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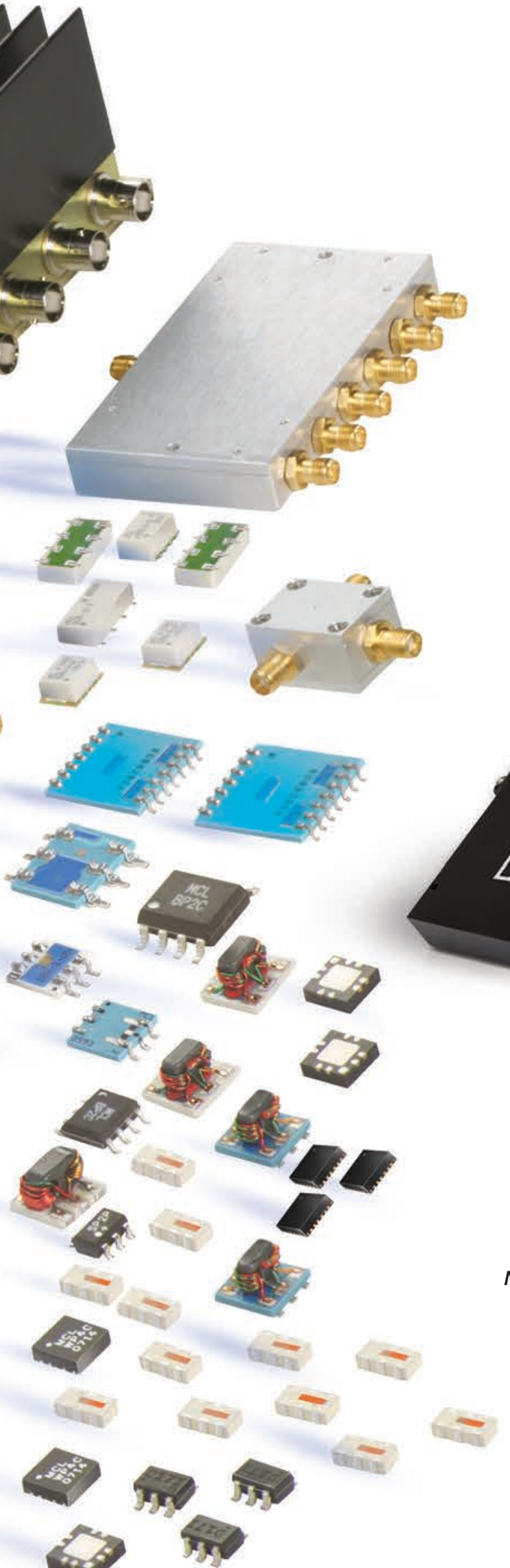

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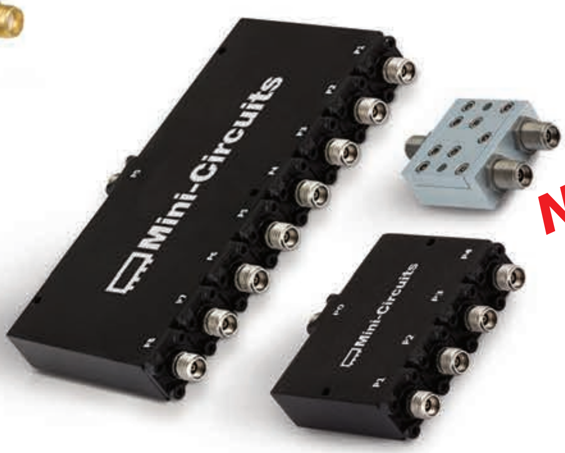

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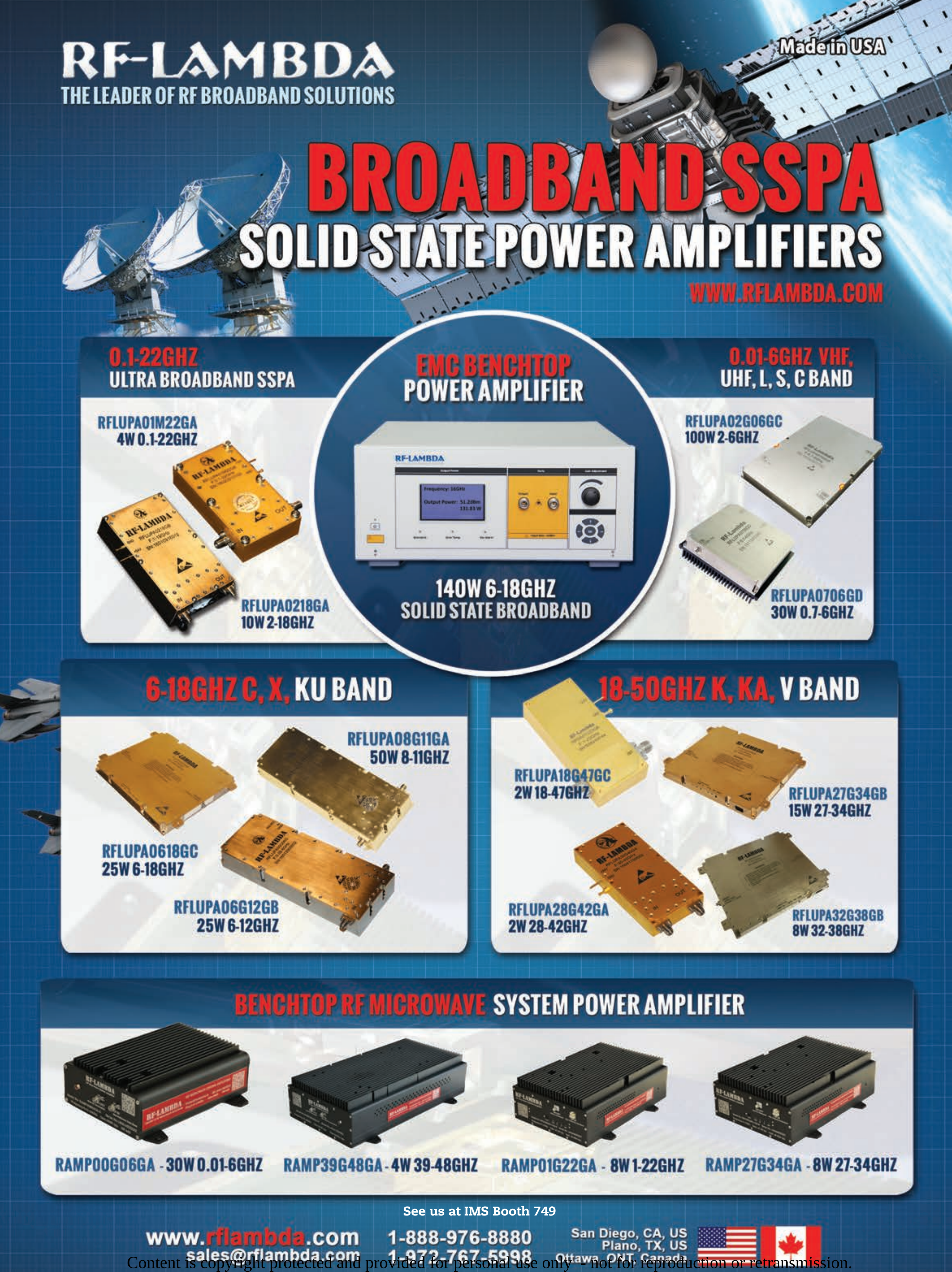
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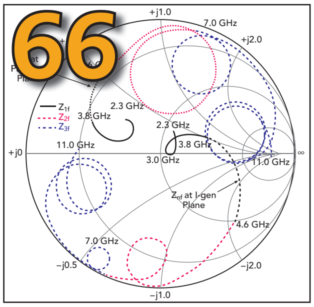

