal format, frequency stability, jitter, and package style are key factors. Additional parameters to consider include supply voltage, power consumption, frequency pushing, frequency pulling, frequency tuning speed (for VCXOs), and post tuning drift (for VCXOs).

For military applications, crystal oscillators are screened according to applicable standards. These include MIL-STD-883 for bond pull, thermal shock, stabilization bake, temperature cycling, and constant acceleration testing; MIL-STD-202 for gross leak and fine leak; and MIL-STD-55310 for aging. The package styles for commercial clock oscillators involve packages with pins and surface-mount configurations *(see figure)*. Clock oscillator packages are as small as 2.5 × 2.0 mm to meet tight circuit requirements.

A SAMPLING OF AVAILABLE XOs

What is an example of a low-jitter clock oscillator suitable for defense applications? The TX-707 series TCXOs from Vectron International *(www.vectron.com)* covers a center frequency range of 8 to 52 MHz with fundamental-frequency HCMOS or clipped sine-wave output signals. Housed in a compact 7- × 5-mm surface-mount-technology (SMT) package, TX-707 TCXOs are shipped with initial frequency stability of ±1 ppm and maintain frequency stability of ±1 ppm after one year and ±4 ppm for 15 years. Models are available for +3.3- or +5.0-V dc supplies (10-mA typical current consumption) at operating temperatures from -40 to +85°C.

Typical SSB phase noise from 50 MHz for the TX-707 series is –82 dBc/Hz offset 10 Hz from the carrier, –113 dBc/Hz offset 100 Hz, –135 dBc/Hz offset 1 kHz, and –155 dBc/Hz offset 100 kHz from the carrier. A jitter specification is not provided, although the clock oscillator features a fast rise time of 5 ns.

For somewhat higher-frequency operation, the BOCS2 series clock oscillators developed by Bliley Technologies *(www.bliley.com)* are OCXOs available with fundamental-frequency outputs from 1.5 to 60 MHz and third-overtone output center frequencies from 50 to 170 MHz. They can supply CMOS/TTL or HCMOS output types.

The BOCS2 OCXOs maintain frequency of stability of ±3 ppm after one year and ±5 ppm for the first five years for excellent long-term frequency stability. These oscillators exhibit low phase noise, with typical performance of –60 dBc/Hz offset 10 Hz from a 100-MHz carrier, –95 dBc/Hz offset 100 Hz from the same carrier, –125 dBc/Hz offset 1 kHz from the carrier, and –144 dBc/Hz offset 100 kHz from a 100-MHz carrier. The phase jitter is typically only 0.2 ps at 12 kHz to 20 MHz from the carrier.

When frequency tuning is required, a VCXO from Greenray Industries' *(www.greenrayindustries.com)* Y1600 series provides HCMOS outputs from 10 to 50 MHz with a ±10-ppm frequency adjustment range. The VCXO features initial accuracy of ±3 ppm with an aging rate of less than ±1 ppm for the first year. Even with the convenience of tuning, these clock oscillators feature outstanding phase-noise performance, with SSB phase noise of –105 dBc/Hz offset 10 Hz from a 10-MHz carrier, –135 dBc/Hz offset 100 Hz from the same carrier, –155 dBc/Hz offset 1 kHz from the carrier, and –162 dBc/Hz offset 100 kHz from a 10-MHz carrier.

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Engineers Turn to SSPAs to Boost Radar Pulses

For a function that once required a tube amplifier, semiconductor amplifiers are raising pulsed power levels for radars and other applications at higher frequencies.

PULSES PROVIDE target detection for a wide range of radar systems in military, industrial and, increasingly, in commercial automotive systems. The systems rely on working with pulses at suitable transmit power, which is usually provided by a pulsed high-frequency power amplifier (PA).

Such PAs were once almost entirely designed with traveling-wave tubes (TWTs) and vacuum-tube technology. More and more, however, solid-state PAs are working their ways into military radar systems as well as electronic warfare and electronic countermeasures (ECM) that require pulsed signals. While not always smaller or lighter than TWT amplifiers (TWTAs), SSPAs are cost-effective and reliable even in the most challenging operating environments.

The power transistors in pulsed SSPAs for military radar systems have traditionally been based on silicon (Si) substrate materials, such as Si bipolar transistors, Si MOSFETs, or Si LDMOS devices. At higher operating frequencies, transistors have been fabricated on different semiconductor materials, including GaAs. More recently, a pair of wide-bandgap (WBG) semiconductor substrates, gallium nitride (GaN) and silicon carbide (SiC), have served as starting points for the high-power transistors used in pulsed radar SSPAs. WBG substrate materials feature excellent thermal characteristics for reliable operation at high power levels, even in compact amplifier housings with minimal heat sinks.

For any SSPA intended for a radar application, several performance parameters can serve as guidelines for matching the component to an application, starting with frequency range. The output power will depend on pulse characteristics, such as the pulse width, and the duration that the pulse is in the "on state," which is its percentage of duty cycle. SSPAs working with shorter pulse widths and pulse duty cycles will typically provide higher output power levels than amplifiers boosting longer pulse widths at longer duty cycles. In addition, SSPA gain is a measure of the level of input signal power that will be needed to reach the SSPA's rated output power level.

An example of a pulsed SSPA based on GaN is the S-band APRA-S2500A from Advantech Wireless *(www.advantechwireless.com)*, which can be used from 2.7 to 2.9 GHz *(see figure)*. It delivers as much as 2500 W over its 200-MHz bandwidth when fed with an input power level of 0 dBm. The SSPA operates with pulse widths from 0.1 to 100.0 µs and pulse duty cycles to 10%. It suffers minimal pulse distortion, with fast pulse rise/fall times of better than 100 ns and minimum pulse droop of 1% or better at 100-µs pulse width. The amplifier is equipped with input and output sample ports for monitoring signal quality and reliability.

The high power levels possible with GaN transistors has several companies developing GaN-based pulsed SSPAs as replacements for TWT amplifiers in radar systems. API Technologies *(www.micro-apitech.com)* is one of these firms, offering GaN-based pulsed SSPAs with output levels to 1 kW through 18 GHz.

HD Communications Corp. (www.rfamplifiers.com) has developed pulsed SSPAs based on both Si LDMOS and GaN device technologies. For example, model HD32091 is a rack-mountable GaN-based SSPA with 10 kW peak output power from 1 to 2 GHz. Suitable for long pulsed L-band applications, the Class AB linear amplifier works with pulse widths from 4 to 650 µs at 15% maximum duty cycle. The rugged SSPA has built-in control, monitoring, and protection circuits.

The APRA-S2500A is a GaN-based S-band SSPA capable of 2500 W pulsed output power from 2.7 to 2.9 GHz. *(Courtesy of Advantech Wireless)*

For lower-power radar applications in smaller packages, the model TGA2307-SM packaged MMIC amplifier from Qorvo *(www.qorvo.com)* takes advantage of GaN's high power density and SiC's enhanced thermal characteristics, using a GaN-on-SiC semiconductor process. It produces 50 W output power at C-band frequencies from 5 to 6 GHz while operating with pulse width of 100 µs at 1% duty cycle. The SSPA, which comes in a 6- × 6-mm overmold QFN plastic package, can also be used in continuous-wave (CW) applications.

These SSPAs represent just a sampling of the growing number of semiconductor-based power amplifiers available for pulsed-radar applications, with additional suppliers including Empower RF Systems *(www.empowerrf.com)*, Instruments for Industry *(www.ifi.com)*, LCF Amplifiers *(www.lcfamps.com)*, and Teledyne Defence & Space *(www.teledynedefence.co.uk)* providing SSPAs at pulse output-power levels to 1 kW at frequencies to 18 GHz.

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MMIC Filter Die Stops Reflections

THE X-SERIES of reflectionless monolithic-microwave-integrated-circuit (MMIC) filters includes two- and three-section filters with as much as 50-dB stopband rejection. The compact filters, with passbands from dc to 21 GHz and stopbands as high as 26 GHz, employ a patented filter topology to eliminate stopband reflections, which can be sources for intermodulation distortion (IMD). The filters team well with sensitive reflective components, such as mixers and multipliers, as well as wideband amplifiers. Model XHF-652M-D+ is one example. The RoHS-compliant highpass filter has a passband of 6.6 to 11.0 GHz and stopband of dc to 5 GHz; typical stopband rejection is 38 dB. The 50-Ω filter die, which measures 1400 × 1400 μm, operates from –55 to +105°C.

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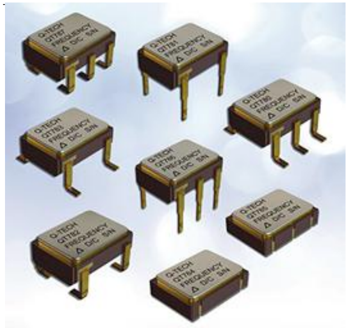

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THE QT780 SERIES of space-qualified hybrid crystal oscillators has been designed for use as the primary clocks in low-earth-orbit-satellite (LEOS) systems, small communications satellites, and broadcast satellites. These devices come in a broad range of operating frequencies, from 230 kHz to 162.5 MHz, in low-profile packages as small as measuring 5.0 × 7.0 mm and including surface-mount-technology (SMT) packages. The hybrid oscillators consist of a miniature strip quartz crystal and an IC operating at different supply voltages: 1.8, 2.5, 3.3, and 5.0 V dc. The sources include 50-krad total-ionization-dose radiation hardening and shock resistance to 20,000 g's. They are available with optional screening to MIL-PRF-55310.

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MODEL DB-3774B is a lightweight microwave power module (MPM) capable of 1 kW peak output power from 6 to 18 GHz at 5% maximum duty cycle. Well-suited for electronic-warfare (EW) and radar systems, the MPM combines a solid-state driver amplifier featuring high gain with a miniature conduction-cooled traveling-wave tube (TWT) for high output power. The high-voltage power supply operates on 270 Vdc prime power, with an option for operation on a +28-Vdc supply. Custom frequency bands are also available. The MPM weighs just 18 lbs. and measures 7 × 3 × 18 in.

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A FAMILY OF satellite-communications (satcom) beamformer integrated circuits (ICs) has been expanded with the addition of two ICs for use at Ku-band frequencies. The ICs are designed for active-antenna-based phased-array satcom ground terminals that can perform automatic alignment and automatic positioning in support of satcom-on-the-move applications with low-earth-orbit (LEO), geostationary-earth-orbit (GEO), and medium-earth-orbit (MEO) satellites. These second-generation ICs—the model AWMF-0146 receiver IC and the model AWMF-0147 transmitter IC—each support four dual-polarization radiating elements with full polarization flexibility. The ICs are housed in wafer-level chip-scale packages (WLCSPs) for excellent thermal management in small sizes. The ICs are targeted at phased-array ground and avionics satcom systems.

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THE IPP-7148 is a 90-deg. surface-mount-device (SMD) coupler with wide frequency range of 690 to 6000 MHz. Although supplied in a package measuring a mere 0.50 × 1.00 × 0.167 in., the coupler handles power levels to 130 W CW. It boasts low insertion loss of 0.8 dB or less with low VSWR of 1.35:1 or less. The coupler achieves better than 16.5-dB isolation between ports. It exhibits amplitude balance of ±0.9 dB and phase balance between channels of ±6 deg. The tiny component is rated for operating temperatures from –55 to +85°C.

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3U VPX Board Packs More Processing Power

THE NEWEST MEMBER of the Jade family of high-performance 3U VPX modular boards is model 54851 with enhanced analog and digital circuitry for flexible system and test signal-processing applications. It contains two 12-b, 500-MHz analog-to-digital converters (ADCs), two programmable multiband digital downconverters, and one digital upconverter. The versatile VPX module also features two 800-MHz 16-b digital-to-analog converters (DACs). The board is based on the Xilinx Kintex UltraScale field-programmable gate array (FPGA) and was introduced with three wideband input/output (I/O) options: Option 110 with optical connections based on VITA 66.5, Option 11 with RF connections based on ANSI/VITA 67.2, and Option 112 with RF connections based on ANSI/VITA 67.3. Future versions will be available with higher-density optical and RF/microwave connectors.

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Flexible Cables Connect 65 GHz

THE LAB-FLEX coaxial cable assemblies provide durability even with extensive flexure. The Lab Flex 115S cables, with a diameter of 0.105 in., have a maximum frequency of 65 GHz and 50-Ω impedance. The mmWave cables exhibit typical loss of 57.6 dB per 100 ft. cable at 5 GHz. The velocity of propagation is 76% and the shielding effectiveness is better than 90 dB at 18 GHz. The capacitance is 27 pF/ft while the delay is 1.34 ns/ft. The average power-handling capabilities are 390 W at 1 GHz, 90 W at 18 GHz, 60 W at 40 GHz, and 50 W at 50 GHz. The durable cables are designed for minimum bend radius of 0.5 in. and operating temperatures from –55 to +200°C.

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WHY IP2 MATTERS for Wideband Amplifiers

Amplifier distortion exists in several forms. One form occurs when an amplifier is driven by a signal with a sufficiently large amplitude, thus causing the amplifier to approach its 1-dB compression (P1dB) point. Another type of distortion involves the scenario in which two signals—with frequencies that are different but still close to one another in value—are driving an amplifier, resulting in second- and third-order distortion. Second-order distortion and why it must be considered in the case of wideband amplifiers is the focus of Custom MMIC's application note, "IP2 Measurements of Wideband Amplifiers."

The application note begins by presenting a spectrum plot of two sinusoidal signals. While the two signals have distinct frequencies, the values of these frequencies are close to one another. Next, spectrum plots of an amplifier's output when driven by these same two input tones are shown. The spectrum plots include the fundamental output tones, as well as second- and third-order distortion tones.

For a narrowband amplifier, the second-order tones are outside its bandwidth. Hence, second-order distortion can likely be ignored in the case of narrowband amplifiers. However, the second-order tones are within the bandwidth of a wideband amplifier, meaning that second-order distortion must be considered in such cases.

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The app note continues with an explanation of how the second-order intercept (IP2) point is derived. Plots are shown of the output power level of the fundamental and second-order difference tones of Custom MMIC's CMD192 amplifier when driven by two signals. The IP2 value is obtained by drawing straight lines through the fundamental and second-order responses, with the IP2 point being where the two lines intersect.

Several factors must be considered when attempting to perform IP2 measurements. For one, the levels of the fundamental and second-order tones must be within the linear region of the amplifier. The sum of the two input signals' frequencies must also be within the amplifier's bandwidth. Lastly, one must ensure that the spectrum analyzer being used for the measurement is not distorting the results.

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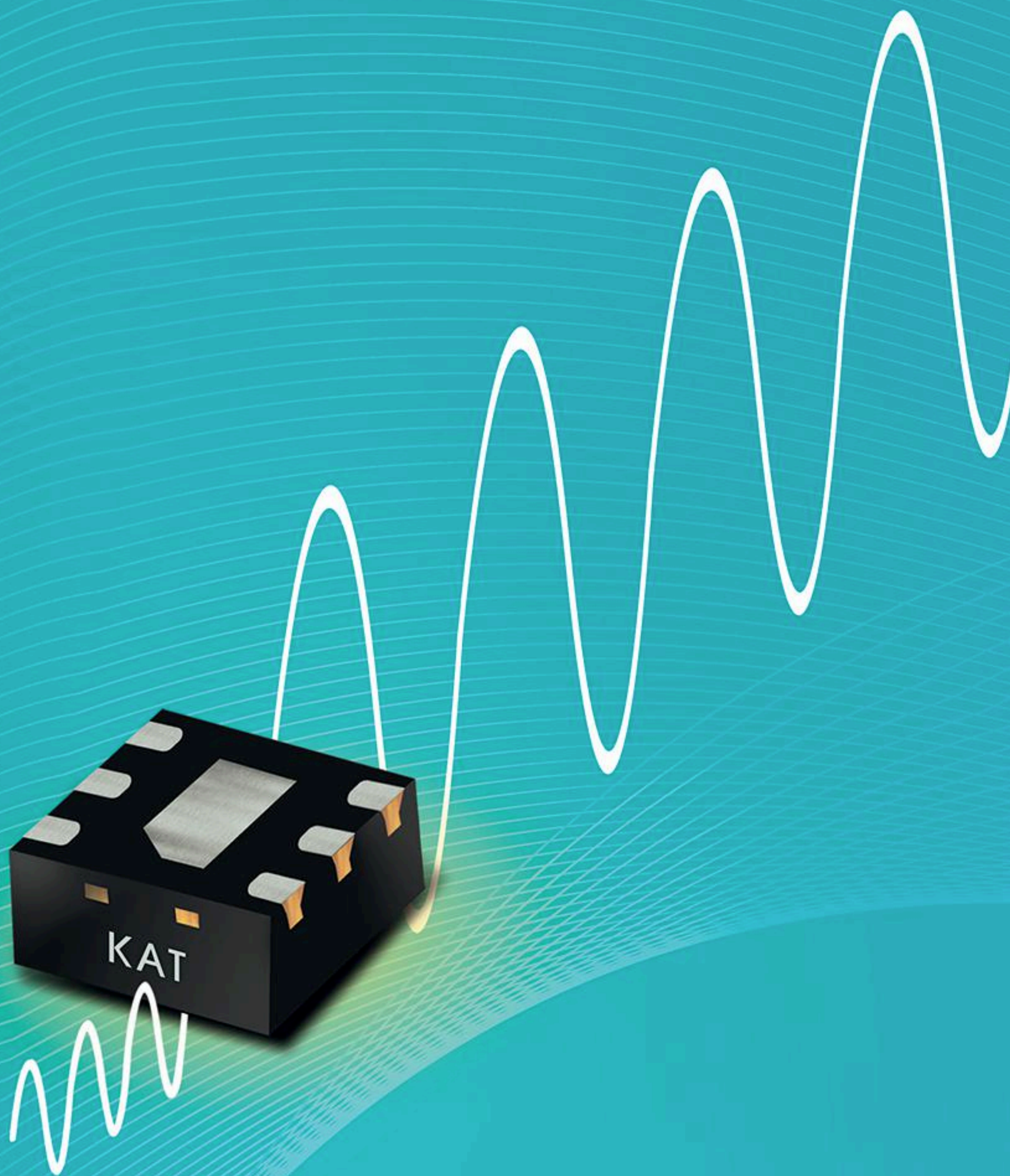
NO QUESTION, A signal generator is a significant part of any RF/microwave test bench. When purchasing signal generators on a limited budget, teams may face the dilemma of deciding what to buy. This decision can be even more difficult for companies developing radar and wireless network systems, as these applications may require a larger number of signal generators along with the need for modular capability. In the technical brief, "10 Signal Generator Features You're Probably Paying Too Much For," Vaunix discusses many aspects of a signal generator so that an informed decision can be made when purchasing one.

The tech brief starts out by explaining that frequency range is the key factor when contemplating a signal generator. However, frequency range can also be one reason why companies overpay for test equipment. Specifically, test teams often purchase one ultra-wideband instrument that operates at frequencies beyond what's actually needed, so they wind up essentially paying for unnecessary performance. According to the document, a modular, self-programmable solution offers an alternative approach.

The brief then delves into phase noise. The phase-noise performance of a signal generator depends on the oscillator technology and frequency-synthesis circuitry. Furthermore, the tech brief points out that the phase noise of a signal generator is a limiting factor for only some applications, and subsequently states that paying for phase-noise performance only slightly better than what's needed may dramatically increase the cost of the equipment.

Frequency resolution is mentioned, too, as some applications may require signals to be generated at very precise frequencies. In such cases, an extremely fine frequency resolution is critical. However, according to the document, frequency resolution of a few hundred hertz—or even higher—is adequate for most applications. Cost-effective options are available for use cases in which frequency resolution below 100 Hz isn't essential.

Other factors mentioned include frequency-switching speed, output-power range, and harmonics, among others. Lastly, the tech brief includes a table that compares many of the signal generators currently on the market.