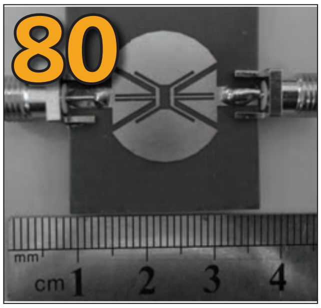

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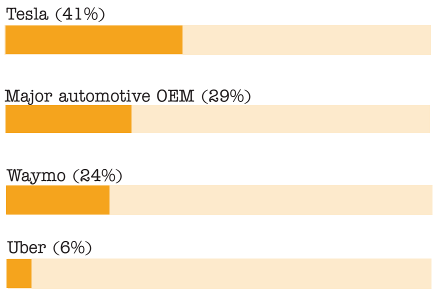

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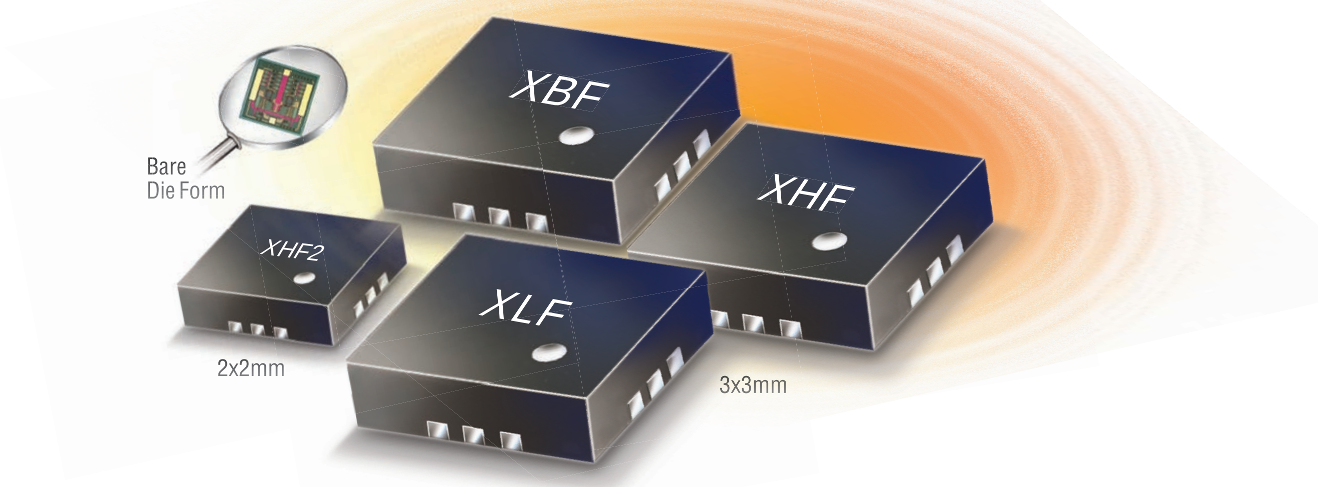

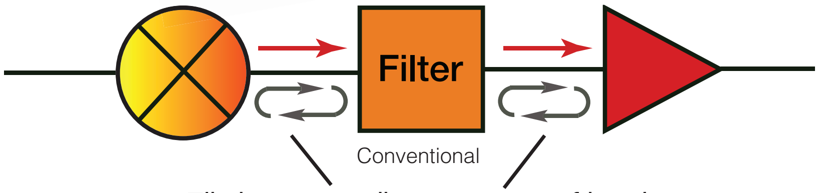

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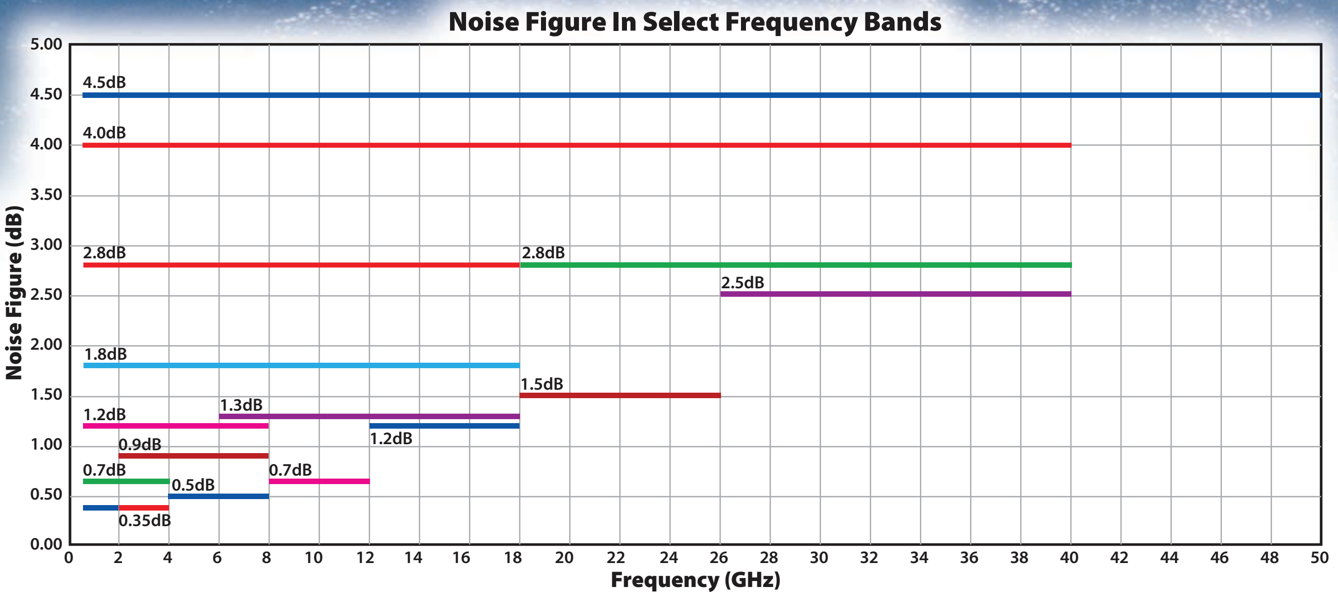


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5G Update: Standards Emerge, Accelerating 5G Deployment

Pasternack
Irvine, Calif.