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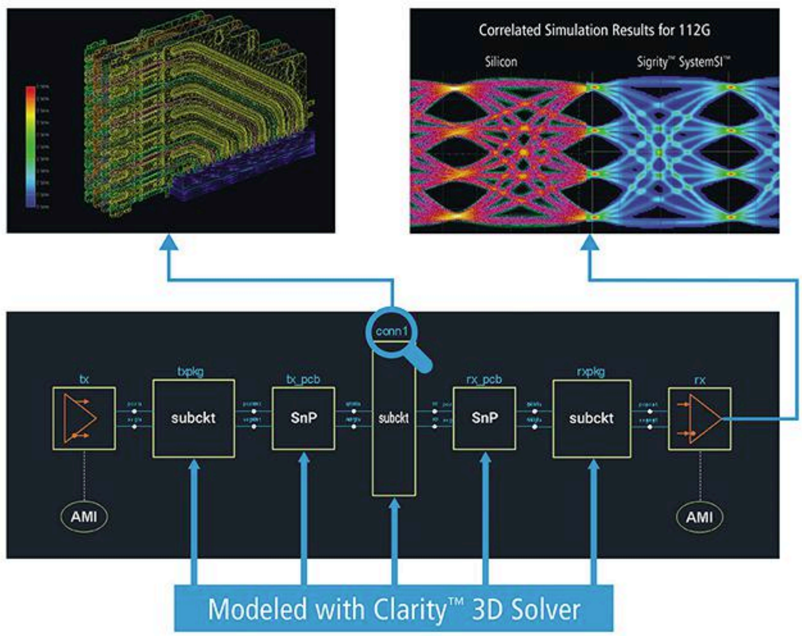
This EM simulator performs system-level analysis on 3D structures within many different types of complex designs, such as IC-to-package and package-to-board interconnections.

System designers now have a powerful new software tool for analysis and simulation at the circuit board and integrated-circuit (IC) package level—the Clarity 3D Solver from Cadence *(www.cadence.com)*. From a software developer long associated with efficient and effective semiconductor design tools, this three-dimensional (3D) electromagnetic (EM) simulation software takes design and analysis at least one level higher—to the system level. Thus, one can study the effects of different circuit structures, such as package interconnections, on the overall performance of the circuit/system.

The 3D analysis software is well-suited for simulating the impact of different materials on ICs, system on IC (SoIC) devices, and system-in-package (SiP) designs, and even to predict the effects of different interconnections within each PCB and from PCB to PCB. Perhaps best of all, the Clarity 3D Solver does not require a specialized computer for its system-level simulations: It performs simulations even on a laptop computer! For users with more powerful computing resources, Clarity 3D Solver has nearly linear scalability in terms of processing power when using multiple machines to analyze complex structures.



The Clarity 3D Solver allows system designers to study as much of a design as desired, making efficient use of available computer processing power. ***(Courtesy of Cadence)***

System-level simulators have often been associated with oversized models of circuit assemblies dominated by a single complex component, such as a frequency synthesizer, and requiring extensive computing power to analyze system-level behavior like receiver sensitivity. Even when considering the EM behavior of high-frequency transmission lines, such as microstrip or stripline, in planar form in two dimensions (2D), software simulators have traditionally required breaking a design into pieces or subsystems that can be analyzed and simulated separately to effectively use available computer processing power.

The Clarity 3D Solver not only performs EM analysis of high-frequency circuit structures in 3D, such as through transmission lines as well as through plated viaholes in a PCB, but can handle the additional simulation data from all three dimensions without special computer needs. The firm's advanced distributed multiprocessing technology fully leverages the computing power at hand, including in "the cloud."

System designers are faced with growing demands for increasing functional density, which involves design approaches like multilayer circuit substrate materials, multifunction monolithic microwave integrated circuits (MMICs), and system-in-package (SiP) and system-on-IC (SoIC) devices mounted on high-thermal-conductivity PCBs. Software tools such as SiP Layout from Cadence have been used for complex 3D SiP designs, to analyze the interconnections between semiconductor die and package connections.

Fortunately, the Clarity 3D Solver readily integrates this package-level simulation tool with the many 3D mechanical and electrical structures of a full system design, allowing a smooth flow between design and optimization. Therefore, a design developed as a 3D SiP, for example, can be optimized in the system-level Clarity 3D Solver without being redrawn.

In addition to its integration with SiP Layout, the Clarity 3D Solver can be integrated with the Virtuoso and Allegro software tools from Cadence. Virtuoso is a popular custom IC design platform that includes design and analysis functions across ICs, packages, modules, and PCBs for ready integration at the system level. Allegro is a PCB design and analysis solution that similarly enables a circuit to be integrated and modeled as part of a larger system in the Clarity 3D Solver.

SOLVING SYSTEMS

The Clarity 3D Solver allows system designers to treat a design as a block diagram that interconnects several components and/or subsystems in a serial (see figure) or parallel orientation. By selecting the components within the block diagram for analysis, a designer can choose as much or as little of the system for design and optimization. The approach conserves computer resources and performs simulations with the most practical application of computer power possible.

In addition, the software automatically matches the complexity of a simulation to the available computer resources. Distributed multiprocessing technology is used to share the computing power of multiple central processing units (CPUs) when available, such as within a network, to perform complex analysis tasks in the shortest times possible.

The Clarity 3D Solver software can be accessed on premises or from "the cloud" and will run on almost any reasonably equipped modern PC, including a laptop. While it can also provide outstanding performance from a high-performance-computing (HPC) workstation, this is a software tool that's very memory-efficient, enabling it to capably run on a bank of low-cost computers, distributing simulation tasks among the multiple CPUs.

With its processing flexibility, the software is able to perform complex tasks, such as a study of the various coaxial-connector interfaces on a PCB, without the need to separate the system into smaller subsections. The software, which can do true 3D model extraction of circuit structures, is designed to read design data from multiple sources, e.g., electronic-computer-aided-design (ECAD) and mechanical-computer-aided-design (MCAD) software, and even merge mechanical structures like cables and connectors within a design. As a result, it's possible to integrate many different designs within a Clarity 3D Solver simulation. The software can create accurate S-parameter models of circuit structures for analysis purposes, such as for signal-integrity (SI), power-integrity (PI), and electromagnetic-compatibility (EMC) analysis, with accuracy that matches closely with measured results.

Even with the complexity and large amount of data represented by 3D circuit structures, for example, coaxial connector interfaces or semiconductor die within high-pin-count packages, the Clarity 3D Solver software can perform an analysis in a relatively short time, using a process known as parallelization to achieve enhanced processing power when using multiple CPUs. Parallelization allows the use of as many computers and CPUs as possible, reducing the simulation processing time. Solution times are directly related to the number of computers and computer cores available: If the number of cores can be doubled, then the performance of the Clarity 3D Solver may be doubled, with the processing time nearly cut in half.

One of the satisfied users of the Clarity 3D Solver software is Teradyne and its semiconductor group. As Rick Burns, the vice president of engineering for the Semiconductor Test Division at Teradyne explains, "At gigabit speeds on our highly dense PCBs with over 30 layers, we depend on accurate interconnect extraction of our complex structures to support signal integrity analysis."

Burns notes the difference that the Clarity 3D Solver has made: "With the Cadence Clarity 3D Solver, we can achieve the necessary accuracy in a fraction of the time it has previously taken. This has opened up a new era of analysis possibilities for us since we can now run dozens of simulations in the time it has previously taken to run one. This reduces design respins and helps us fulfill our promise of delivering the highest throughput and lowest cost of test for our customers."

As is clear from the Teradyne example, the Clarity 3D Solver has made a significant impact in a major test application, helping accelerate the development of many other test designs. It should also aid designers in two rapidly growing high-frequency application areas, for the millimeter-wave radar systems in advanced driver assistance systems (ADAS) for autonomous vehicles and in 5G wireless communications systems. Both applications seek the high functional density that can be optimized with a 3D electromagnetic modeling tool like the Clarity 3D Solver. mw

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JACK BROWNE | Technical Contributor

Package Pricing Bundles Entry-Level Instruments

This novel pricing plan allows customers to purchase full-featured benchtop test instruments for significant discounts according to the number of packages.

Working at the test bench with as much measurement power as possible is no longer a luxury—it's a necessity for any engineering firm hoping to make progress in the rapidly changing modern RF/microwave landscape. But Rohde & Schwarz *(www.rohde-schwarz.com)* hopes to make it easier to procure the necessary measurement capabilities with a novel "package deal" by which customers can purchase several entry-level instruments, fully equipped for present and future requirements, at a discounted package price.

Called the "This Changes Everything" promotion, the discount applies to many different types of instruments, including oscilloscopes, spectrum analyzers, power supplies, and power analyzers. It allows customers to add an instrument with all of the options and features required for a test bench that delivers today's and tomorrow's measurement requirements, while saving on the test budget at the same time.

A customer can add available measurement power as part of an instrument package, with all the options and features, but supplied at a discount price. All too often, test instruments are added according to current requirements. But as test needs change, the performance limits of test gear can be quickly exceeded, calling for costly upgrades and modifications. The "This Changes Everything" promotion gives customers a chance to specify a full equipped, full-option instrument and pay much less than those options once cost, resulting in a new instrument on the test bench with more performance than might have originally been thought possible on an available budget.

Bob Bluhm, vice president of Value Instruments at Rohde & Schwarz, explains, "We want to equip our customers to prepare for the future now, before their design requirements change—because we know they will. Our all-inclusive promotion offers our customers thousands of dollars in savings on complete solutions." The package promotion is planned from May 20, 2019 through December 31, 2019.

The package pricing promotion includes five oscilloscopes, two spectrum analyzers, three power supplies, and one power analyzer. Many of these are multifunction instruments, integrating a number of measurement capabilities within one benchtop enclosure. For example, all of the oscilloscopes are housed with a logic analyzer, protocol analyzer, waveform and pattern generator, and voltmeter in the same instrument case.

1. The R&S RTB2000 entry-level oscilloscope captures signals over a bandwidth of 70 to 300 MHz.

Among the oscilloscopes, the R&S RTB2000 *(Fig. 1)* covers bandwidths of 70 to 300 MHz at sample rates to 2.5 Gsamples/s. It contains as much as 20 Msamples of memory and features 10-b analog-to-digital-converter (ADC) resolution. Signal information is shown on a 10.1-in. capacitive touchscreen with 1280- × 800-pixel resolution. For this instrument as well as the R&S RTM3000 and R&S RTA4000 oscilloscopes, several performance-boosting options are available as part of the package plan: performance bandwidths to 1 GHz, as many as four analog and 16 digital channels, sample rates to 5 Gsamples/s, and up to 1-Gsample segmented memory.

The R&S FPC1500 *(Fig. 2)* is one of the two entry-level spectrum analyzers in the promotion, with a frequency range of 5 kHz to 2 GHz, resolution bandwidth settings as fine as 1 Hz, and built-in tracking generator and independent CW signal generator. As an option, it can be equipped with a one-port vector network analyzer (VNA) with Smith chart display. The R&S FPC1500 shows signals on a 10.1-in.-wide XGA (WXGA) display screen with 1366- × 768-pixel resolution. The other spectrum analyzer in the promotion, the R&S FPC1000, has a frequency range of 5 kHz to 1 GHz. Options for the analyzers include moving the frequency range to 3 GHz, having lower phase noise, and a lower displayed average noise level (DANL) of typically –165 dBm.

Among other instruments in the package pricing promotion are three power supplies, including the R&S HMP4040 power supply and the R&S HMC8015 power analyzer. The power supplies can be equipped with two, three, or four channels, with maximum voltages from 128 to 300 V and maximum current of 40 A, with as much as 10 A current per channel. The R&S HMC8015 power analyzer provides ac-dc load characterization with a power measurement range of 50 µW to 12 kW and basic accuracy of 0.05%. It can test over analog bandwidths from dc to 100 kHz at a sampling rate of 500 ksamples/s.

These are entry-level instruments that pack a great deal of measurement power, with or without the options. By purchasing the "loaded" versions of any of these instruments, including all options and extra capabilities, as much as 10% or more of the purchase price can be saved along with the time and headaches of having to upgrade the instruments as needed. This helps manage the test-and-measurement budget today while providing for the measurement needs of tomorrow. mw

2. The R&S FPC1500 is a versatile spectrum analyzer with frequency range of 5 kHz to 2 GHz and option to extend to 3 GHz.

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Software

JIYOUN MUNN | RF Technical Product Manager, COMSOL
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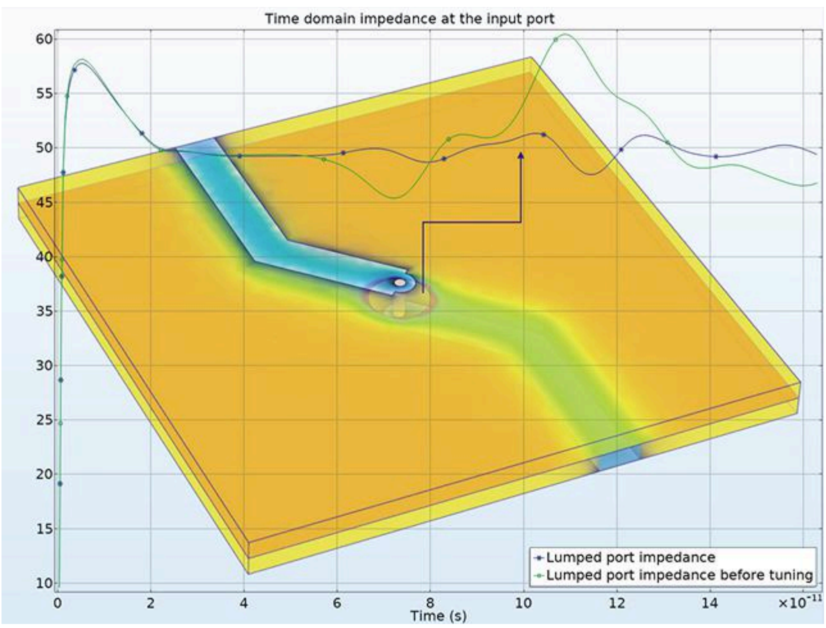
Simulation Domain Transformation Between Time and Frequency

Thanks to its fast Fourier transform process, a software tool can convert data between the frequency domain and time domain.

The momentum for realizing the 5G network has reached a fever pitch, with many of the major wireless providers touting the proposed launch of the network. However, one question remains: "What still needs to be done to make this a reality?" System and device design engineers working on the frontlines of 5G, the Internet of Things (IoT), and millimeter-wave (mmWave) communications can benefit from electromagnetic (EM) simulations with a cost-effective procedure. Simulation offers a virtual test environment that ultimately reduces the duration of the design cycle.



1. TDR analysis shows the impact on the signal quality due to the various via and anti-via sizes.

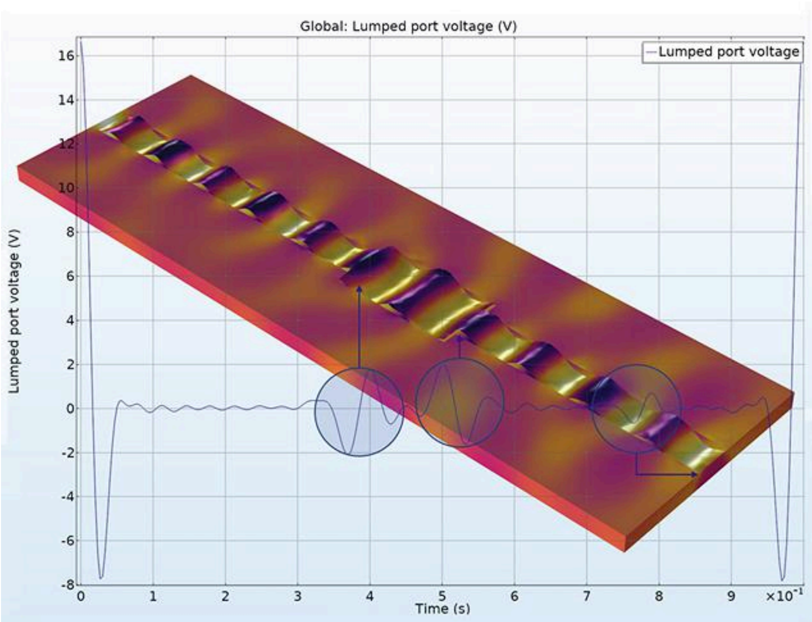
Conventional EM numerical analyses, such as finite-element method (FEM) and method of moments (MoM), are typically performed in the frequency domain for S-parameter calculations. S-parameters provide information like impedance mismatch, insertion loss, and phase variation as a function of frequency. This type of analysis is compatible with typical network-analyzer measurements conducted in the laboratory.

The simulation analysis can also be examined in the time domain for the purposes of time-domain reflectometry (TDR). With TDR data as a function of time, it's possible to identify the abnormal area on a circuit where the performance of a device has diminished due to a signal discontinuity and impedance mismatch.

Contrary to the methods mentioned above, the finite-difference-time-domain (FDTD) method is studied in the time domain. However, S-parameters and the antenna radiation pattern are presented in the frequency domain through the Fourier transform. The Fourier transform makes it possible to convert the simulated results from one domain, such as frequency, to another domain, such as time. This provides designers with more information so that they can make informed decisions concerning device designs.

EM PHYSICS INTERFACES AND FOURIER TRANSFORM

When using FEM to analyze high-frequency EM problems, we often pri-



2. The voltage fluctuation at the excitation lumped port gives the round-trip time of a signal to the discontinuities. It's possible to detect potentially defective parts of a transmission line using a TDR plot.

oritize investigating the S-parameters in the frequency domain. Using a fast Fourier transform (FFT) process, we are able to convert the data between the frequency domain and time domain.

The RF Module, a high-frequency EM simulation add-on tool that's available in COMSOL Multiphysics software, provides a series of useful physics interfaces to conduct such analysis. They include:

- Electromagnetic Waves, Frequency Domain (frequency-domain finite element method, FDFEM)
- Electromagnetic Waves, Transient (time-domain finite element method, TDFEM)
- Electromagnetic Waves, Time Explicit, (time-domain discontinuous Galerkin method, DG)
- Transmission Line (frequency-domain transmission-line equation)

Those physics interfaces play the expected role of computing traditionally domain-specific results. They can also be extended to extract more information beyond the original computational domain. After finishing the simulation with Electromagnetic Waves, Frequency Domain, the results include traditional S-parameters, near electric- and magnetic-field distribution, and far-field norm radiation patterns. If the bandwidth of the frequency sweep in a simulation is wide enough, performing frequency-to-time Fourier transform on the dependent variable of the governing equation will lead to the frequency-dependent solutions being converted to time-dependent information (*Fig. 1*).

The Electromagnetic Waves, Transient TDFEM physics interface is more suited for problems with nonlinear material properties, or for signal-path discontinuity analysis like time-domain reflectometry. When the time step used in the simulation is fine enough, the time-dependent solutions can be converted to frequency-dependent S-parameters in a very wide bandwidth by time-to-frequency Fourier transform.

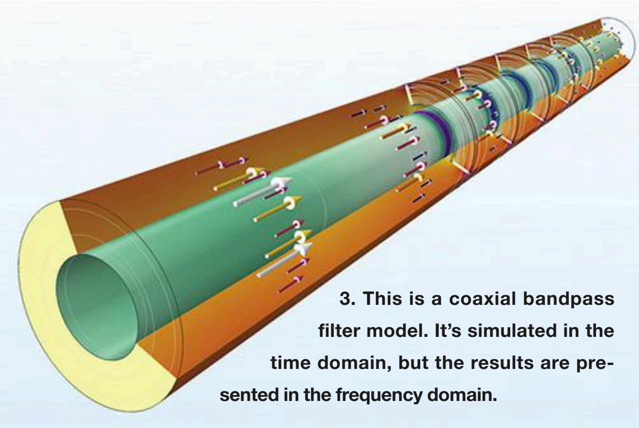
TDR ANALYSIS FROM FREQUENCY DOMAIN WITH FREQUENCY-TO-TIME FFT

While the main focus of the frequency-domain simulation involves computing S-parameters to study the performance of devices, it can be inspected in the time domain as well. After this conventional frequency-domain simulation is conducted, using the frequency-to-time FFT provides the impulse response for the input signal. Since it's not a static case, the frequency-domain simulation may not include the result at dc. The FFT outcome is a time-domain bandpass impulse response of the device.

The characteristics of the frequency data that are used to input the frequency-to-time FFT define the quality of the time-domain outcome. If the starting frequency is not low enough, the FFT results may develop a visible low-frequency envelope noise. Alternatively, if the bandwidth is not wide enough, the resolution of the time-domain signal output will not appear sharp and clear in the simulation results.