5G technologies and standards have recently emerged from buzz and corporate blustering to real and rapidly paced definitions and development. When 5G visions were first announced, many considered the performance targets in these predictions to be pipe dreams. However, corporate initiatives to develop 5G technology with real 5G radio and networking platforms and international collaboration on 5G standards has proceeded at a pace few could predict. If this progress means to meet performance targets for 5G, manufacturers must accelerate their timetables and their supply chains to meet the demands of new and competitive 5G hardware and systems.

The race to capture the global business for upcoming 5G solutions—consumer, commercial and government—is starting to resemble the historic space race between Russia and the U.S. The major difference is this goes far beyond a race between two sovereign superpowers, with many international companies and countries in the competition. True 5G solutions require many layers of national and international regulation, as well. Major international telecommunications companies and manufacturers are all competing to demonstrate 5G capabilities and features, while simultaneously paving the way for viable mmWave radio access unit and radio access network (RAN) technology. With spectrum, radio and network standards solidifying ahead of schedule, the pioneering aspects of 5G—mainly the expansion into many more verticals or slices than mobile broadband—are gaining focus and investment.

EARLY 5G FEATURES AND USE CASES

Though the expected features and use cases for 5G are diverse and extensive, the start of the 5G rollout will likely address only a few of the featured use cases: enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC) and massive Internet of

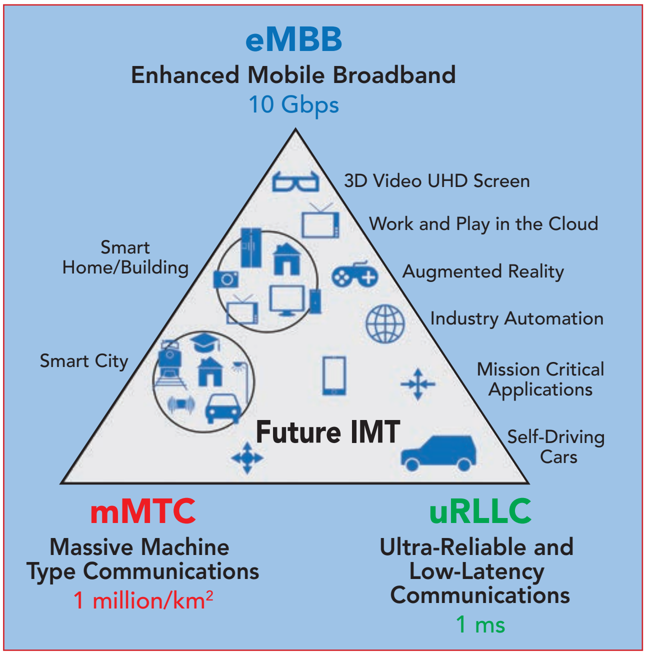

Fig. 1 **The primary use cases for 5G. Source: Werner Mohr, The 5G Infrastructure Association.**

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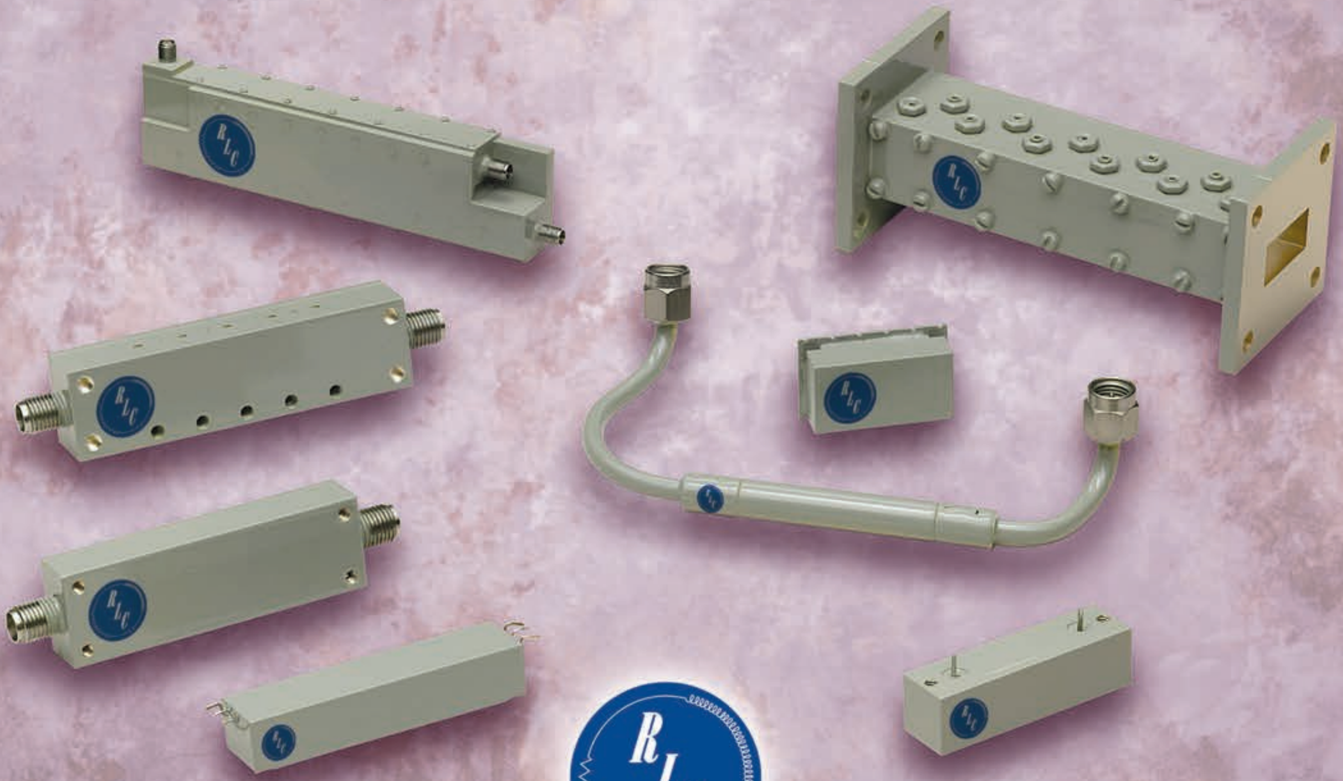

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Things (mIoT) or massive machine-type communications (mMTC), as illustrated in ***Figure 1***. These provide increased throughput and performance for user equipment (UE), while offering a mobile network designed to support the massive number of new IoT, or Industry 4.0, applications. Interestingly, these early 5G features will likely be implemented at sub-6 GHz frequencies (current cellular bands, ≤ 1, 3.5 and 3.7 to 4.2 GHz and various combinations based on country) before 2020, offering opportunities in the vehicle and broadcast market, infrastructure and, primarily, mobile.

EARLY 5G FACTORS AND INFLUENCERS

The main 5G standards bodies and organizations are consistent with past generations of mobile wireless, i.e., 3GPP, GSMA, ITU and each country's spectrum regulatory agency. Importantly, the heads of industry-leading companies are driving these organizations' focus and standards developments. Other industry consortiums and alliances, such as the Next Generation Mobile Networks (NGMN) alliance and TM Forum, are also contributing and advising in the development of 5G standards and specifications.

With the forecast increase in competition for 5G services, and the need to provide lower cost data services now, there is a general impetus to hurry along the advent of 5G. With so many companies and countries taking the initiative with announcements of 5G deployments, these industry and interna-

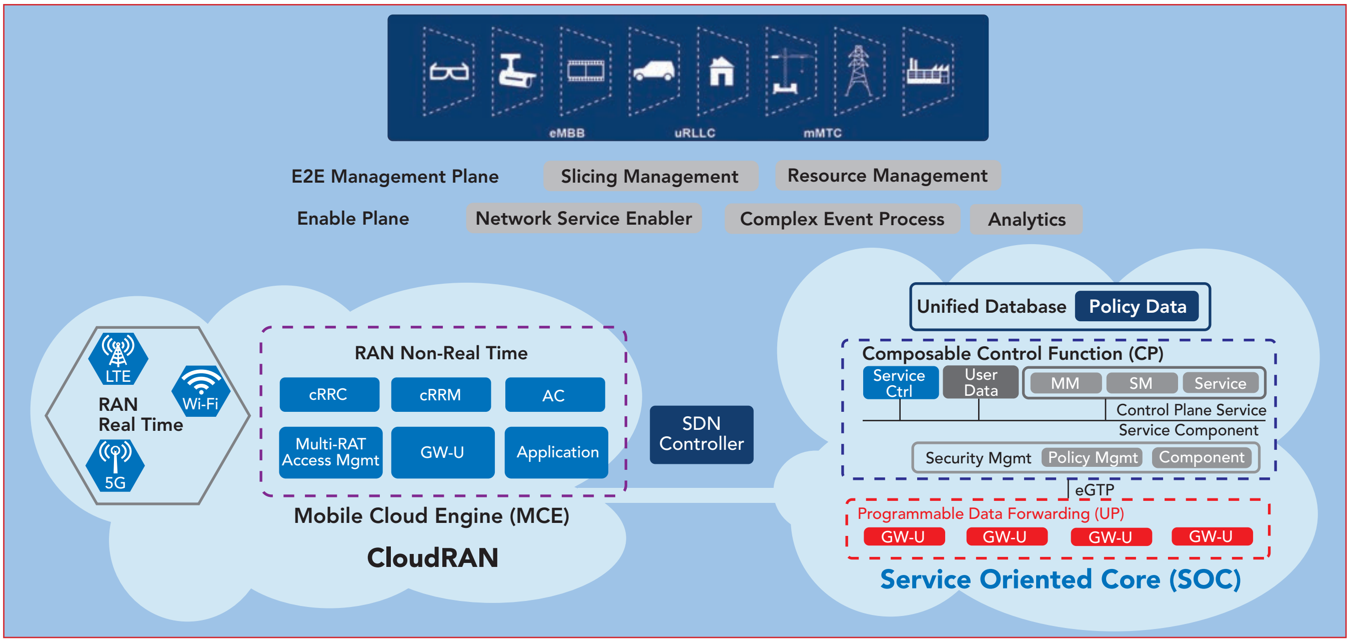

Fig. 2 A new virtualized cloud radio access network architecture will enable operators to serve the multiple use cases envisioned for 5G. Source: Huawei.

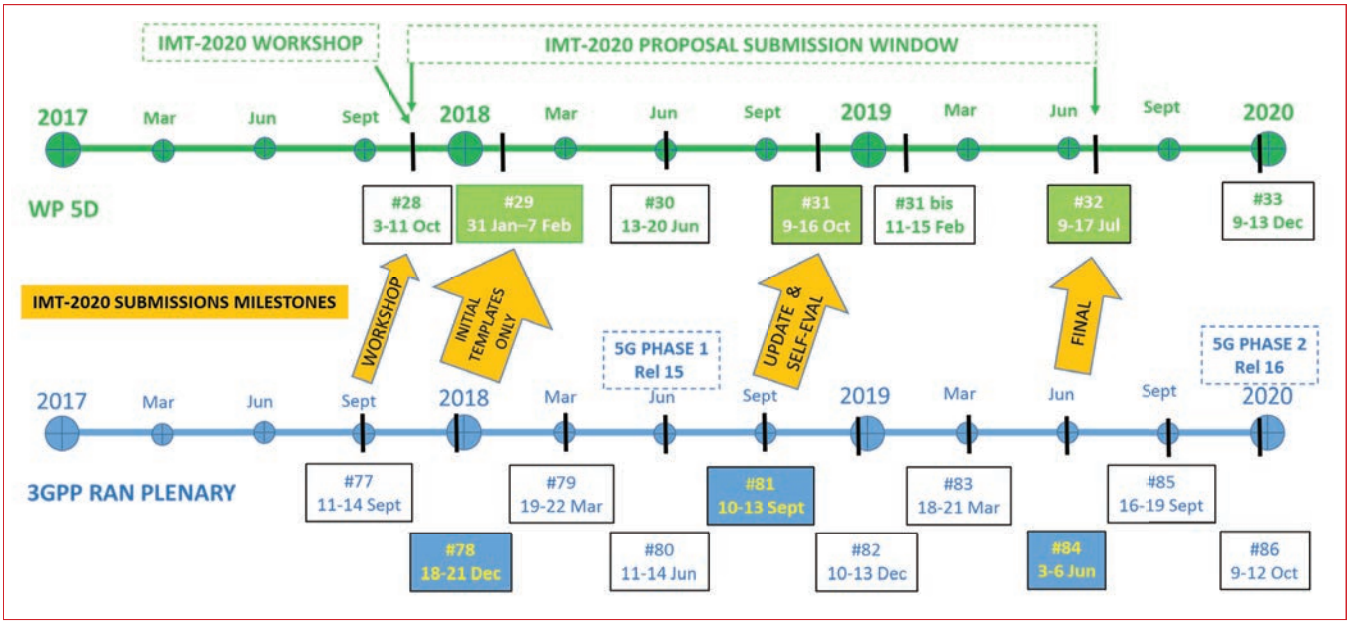

Fig. 3 3GPP timeline for 5G specifications. Source: 3GPP.

tional consortiums have been moving quickly with specifications, standards and spectrum allocation.

Referencing the Verizon 5G Technical Forum (V5GTF), companies feeling the pressure to commercialize more rapidly are even creating new forums to accelerate the development of 5G technologies. Another example of carrier-led efforts to advance 5G is the merger of the xRAN forum and C-RAN Alliance, with the focus of evolving RAN technology from hardware-defined to virtualized and software-driven. Industry forums in market verticals other than mobile are also forming to accelerate adoption and standardization. For example, the 5G Automotive Association encourages collaboration among telecommunication and automotive companies.