The frequency step defines the alias period and location in the time domain. After performing the FFT, the signal fluctuations in the time domain show where the discontinuities lie on the signal path (*Fig. 2*).

The frequency-domain study in this model is performed from 1 MHz to 30 GHz. The initial results are converted to the time domain. The simulation results demonstrate the lumped-port voltage. Several overshoots and undershoots are also observed. The location of the physical discontinuities that cause undesirable impedance mismatches can be spotted by identifying material properties for the phase-velocity calculation and determining the round-trip travel time of the input signal from the port to a location where one can pinpoint the signal fluctuation.



3. This is a coaxial bandpass filter model. It's simulated in the time domain, but the results are presented in the frequency domain.

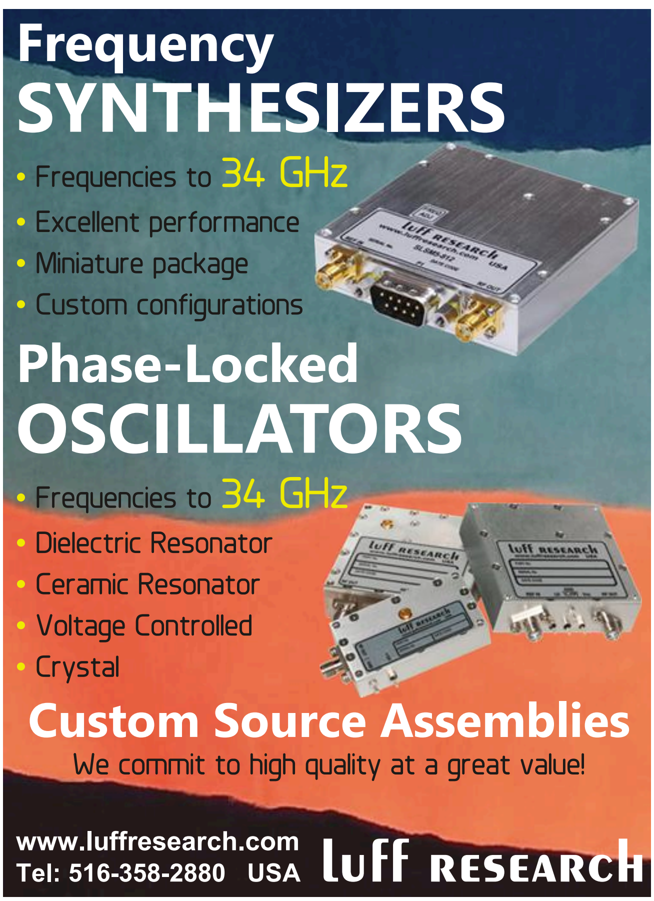
The signal responses of circuits and antennas in a very wide band along with a fine frequency step can be achieved by running a one-shot time-domain simulation and converting the results to the frequency domain via time-to-frequency FFT.

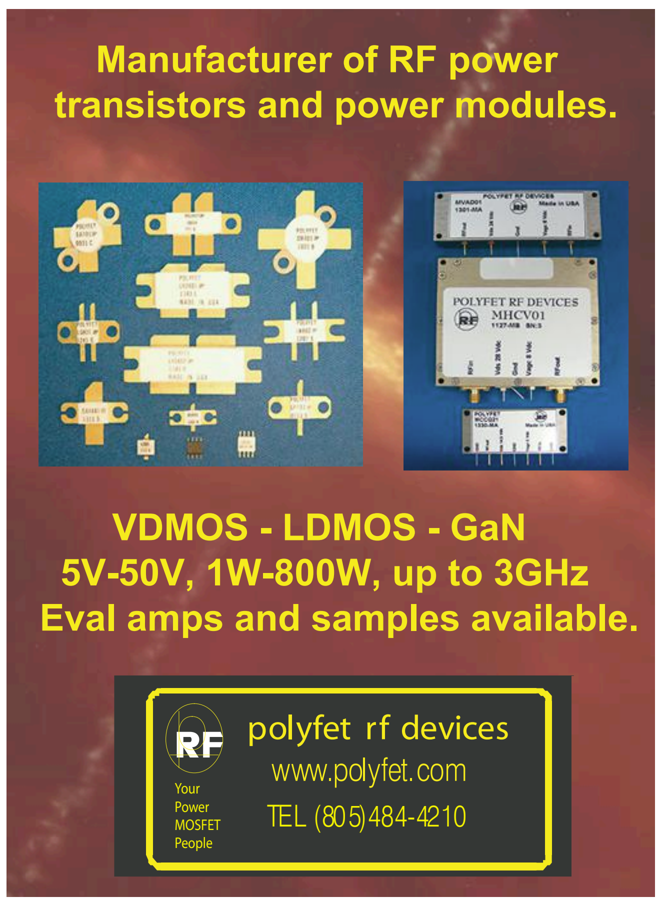
WIDEBAND S-PARAMETERS AND FAR-FIELD RADIATION PATTERN FROM TIME DOMAIN WITH TIME-TO-FREQUENCY FFT

The signal responses of circuits and antennas in a very wide band along with a fine frequency step can be achieved by running a one-shot time-domain simulation and converting the results to the frequency domain via time-to-frequency FFT. This type of conversion requires a modulated Gaussian input energy to excite the device being simulated and a sampling rate defined by the time-step to fulfill the Nyquist criterion (*Fig. 3*).

The modulated Gaussian pulse in the time domain can be viewed as a Gaussian pulse shifted to the modulation center frequency in the frequency domain. The simulation results demonstrate that the computed S-parameters are distributed around the modulation center frequency, f_0, with the bandwidth $2f_0$. The resolution of the results in the frequency domain is determined by the maximum time of the input time-domain signal.

With the modulated Gaussian pulse, the energy level in the circuit decays as





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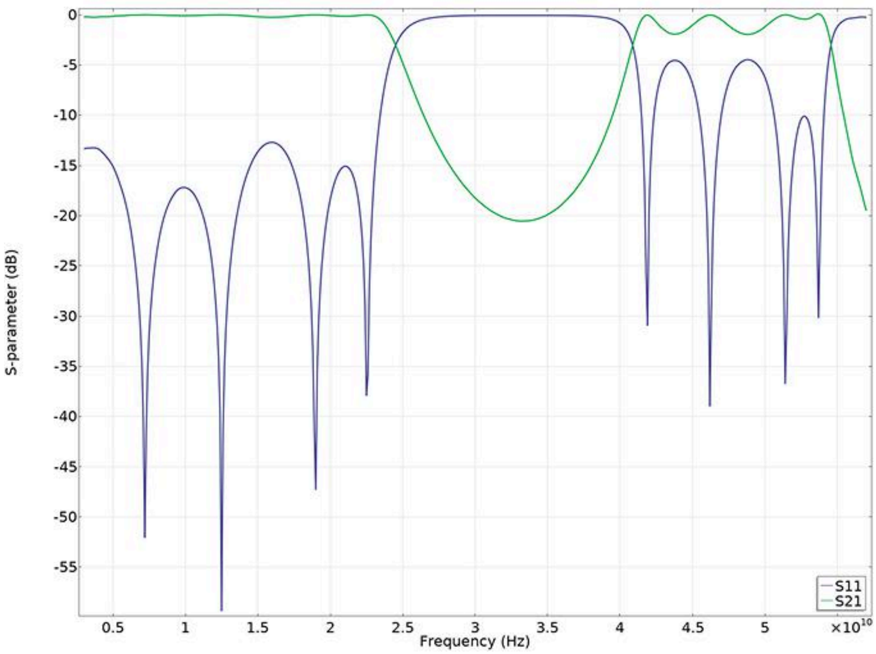

4. Shown are wideband S-parameters of a coaxial bandpass filter after FFT. The modulation center frequency is 30 GHz.

time passes until it eventually reaches close to zero level. To provide a long-time input signal, the simulation need not be performed for the length of time. As soon as the energy level in a specific probing domain is attenuated enough, the simulation can be stopped, and the remaining time can be filled with zeros. Using this zero-padding technique, it's not necessary to sacrifice a long time of operation to obtain a fine frequency resolution (*Fig. 4*).

The energy level of the area, such as the beginning and end of the Gaussian pulse, is relatively low. In turn, the quality of the signal is vulnerable to the numerical noise. The outcome of the FFT can be filtered to truncate these ranges next to 0 and $2f_0$ Hz to enhance the data quality.

Wideband antenna far-field radiation patterns are also useful results of the time-to-frequency FFT process. The related antenna postprocessing variables

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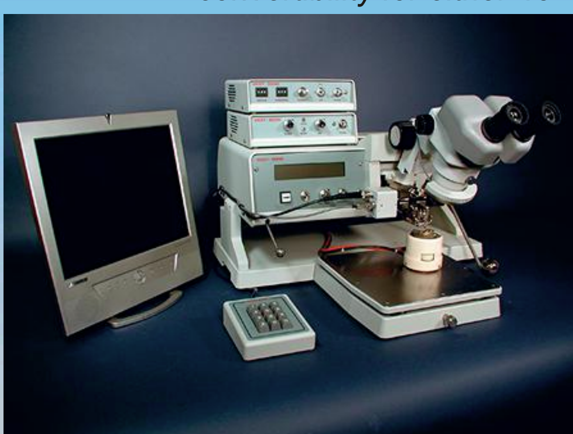