Some explanation for this rapid pace could be the concern that collaboration-based organizations have for early adopting companies and countries developing their own regional standards to meet the demand ahead of the competition. For example, some companies, namely AT&T and Verizon, have already claimed they will provide 5G services in select cities in 2018. These 5G services will not necessarily meet all 3GPP 5G specifications, but will likely provide superior throughput to current 4G services and be readily upgraded, most likely through software, to the final 5G specifications. Without 5G capable handsets, either sub-6 GHz or mmWave, it is likely that these companies will offer either hotspot or fixed wireless access (FWA) services instead.[1-2] While the UE may not yet be available, 5G base station and terminal equipment is; Huawei recently announced 5G end-to-end solutions.[3] These offer sub-3 GHz, C-Band and mmWave operation with massive MIMO technology and are reportedly fully 3GPP 5G compliant. In a demonstration with Telus in Canada, a 5G wireless to the home trial using Huawei equipment reportedly demonstrated 2 Gbps, single-user download speeds.[4]

With a lack of a standardized infrastructure in market verticals other than mobile wireless, however, the standardization and specification for vehicle and industrial applications may take far longer than anticipated. This could explain, somewhat, the additional focus of telecommunication service providers on 5G applications in the broadcast and home internet services markets. FWA using sub-6 GHz and mmWave 5G capabilities could provide gigabit internet speeds to homes without expensive fiber installation and even undercut the cable television and home phone service giants.

5G STANDARDS AND SPECIFICATIONS

The GSMA recently released a report, "Mobile Economy," which claims that two-thirds of the world's mobile connections will be running on 4G and 5G services by 2025, with 4G accounting for over half of the global connections and 5G accounting for approximately 14 percent.[5] Not surprisingly, the demand has caused standards and specification organizations to step up their timetables, and market pressures are solidifying 5G radio specifications earlier than expected.[6] However, the "5G precursor" specifications being released now are not the finalized 5G specifications and standards, rather evolutionary steps from 4G specifications that will be compatible with the future 5G specifications.

The latest 3GPP specification defines the non-standalone 5G new radio (NSA 5G NR),[7] which requires an LTE anchor and 5G NR cell. The LTE anchor provides the control plane and control plane communications, while the 5G NR will provide enhanced data capacity. The NSA 5G NR specification currently only covers frequency range 1 (FR1), between 450 and 6000 MHz. These bands are designated in Table 5.2-1 in the 3GPP specification document 38101-1,[8] and are subject to modification when Release 15 is issued in June 2018. The maximum bandwidth for FR1 NR bands is 100 MHz, of which only n41, n50, n77, n78 and n79 are capable. These bands are also designated as time-division duplex (TDD) bands, for which carrier aggregation (CA) should enable greater than 100 MHz functional bandwidth.

Also in this release are the descriptions of new RAN architecture

options. The new architecture is built around a network virtualization strategy, where the control and user planes are separated. Referred to as network function virtualization (NFV) and software-defined networking (SDN), these features are designed to enable future network flexibility and a variety of applications. This methodology is meant to continue providing enhanced mobile telecommunications, while adding diversity of services—hence, independent network slicing.[9]

Future 5G "Cloud RAN" capabilities (see ***Figure 2***) are meant to support multiple RANs, standards and operators using the same physical infrastructure or core network. Such an adaptable RAN would allow for various applications and industries to rely on the same hardware and network assets, physical infrastructure to pave the way for future opportunities. The system to provide capabilities for service-level agreements for a collection of devices is dubbed "network slicing" by 3GPP.

The future 5G standard, what will be concluded in the complete 3GPP Release 15, or 5G Phase 1, will be finalized in June 2018 (see ***Figure 3***). Before the end of 2019, 3GPP will provide updates to Release 15, and a clearer vision of Release 16, or 5G Phase 2, will become available in December 2019. Currently, there is little information on how 5G rollouts will occur and what industries, outside of mobile wireless, will begin adopting the capabilities of 5G. Though trials have been performed and early 5G network and radio access hardware is available, UEs have yet to be released, and operators have virtually no experience and limited understanding or expectations of 5G. Furthermore, mmWave hardware is not yet widely available and, without this valuable experience, solidifying 5G mmWave specifications is impractical. The mmWave frequency designations for 5G will not be identified for the ITU until WRC-2019, in time for IMT-2020.

5G Phase 1 is still based on OFDM waveforms, though there are a variety of candidate waveforms which may eventually supersede OFDM. Specifically, 5G phase 1 leverages cyclic prefix OFDM (CP-OFDM) for the downlink, and both CP-OFDM and discrete Fourier transform spread OFDM-based (DFT-S-OFDM) waveforms for the uplink. 5G Phase 1 allows for flexible subcarrier spacing, where the subcarriers can be spaced at 15 kHz $\times 2^n$ to a maximum of 240 kHz with a 400 MHz carrier bandwidth. Up to two uplink and four downlink carriers can be used, for a combined uplink bandwidth of 200 MHz and downlink bandwidth of 400 MHz.

CURRENT 5G HARDWARE

For the past few years, many telcos and hardware/platform manufacturers have been engaging in a game of 5G one-upmanship. Early demonstrations included mmWave throughput, mMIMO, CA and a variety of software and hardware examples. Many of the latest 5G trials and demonstrations involved technology more aligned with the upcoming 3GPP Release 15, capable of being updated by software to meet the final 5G Phase 1 specification and future updates.

Hence, many of the recently released and announced 5G modems and transceivers are able to be updated via software, and offer throughput handling capabilities that account for greater bandwidth availability at currently unavailable mmWave frequencies. Many leading hardware manufacturers and telecommunication companies are continuing to push to advance 5G trials and deployments by 2019, well ahead of a final specification, by leveraging NSA 5G NR and technology that can be modified to meet the finalized specifications.[10] Given the nature of the race to commercialize 5G, and the likelihood of future 5G specifications adjusting to the findings of early trials and deployments, programmability and flexibility of both the software and hardware of 5G radios and core networks are essential.

Another factor to consider with 5G hardware is not only backward compatibility, but dual connectivity of 4G LTE and 5G systems. Similar to how prior generations of mobile wireless were eventually integrated into the latest specifications, it is likely that current 4G LTE rollouts will be merged into future 5G speci-

fications. Supporting dual connectivity, backward compatibility and future 5G specifications will require highly adaptable RF hardware that can allocate resources based on the actual environment, not just preprogrammed scenarios.[11-12]

As the finalized 5G mmWave spectrum and radio hardware is not yet determined, and extensive mobility trials with mmWave frequencies are still underway, the first round of 5G mmWave technology will provide fixed wireless service (FWA). This approach minimizes many of the challenges associated with a complete 5G solution, including mmWave mobility concerns around non-line-of-sight and antenna beam tracking with moving UEs. Also, FWA 5G modems and transceiver chips can be larger, use more power and cost more than modem and transceiver chips for UE.