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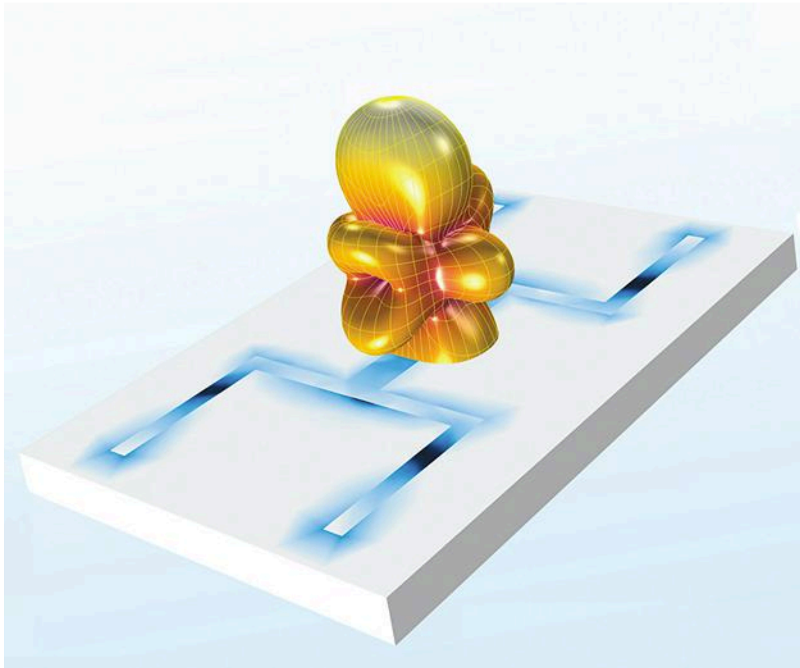
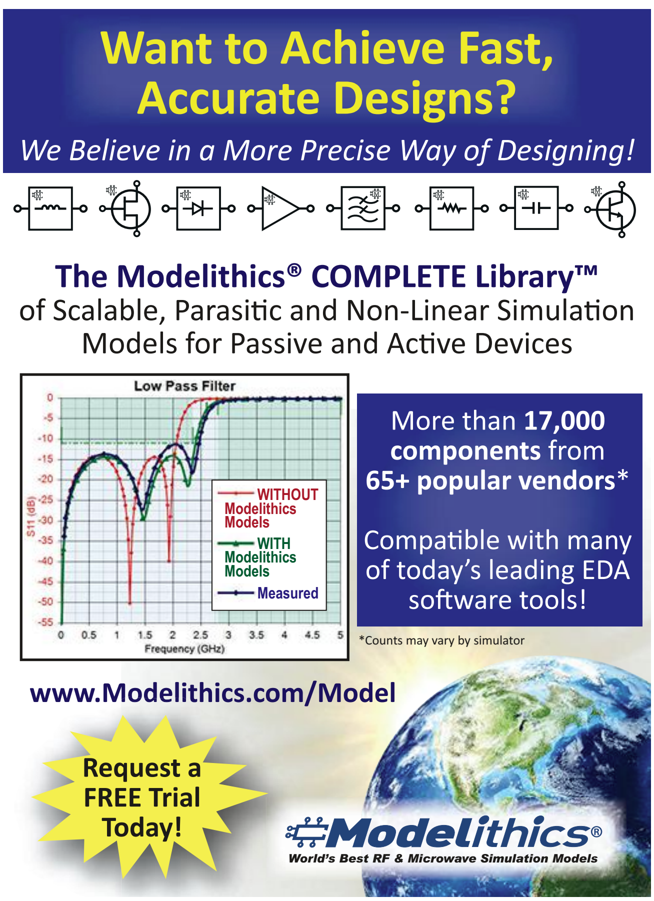
like antenna gain and realized gain are properly scaled based on the input power levels proportional to the Gaussian pulse (*Fig. 5*).

SIMULATION TECHNIQUES ENHANCING THE MODELING CAPABILITY

In reality, it may appear that computational resources are quite limited in addressing 5G and mmWave communications due to the increasing size of the analysis. It's inevitable to experience the limitation of the resources and the time needed to find a simple and efficient way to set up the physics with relevant computational representation. The Fourier transform technique described with examples here won't be the ultimate solution for all modeling issues, but it will offer an alternative method to detour the obstacles associated with enhanced postprocessing studies. mw



5. The 3D antenna gain pattern in a dB scale is plotted for a printed dual-band strip antenna, with the norm of electric field on the antenna board at 2.25 GHz.



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IMS2019 and RFIC 2019 Keynote Speakers

RFIC Plenary Session Speaker
Sunday, 2 June 2019

Dr. Greg Henderson – *Senior Vice President Automotive, Communications and Aerospace & Defense, Analog Devices, Inc.*

"The Digital Future of RFICs"

RFIC Plenary Session Speaker
Sunday, 2 June 2019

Dr. Ir. Michael Peeters – *Program Director, Connectivity + Humanized Technology, imec*

"Do the Networks of the Future Care about the Materials of the Past?"

IMS Plenary Session Speaker
Monday, 3 June 2019

Dr. William Chappell – *Director of the Microsystems Technology Office (MTO), Defense Advanced Research Projects Agency (DARPA)*

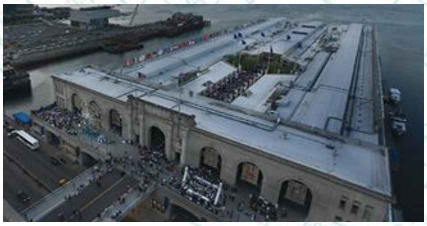
"The Mind and Body of Intelligent RF"

MTT-S Awards Banquet Speaker
Wednesday, 5 June 2019

Dr. Ryan C.C. Chin – *CEO and Co-founder, Optimus Ride Inc.*

IMS Closing Session Speaker
Thursday, 6 June 2019

Dr. Dina Katabi – *Andrew & Erna Viterbi Professor of Electrical Engineering and Computer Science at MIT, Leader of NETMIT research group at CSAIL, Director of the MIT Center for Wireless Networks and Mobile Computing*



The IMS Welcome Reception will be held on Monday, 3 June 2019 at the Seaport World Trade Center Headhouse in Boston. The reception immediately follows the conclusion of the IMS Plenary Session.

For the latest on IMS and Microwave Week visit www.ims-ieee.org

CHRIS DeMARTINO | Technical Engineering Editor

A Recap of WAMICON 2019

From the tutorials to the panel session plus other festivities, WAMICON 2019 had something to offer everyone who attended.

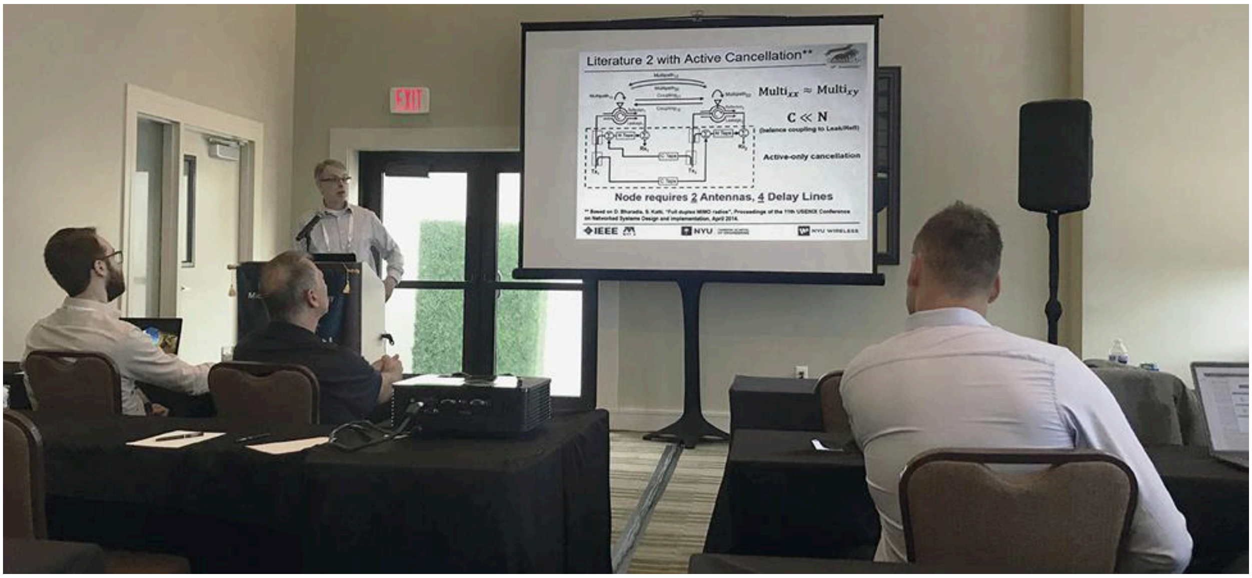
Cocoa Beach, Florida played host to this year's IEEE Wireless and Microwave Technology Conference (WAMICON), which convened April 8-9 at the Hilton Cocoa Beach Oceanfront hotel. This year's event, which marked WAMICON's 20th anniversary, featured several tutorials, a panel session, an exhibition, and much more.

Simulation software was a main emphasis of WAMICON 2019, evidenced by the panel session titled, "Emerging Simulation Technologies: Can today's EDA tools solve tomorrow's designer challenges?" Five participants made up the panel: Todd Cutler from Keysight Technologies (*www.keysight.com*), John Park from Cadence (*www.cadence.com*), John Dunn from AWR Group, National Instruments (NI; www.awrcorp.com), Theunis Beukman from Dassault Systèmes (provider of CST Studio Suite; *www.3ds.com*), and Matt Commens from ANSYS (*www.ansys.com*) (*Fig. 1*).

Toward the end of the session, all of the panelists were given an opportunity to discuss a little bit of what they think lies ahead for simulation-based design. Theunis Beukman spoke first, explaining that multi-domain simulations already represent a challenge that will only increase in scope. Beukman also noted that "complex phased-array systems are a big challenge" before explaining the need for full co-simulations rather than just segregated solutions.

Matt Commens emphasized the importance of automation. "We get into the simulation business because it's really interesting, it's very technical, and there are a lot of physics," he said. "We want to show everybody all the bells and whistles and all the different knobs they can turn. At some point, that's just not good enough. We need to do a better job of making more of this automated. I often have a discussion with our developers and I say let's just ask the user for information that they know—not information that we know."

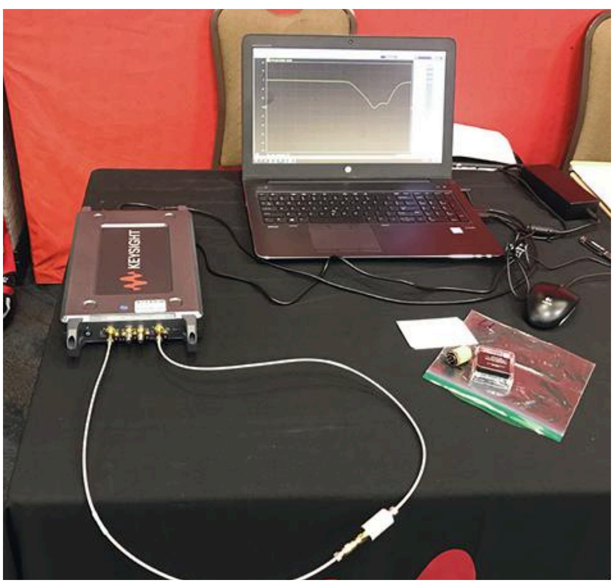
1. The panel session consisted of five representatives from different simulation software providers.



2. Michael Knox's paper titled, "Simplified Tapped Delay Line Architecture for Active Cancellation in a 2x2 IBFD MIMO Transceiver," was recognized as the best paper of WAMICON 2019.

According to John Park, a big challenge will be to come up with a system-level solution. "Today, everybody can find tools for their own niche," he explained. "In the future, with 5G and other technology, everything is coming together. You can't just think about my filter, my chip, my package, etc. You have to think about the entire system. That changes the EDA tool dramatically from an integration level as well as a capacity level."

John Dunn believes that the cloud is a game changer in the realm of simulation software—and that companies need to figure it all out. Dunn also spoke along the lines of what Matt Commens said regarding automation: "I think that as we do these problems, there has to be more automation of these setups for the average user while letting the expert be able to override them to get better performance. It's a real challenge for us to do that."



3. Keysight's P9375A Streamline USB vector network analyzer, on display at the exhibition, operates to 26.5 GHz.

Lastly, one of the points mentioned by Todd Cutler is the importance of just simply letting engineers design. "Right now, engineers spend too much time messing around with their tools," he said. "If the tool is working better, they spend more time designing and innovating rather than messing around."

Cutler also served as the plenary speaker for WAMICON 2019—his presentation was titled "The Future of High-Frequency Design and Test." He spoke about some of the inefficiencies with respect to workflows, with one point being that a "huge amount of time" is often spent correlating simulated results with test results. Cutler explained that one of the reasons why this occurs is because engineers use many different tools.

A consequence of using many different tools, according to Cutler, is that "it's hard to get all of them to work together." Specifically, a large percentage of design engineers use more than five design tools and a large percentage of test engineers use more than three test tools.

Furthermore, Cutler spoke about the interoperability challenges associated with data, explaining that "data is generally stored in different places in different formats—and it's just not easy to share." He then mentioned the cloud as a means for managing and storing data in a more efficient way.

4. Here, Charlotte Blair poses at ANSYS's booth. The company showcased technology such as 3D components.

5. Charlotte Blair also spoke at the Joint Young Professionals and Women in Microwaves reception.

Cutler also remarked that "most organizations have individual groups. There's a design group, a test group if you're going to qualify a design before it comes out, a manufacturing test group, etc." He noted that different groups often operate separately from one another. However, a more unified approach must be considered, according to Cutler.

Specifically, Cutler said, "We believe that there's a great opportunity to apply some of the technologies available to help unite this workflow and simplify the overall work. A big part of this is data sharing." Cutler then brought up results from a survey, which revealed that sharing data across teams is the number one way to reduce time to market.

So, what approach should companies take in the future? Again, the answer lies in "a unified and coherent workflow," according to Cutler. He then explained some of the principals behind achieving this "connected design and test" vision.

TUTORIALS, EXHIBITION, AND MORE

As stated, WAMICON 2019 placed a heavy focus on simulation software. Tutorials were given by several representatives from simulation software providers, such as Matt Commens and John Dunn. In addition, Brian Rautio from Sonnet (*www.sonnetsoftware.com*) gave a tutorial, as well as Shu Li from Dassault Systèmes and Wilfredo Rivas-Torres from Keysight.

Among the many paper presentations was John Park's "Challenges of designing heterogeneous (multi-PDK) packages." Michael Knox from the New York University Tandon School of Engineering received the best paper award for his work titled "Simplified Tapped Delay Line Architecture for Active Cancellation in a 2x2 IBFD MIMO Transceiver (*Fig. 2*)."

The exhibition featured displays from companies such as Keysight, Copper Mountain Technologies (*www.coppermountaintech.com*), ANSYS, Reactel (*www.reactel.com*), Mini-Circuits (*www.minicircuits.com*), Rohde & Schwarz (*www.rohde-schwarz.com*), and Modelithics (*www.modelithics.com*). Others included Sonnet, VIDA Products (*www.vidaproducts.com*), and NSI-MI Technologies (*www.nsi-mi.com*).

Among the products highlighted was Keysight's P9375A Streamline USB vector network analyzer (VNA) (*Fig. 3*). Also featured was the latest technology from ANSYS, such as 3D components and other recent innovations (*Fig. 4*).

Speaking of ANSYS, the company's own Charlotte Blair was one of the speakers at the Joint Young Professionals and Women in Microwaves reception, which capped off the conference (*Fig. 5*). The speakers were able to share their own personal stories, as well as offer career advice. One interesting story was told by Laura Levesque of Modelithics. She spoke about how she started out in avionics engineering and then entered the RF/microwave industry by first working as a technician at Modelithics, before ultimately moving on to her current role with the company.

The General Chair of WAMICON 2019 was Hjalti Sigmarsson from the University of Oklahoma. Quenton Bonds from the Goddard Space Flight Center will serve as the General Chair of WAMICON 2020. Bonds has high hopes for next year's conference; one of the goals is to double the attendance. If you're reading this, you can help him achieve that feat by attending WAMICON 2020, which will take place on Florida's Gulf Coast. mw

Broadband Amplifier Delivers Wide Dynamic Range to 2.7 GHz

MODEL ZFL-272VH+ is a broadband amplifier with wide dynamic range from 30 MHz to 2.7 GHz. It provides typical gain of 17 dB at 1 GHz and 12.6 dB at 2,7 GHz, while the output power at 1-dB compression is typically +29.1 dBm at 30 MHz, +29.5 dBm at 1 GHz, and +25 dBm at 2.7 GHz. The dynamic range can be seen from high typical output third-order intercept points (OIP3) of +49.8 dBm at 30 MHz, +47.2 dBm at 1 GHz, and +42 dBm at 2.7 GHz. The robust RoHS-compliant amplifier even maintains low noise figures of 4.2 dB at 30 MHz, 3.4 dB at 1 GHz, and 5.2 dB at 2.7 GHz. Ideal for cable-television (CATV) and cellular base-station infrastructure applications, the 50-Ω amplifier draws 350 mA at +15 Vdc and has an operating temperature range of –40 to +60°C. It's supplied with SMA connectors.

MINI-CIRCUITS, P. O. Box 350166, Brooklyn, NY11235-0003; (718) 934-4500, www.minicircuits.com

Tiny LTCC Filter Rejects 0.5 to 2.4 GHz

MODEL HPSC-492R+ is a miniature low-temperature-cofired-ceramic (LTCC) high-pass filter with negligible loss in the passband above 4.9 GHz and high stopband rejection from 0.5 to 2.4 GHz for interference control at ISM-band frequencies and Bluetooth, Zigbee, and WLAN applications. The typical insertion loss is just 0.4 dB in the passband from 4.9 to 5.85 GHz with typical VSWR of 1.20:1, while the typical rejection is 25 dB in the stopband from 0.5 to 2.4 GHz and 34 dB in the stopband from 2.4 to 2.5 GHz. The tiny, aqueous washable filter measures just 0.026 × 0.020 × 0.015 in. (0.65 × 0.50 × 0.37 mm) and has an operating temperature range of –40 to +85°C.

MINI-CIRCUITS, P. O. Box 350166, Brooklyn, NY11235-0003; (718) 934-4500, www.minicircuits.com

Gain Equalizers Extend to 6 GHz

THE VEQY SERIES of coaxial gain equalizers includes models with 1-dB (model VEQY-1-63+), 5-dB (model VEQY-5-63+), and 10-dB (model VEQY-10-63+) gain equalization across the frequency range from dc to 6 GHz. Ideal for leveling the gain-vs.-frequency response of amplifiers, receivers, or transmitters, the absorptive gain equalizers come in compact coaxial packages for ease of installation in coaxial systems. Units such as the model VEQY-1-63+ provide flat insertion-loss responses across the frequency range, with insertion loss of 1.5 dB at 1 GHz, 1.3 dB at 2 GHz, 1.1 dB at 3 GHz, 0.9 dB at 4 GHz, 0.7 dB at 5 GHz, and 0.6 dB at 6 GHz. The gallium-arsenide (GaAs) MMIC gain equalizers exhibit typical VSWR of 1.1:1 and handle input power levels to +31 dBm. They are designed for operating temperatures from –40 to +85°C.

MINI-CIRCUITS, P. O. Box 350166, Brooklyn, NY11235-0003; (718) 934-4500, www.minicircuits.com

Varistors Provide Voltage Protection to +175°C

TRANSGUARD VT SERIES MULTILAYER-VARISTOR (MLV) transient-voltage-suppression (TVS) devices are rated for operation to temperatures from –55 to as high as +175°C. Qualified to AEC-Q200, they come in compact surface-mount 0603 and 0805 packages for reliable bidirectional overvoltage protection. The varistors provide broadband electromagnetic-interference (EMI) filtering in the off state to reduce the need for discrete multilayer ceramic capacitors (MLCCs) in sensitive circuits. They provide high current and energy-handling capabilities, low leakage current, and multi-strike capabilities, and are compliant with the electrostatic-discharge (ESD) performance requirements defined in the AEC-Q200, IEC 61000-4-2, and ISO 10605 standards. Standard parts are shipped on tape-and-reel in quantities of 1,000, 4,000, and 10,000.

AVX CORP., One Avx Blvd., Fountain Inn, SC 29644; (864) 967-9311, www.avx.com

Low-PIM Cables Add Connector Options

A line of custom cables with low passive intermodulation (PIM) has been extended to include more connector options. The cable assemblies are now available with 160 standard configurations and PIM levels of less than –160 dBc. The cable assemblies, which are constructed with flexible, lightweight, UL910, plenum-rated, SPP-250-LLPL, RF coaxial cable, feature low insertion loss and VSWR and can operate at temperatures from –55 to +125°C. The cable assemblies are 100% RF/microwave and PIM tested. The latest versions of the cable assemblies are available with straight SMA and QMA connectors as well as right-angle versions of both connector types.