Available 5G modems, typically with integrated 5G transceivers, are offered by Samsung, Qualcomm, Intel, Huawei and others. Some of these early 5G chipsets are reportedly capable of 2 Gbps data rates and mmWave transceiver operation at 28 GHz. Common features include NSA 5G NR compatibility, with a variety of beamforming techniques, antenna switching, 3D frequency planning tools and virtualized RAN.[13-14]

Currently, device and network hardware manufacturers, with associated telecommunications service providers and test and measurement manufacturers, are engaging in 5G NR trials with simulated UEs. Samsung and National Instruments, as well as Datang Mobile and Keysight Technologies, demonstrated what will likely be commercial 5G base station hardware and 5G UE emulation systems at Mobile World Congress 2018.[15-16] It is likely that 5G UE chipsets will become available in 2019, although it is unknown if these UE will leverage mmWave technology or just the sub-6 GHz 5G FR1 frequencies.

The latest commercially available 5G hardware solutions are typically RF front-end (RFFE) modules designed to account for the new NSA 5G NR frequencies, which can be included with other RFFE hardware to offer a complete solution. These RFFEs include power amplifiers (PA), low noise amplifiers (LNA), switches and filters and differ somewhat from 4G RFFEs. As the power Class 2 specification for higher output power (26 dBm at the antenna) is available for 5G hardware, PAs may be higher power than with 4G, necessary to overcome increased propagation losses at higher frequencies through the atmosphere and common building materials.

With 100 MHz of available Tx bandwidth, techniques like envelope tracking—which currently only supports up to 40 MHz of bandwidth—may not be viable; less efficient techniques, such as average power tracking are more likely for early 5G systems. These early 5G RFFE modules will likely be wideband, requiring additional filtering for the new sub-6 GHz 5G bands, as well as the legacy and still necessary 4G bands. These multi-band filters are currently more complex combinations of surface acoustic wave (SAW), bulk acoustic wave (BAW) and film bulk acoustic wave (FBAR) filter banks and integrated modules.

RF HARDWARE AND TEST SYSTEMS

Given the inclusion of new sub-6 GHz frequency bands in NSA 5G NR, new RF hardware is needed to support these new frequencies—specifically n77, n78 and n79—which were not previously used for mobile wireless. Though not determined in NSA 5G NR, frequency bands below 600 MHz may eventually be supported by 5G for massive low power connectivity such as IoT, Industry 4.0/Industrial IoT and other machine-type communications. The additional subcarrier channel spacing, bandwidth, CA and 4 x 4 MIMO specifications result in the need for large numbers of filters, antennas, LNAs, PAs and switches, with accompanying NSA 5G NR modems and RF transceivers.

The early 5G modems and transceivers do not necessarily need to contend with these challenges, as these commercial devices can operate on select bands. However, 5G base stations for eMBB and future industrial and vehicle applications will require forward and backward compatibility. This means that 5G


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RF hardware will need to service all current mobile frequency bands, as well as 5G FR1 and 5G mmWave FR2 frequencies (see ***Figure 4***). This is a particularly troublesome hardware challenge, as the hardware for many of the existing cellular frequencies may interfere with the NSA 5G NR bands, as dual connectivity is necessary to meet the throughput specifications. Also, the new NSA 5G NR frequency bands surround the ISM bands for Wi-Fi, Bluetooth and other wireless equipment operating in the unlicensed bands.

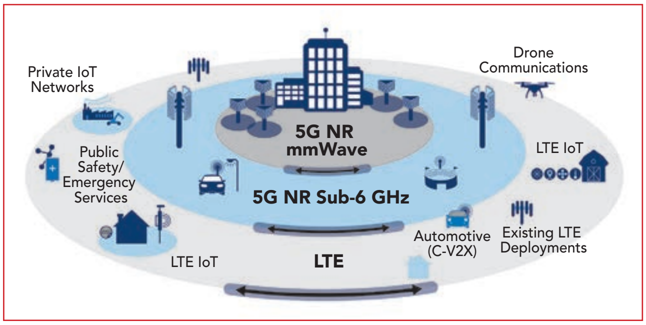

Fig. 4 **Once deployed, standalone 5G services, operating at sub-6 GHz and mmWave frequencies, will need to coexist with LTE. Source: AndroidAuthority.com; used with permission.**

With such closely packed bands and extremely wideband radios, the performance degradation from receiver desensitization is likely with inadequate filtering, PA linearity and harmonic suppression. New NSA 5G NR transmitters can operate with higher output power and higher peak-to-average power ratios for maximum throughput, which may cause problems with co-located 5G receivers in the same base station or nearby 5G devices.

Real estate for RF hardware, especially antennas, is already small in UEs, and 5G specifications may require 4 x 4 MIMO for the downlink and 2 x 2 MIMO for the uplink, meaning six independent RF pathways. 5G antenna tuning technologies will be critical to maximize antenna radiation efficiency over wide bandwidths. These RF pathways must also be much wider than 4G LTE pathways, as NSA 5G NR now supports 100 MHz bandwidth on a single carrier, with more CA options (up to 600 new combinations with Release 15). NSA 5G NR also allows for 200 MHz combined uplink and 400 MHz combined downlink bandwidth. This results in a substantial amount of data to process, challenging for energy efficient UEs and base stations.

It is probable that the RF hardware for UEs will be increasingly integrated, with filter banks, high density switches, antenna tuning, LNAs and PAs integrated into RFFEs with systems on chip (SoC) technologies. 5G UE antennas may also be integrated solutions, possibly with antenna tuning and some pre-filtering and beamforming features included. This level of integration is also plausible to achieve the cost targets to ensure handsets are affordable and meet phone form factors.[17-19] With the increased complexity of 5G and the need for dense RF solutions, it is no surprise that many UE manufacturers are attracted to 5G modem-to-antenna solutions for faster development and deployment.

Many current 4G UEs and base stations rely on LDMOS, GaAs and SiGe PAs, with GaN a recent entry into the base station PA market. As the frequency is extended to sub-6 GHz, LDMOS, which struggle beyond 3 GHz, is less likely to meet 5G specifications, while GaN PAs—and possibly LNAs—are likely to be used in the infrastructure. GaAs and SiGe amplifiers will compete for amplifier and switching functions in the sub-6 GHz 5G applications. To maintain lower cost and smaller form factors than current mmWave PA, LNA and switch solutions provide, highly integrated RF silicon on insulator (SOI) technologies are likely to be used for 5G mmWave applications. Future RFFEs may use RF SOI, SiGe BiCMOS or RF CMOS SoCs that integrate the PA, LNA, switches and control functions to operate mmWave phased array beamforming antenna systems (see ***Figure 5***). It is possible that future RF silicon technologies can be further integrated or combined with other technologies to include