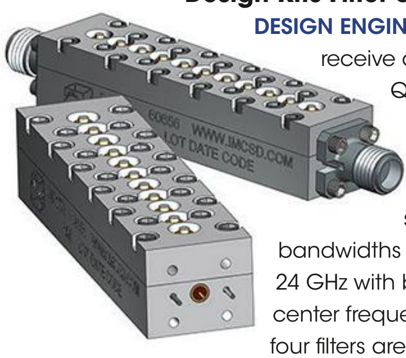
PASTERNACK ENTERPRISES, 17792 Fitch, Irvine, CA 92614; (978) 682-6936, (949) 261-1920, www.pasternack.com

Skew-Matched Cables Now Reach DC to 67 GHz

A LINE OF skew-matched, flexible coaxial-cable pairs now includes dc-to-40-GHz and dc-to-67-GHz sets with as little as 1-ps delay time. Ideal for high-speed networking and high-frequency radar systems, the delay-matched cable pairs feature polarity indicators for matched cable ends and can be supplied with 1.85- or 2.92-mm coaxial connectors. The cables are composed of microporous polytetrafluoroethylene (PTFE) dielectric material with double- and triple-shielded outer conductors. They exhibit typical VSWR as low as 1.40:1 with low insertion loss. The cable sets are 100% tested to 40 or 67 GHz.

PASTERNACK ENTERPRISES, 17792 Fitch, Irvine, CA 92614; (978) 682-6936 (949) 261-1920, www.rosenberger.com

Design Kits Filter 5G Applications



DESIGN ENGINEERS IN is need of filters for 5G wireless cellular infrastructure applications will receive a boost from the four developers' kits available for 5G. Each kit includes four high-Q bandpass cavity filters with the same center frequency for four different bandwidths, with an option to adjust the center frequency of each filter to specific requirements. The filters measure just 1.9 × 0.5 × 0.425 in. and include temperature compensation and 70-dB out-of-band rejection of unwanted signals. The model N257 kit provides filters with center frequency of 26 GHz and bandwidths of 50, 100, 200, and 400 MHz. The N258 kit has four filters at a center frequency of 24 GHz with bandwidths of 50, 100, 200, and 400 MHz. The N260 kit consists of four filters with center frequency of 39 GHz and bandwidths of 50, 100, 200, and 400 MHz, while the N281 kit's four filters are centered at 28 GHz with bandwidths of 50, 100, 200, and 400 MHz. The filters come in compact surface-mount-technology (SMT) waveguide housings, allowing users to drop them into a design to determine the effectiveness at a center frequency and bandwidth.

INTEGRATED MICROWAVE CORP., 11353 Sorrento Valley Rd., San Diego, CA 92121-1303; (858) 259-2600, sales@imcsd.com, www.imcsd.com

Digital Attenuator Has 90-dB Range to 6 GHz

MODEL LDA-906V is a bidirectional digital step attenuator that provides a 90-dB attenuation control range from 200 to 6000 MHz. Attenuation can be changed in 0.1-dB steps with typical accuracy of better than 0.25 dB. The graphical user interface (GUI) provided with the USB-equipped digital attenuator allows for programming of fixed attenuation, swept attenuation ramps, and fading profiles. The 50-Ω attenuator can be supported with LabVIEW drivers, Windows API DLL files, Linux drivers, and Python examples.

VAUNIX TECHNOLOGY CORP., 7 New Pasture Rd., Newburyport, MA 01950; (978) 662-7839, www.vaunix.com

EMI Receiver Boosts Capabilities to 26.5 GHz

MODEL N9048B PAE electromagnetic-interference (EMI) receiver is available with three frequency ranges covering 2 Hz to 26.5 GHz, with available analysis bandwidths of 10, 25, and 40 MHz. The sensitive EMI testers feature low phase noise of –114 dBc/Hz offset 10 kHz from a 1-GHz carrier and –136 dBc/Hz offset 1 MHz from the same carrier. The displayed average noise level (DANL) at 1 GHz is a very low –174 dBc/Hz. The analyzers provide time-domain-scan (TDS) and real-time-scan (RTS) capabilities for real-time measurements at bandwidths as wide as 350 MHz. The overall amplitude accuracy is ±0.22 dB. The instruments are in full compliance with CISPR 16-1-1:2015 and MIL-STD-461G (2015), ensuring the that tested devices comply with worldwide and regional standards.

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

WR-28 Scalar Feed Horn Handles 24 to 42 GHz

MODEL SAF-2434231535-328-S1-280-DP is a dual-polarized, WR-28 waveguide scalar feed horn antenna assembly that operates from 24 to 42 GHz with vertical or horizontal polarization. The antenna features an integrated orthomode transducer (OMT) for high port isolation and cross-polarization cancellation, as well as a broadband scalar horn for low sidelobe levels. The horn antenna exhibits 15-dBi nominal gain at the center frequency with typical half-power beamwidth of 35 deg. and typical sidelobe levels of –25 dB. The typical port isolation between horizontal and vertical ports is 35 dB. The horizontal and vertical ports are equipped with WR-28 waveguide plus UG-599/U flanges and 4-40 threaded holes.

SAGE MILLIMETER INC., 3043 Kashiwa St., Torrance, CA 90505; (424) 757-0168, FAX: (424) 757-0188, www.sagemillimeter.com

Teaching Solution Helps RF/Microwave Students

KEYSIGHT'S RF/MICROWAVE Teaching Solution is a combination of hardware and software designed to help engineering students learn more about the essentials of emerging high-frequency applications, such as 5G cellular wireless communications systems and Internet of Things (IoT) devices. The heart of the teaching tool is the model U3851A RF/microwave circuit design, simulation, and measurement courseware. The courseware includes a modular prototype kit with a 1.8-GHz receiver module, laboratory sheets, and assignments focused on the complete physical design spectrum. The courseware can be teamed with several of the company's test instruments, including signal generators, spectrum analyzers, vector network analyzers (VNAs), and oscilloscopes. Keysight's PathWave design and simulation software can also be used as part of the training courseware.

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

X-Band Filter Screens 9.65 GHz

MODEL IPP-2315 IS a 90-deg. coupler designed for use from 20 to 1000 MHz. It combines two input signals at total power level to 50 W CW in a compact drop-in style package measuring only 1.71 × 1.90 × 0.76 in. The three-port device includes an internal termination capable of handling 20 W power and achieves insertion loss of less than 0.8 dB and VSWR of less than 1.35:1. The amplitude balance is an impressive ±0.30 dB, and isolation between ports is better than 16 dB. The component can be used as an input splitter with the high-power model IPP-2247 for applications involving signal splitting and combining with power amplifiers.

INNOVATIVE POWER PRODUCTS INC., 1170-8 Lincoln Ave., Holbrook, NY 11741; (631) 563-0088, FAX: (631) 563-9898, www.innovativepp.com

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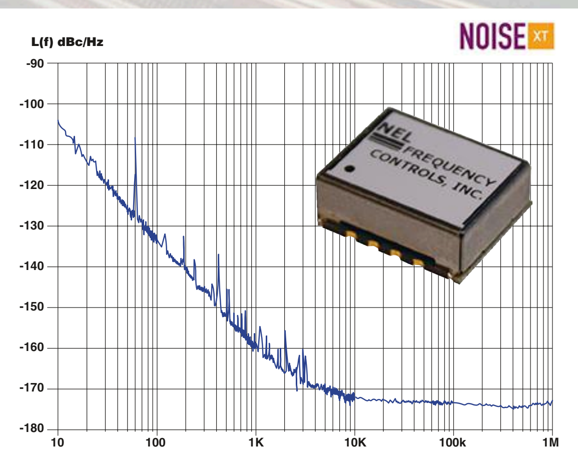

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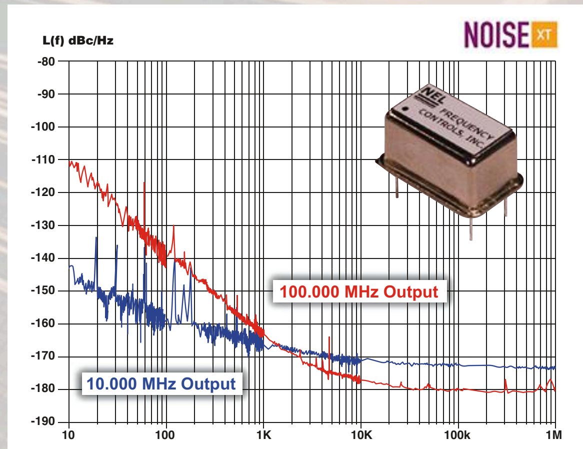

ULPN OCXO @ 10 MHz

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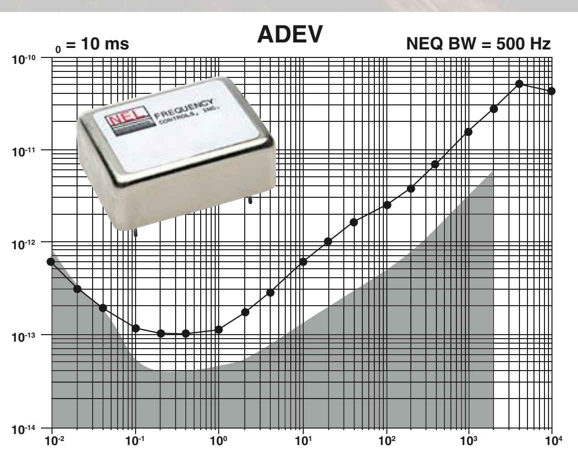
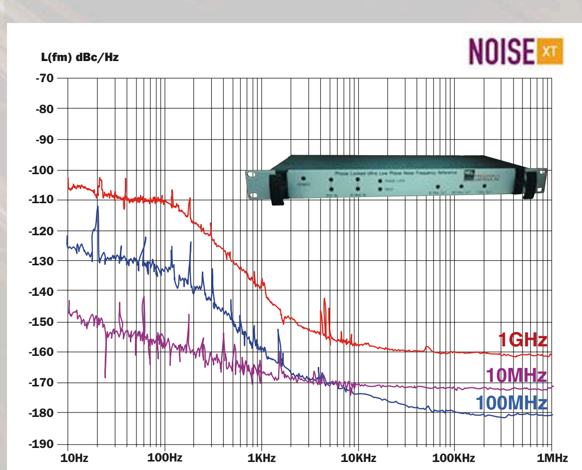


ULPN 10/100/1000 MHz Appliance

Perfect for 5G applications



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