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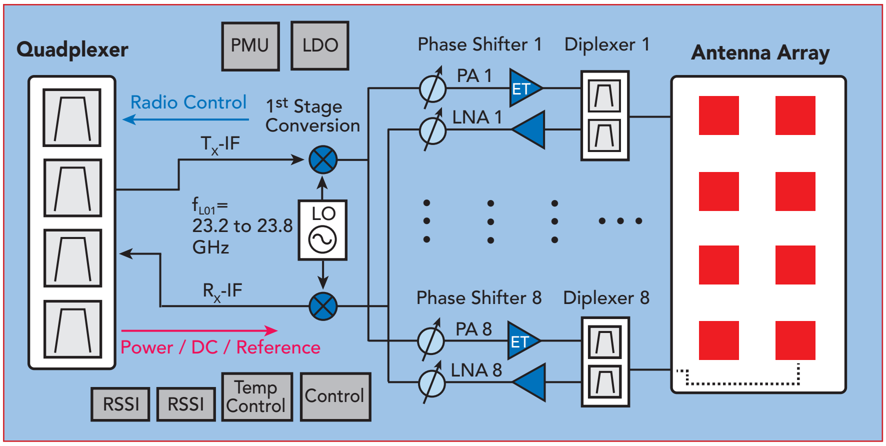

Fig. 5 5G FDD beamforming module architecture. Source: arXiv:1704.02540v3 [cs.IT].

filtering and the digital hardware required to enable hybrid beamforming modules. Future variations of RF SOI or RF CMOS may even be integrated with more advanced digital hardware, such as FPGAs, memory and processors. Baseband processing and accessory DSP functions could be implemented in the package, as well, for compact 5G mmWave solutions.

As frequency routing and filtering is essential for 5G CA and back compatibility with prior mobile generations, integrated SAW, BAW, FBAR and other integrated resonators and filter technologies are essential for UEs and even compact small cells. With the potential for interference and design complexity, 5G modules for UEs will also likely incorporate Wi-Fi and Bluetooth modules, further increasing the filtering and frequency routing complexity. Other integration-capable technologies, such as RF SOI, may be employed for 5G RFFEs, as recent advances in RF SOI enable filter and amplifier co-integration. It may be several years before SOI filters are used for sub-6 GHz 5G applications, although it may be sooner for mmWave systems, as amplifier and switch integration possible with SOI technologies make this an attractive next step.

CONCLUSION

The rapid progression of 5G specifications and the rush of mobile wireless manufacturers and service providers to start 5G trials and deployments has led to a plethora of early 5G demonstrations and interim 5G specifications. In just the past few months, modem, transceiver and RF hardware manufacturers have been announcing 3GPP-compliant 5G solutions, which rely on heavy integration and software reprogrammability to meet current demand and provide future-proofing. This deep level of integration and soon-to-come 5G deployments will require flexible test and measurement systems which can be readily adapted to the changing standards and lessons learned from early trials.[20] Access to 5G accessories and interconnect technologies, especially 28 GHz and other mmWave components and devices, will be essential to prevent delays in trials and deployments.■

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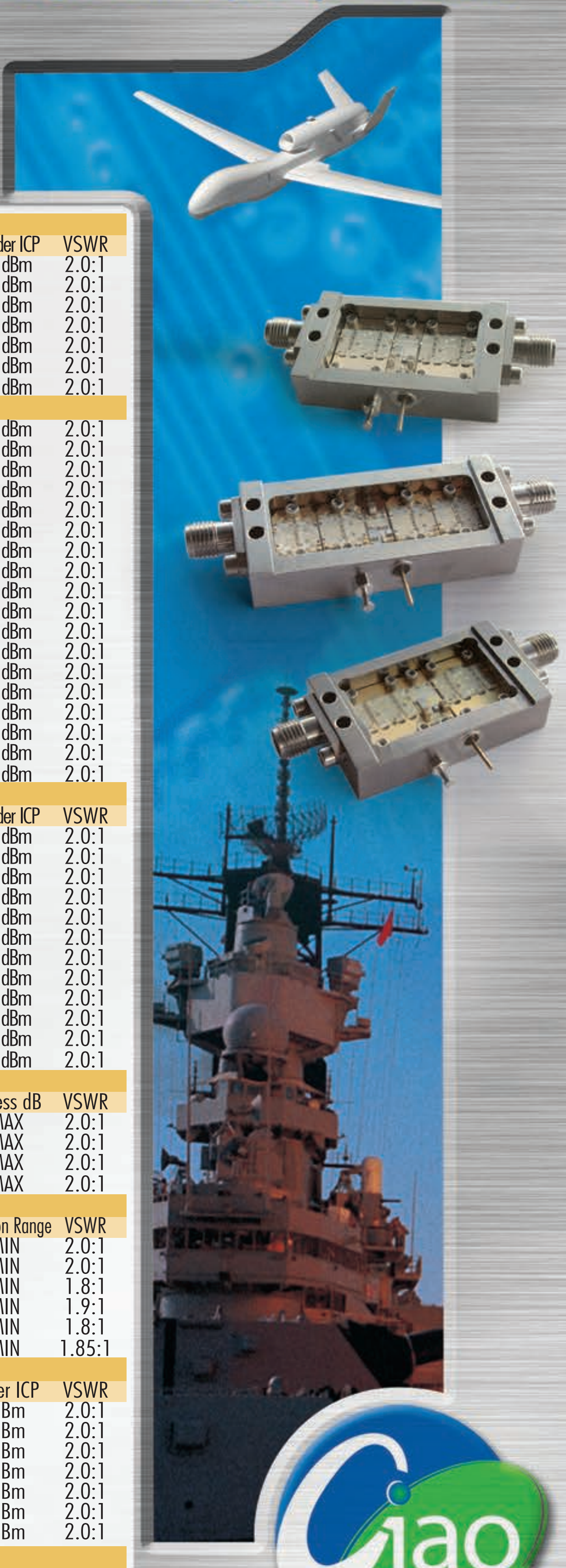

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Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP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

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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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Technology to Control Drone Swarms

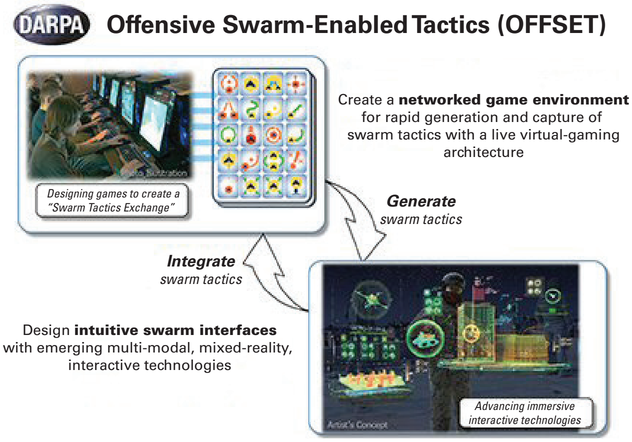
Under DARPA's Offensive Swarm-Enabled Tactics (OFFSET) program, Raytheon BBN Technologies is developing technology to direct and control swarms of small, autonomous air and ground vehicles. The technology includes a visual interface that allows "drag and drop" creation and manipulation of drone tactics, a game-based simulator to evaluate those tactics and a physical swarm testbed to perform live tactics evaluations.

"Operators use speech or gestures to control the swarm. This is a tremendous advantage during operations," said Shane Clark, Ph.D. and principal investigator on the program. "The system provides sensor feeds and mission status indicators for complete situational awareness."

The flexible, scalable programming software and simulation environment means users can coordinate drone behaviors in teams composed of different vehicle types that use various sensors.

DARPA is inviting additional organizations to participate in OFFSET as "sprinters" through an open Broad Agency Announcement. Sprinters can create their own novel swarm tactics and the Raytheon BBN team will work with them to evaluate the tactics in simulation, and possibly field them for live trials.

In 2016, Raytheon, as part of the Office of Naval Research LOCUST program, conducted demonstrations that successfully netted together 30 Coyote unmanned aerial vehicles (UAV) in a swarm.



OFFSET (DARPA Image)

Foundation for US Ballistic Missile Defense System Modernized

The system of systems that enables the disparate elements of the Ballistic Missile Defense System (BMDS) to function as a complete global defense network has been revolutionized. The modernized Command, Control, Battle Management and Communications (C2BMC) system significantly improves collaborative ballistic missile defense planning and provides global and regional combatant commands with rapid operational response capabilities.

Operationally fielded in 2004, the C2BMC network is extremely complex. This system links traditionally autonomous space, sea and terrestrial sensors and their associated systems, gleaning the best target data from each to provide the highest probability of intercepting ballistic missile threats directed against the U.S., its deployed forces, allies and friends.

"Truly integrated ballistic missile defense can never be static," said Dr. Rob Smith, vice president of C4ISR Systems for Lockheed Martin (LM). "C2BMC must maintain pace and be flexible to changes in technology, capability improvements and adversarial conditions."

A LM-led team that includes Northrop Grumman, Raytheon, Boeing and General Dynamics modernized the entire C2BMC global network, which is deployed at numerous locations throughout the world. The team developed, tested and deployed sophisticated track processing, sensor and battle management algorithms to optimize how C2BMC processes data from all the BMDS elements, providing increased capacity to handle larger and more complicated threats.

C2BMC's modernization is predicated on a new open, flexible architecture that eases the integration of new capabilities, increases system reliability, substantially reduces the overall hardware footprint and lowers total system life cycle costs. From an information assurance perspective, the new architecture has been cyber hardened to mitigate threats to the network and systems.

High-Power Microwaves, Lasers Defeat Multiple Drones in US Army Exercise

Forty-five UAVs and drones fell out of the sky during a U.S. Army exercise after Raytheon's advanced high-power microwave and laser dune buggy engaged and destroyed them. These common threats were knocked down during a Maneuver Fires Integrated Experiment at the U.S. Army Fires Center of Excellence.

The event, known as MFIX, brought military and industry leaders together to demonstrate ways to bridge the Army's capability gaps in long-range fires and maneuver short-range air defense. Raytheon's high-power microwave system engaged multiple UAV swarms, downing 33 drones, two and three at a time, while the high energy laser (HEL) system identified, tracked, engaged and killed 12 airborne, maneuvering Class I and II UAVs and destroyed six stationary mortar projectiles.

For More Information Visit mwjournal.com for more defense news.

"The speed and low cost per engagement of directed energy is revolutionary in protecting our troops against drones," said Dr. Thomas Bussing, Raytheon Advanced Missile Systems vice president. "We have spent decades perfecting the high-power microwave system, which may soon give our military a significant advantage against this proliferating threat."

Raytheon and the U.S. Air Force Research Laboratory worked together under a $2 million contract to test and demonstrate high-power microwave, counter-UAV capabilities.

Long-Range Anti-Ship Missile Marks 6th Successful Flight Mission

LM successfully tested a production-configuration Long-Range Anti-Ship Missile (LRASM) from a U.S. Air Force B-1B bomber.

During the test, a B-1B from the 337th Test Squadron at Dyess Air Force Base, Texas, launched a LRASM over the Sea Range at Point Mugu, Calif., successfully impacting the maritime target and meeting test objectives.

"LRASM has now proven itself in six consecutive flight missions," said David Helsel, LRASM program director at LM Missiles and Fire Control. "The reliability and outstanding capability of LRASM will provide an unmatched weapon to our warfighters in their quest for sea control in contested environments."

LRASM (U.S. Navy Photo)

LRASM is designed to detect and destroy specific targets within groups of ships by employing advanced technologies that reduce dependence on intelligence, surveillance and reconnaissance platforms, network links and GPS navigation in EW environments. LRASM will play a significant role in ensuring military access to operate in open ocean/blue waters, owing to its enhanced ability to discriminate and conduct tactical engagements from extended ranges.

LRASM is a precision-guided, anti-ship standoff missile based on the successful Joint Air-to-Surface Standoff Missile–Extended Range (JASSM-ER). It is designed to meet the needs of U.S. Navy and Air Force warfighters in contested environments. The air-launched variant provides an early operational capability for the U.S. Navy's offensive anti-surface warfare Increment I requirement to be integrated onboard the U.S. Air Force's B-1B in 2018 and on the U.S. Navy's F/A-18E/F in 2019.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Canadian Governments, Thales Partner to Develop 5G Superhighway

Together with its industry partners, the Government of Canada and the provincial governments of Ontario and Quebec, Thales Canada announced its $25 million (CAD) investment in ENCQOR, a $400 million (CAD) public-private partnership in ultra-high speed communications infrastructure that will focus on research and innovation.

ENCQOR brings together governments, small and medium businesses and academia to link research facilities and laboratories across Eastern Canada to collaborate on 5G technology development and create Canada's 5G communications superhighway. With download speeds up to 100x faster than current 4G technology, 5G and ENCQOR will transform the capabilities of Canadian businesses to compete in the global marketplace.

Thales will leverage its R&D investments to drive 5G technology developments, securely moving data to drive the evolution of its urban transportation solutions, secure connectivity capabilities and cloud-based big data analytics. In the last three years, Thales has invested over $1.5 billion (CAD) in key digital technologies with the launch of its high-tech Digital Factory in Paris, cortAIx in Montreal and recent acquisitions of technology leaders Vormetric and Guavus.

Mark Halinaty, president and CEO of Thales Canada, said, "From a safer commute to smarter cities, ENCQOR reflects Thales' continued commitment to Canadian innovation in four key domains—connectivity, big data, AI and cybersecurity—to support the creation of new 5G solutions to make life better and keep us safer."

VentureEU to Boost Europe's Innovative Startups

The European Commission and the European Investment Fund (EIF) have launched a Pan-European Venture Capital Funds-of-Funds programme (VentureEU) to boost investment in innovative startup and scale-up companies across Europe. It will provide new sources of financing, giving European innovators the opportunity to grow into world-leading companies. Around 1,500 startups and scale-ups are expected to gain access across the whole EU.

The EU will provide cornerstone investments of up to €410 million—including €67 million of EIF own resources: €200 million from the Horizon 2020 InnovFin Equity, €105 million from COSME (Europe's programme for small and medium-sized enterprises) and €105 million from the European Fund for Strategic Investments (EFSI). The rest of the financing will be raised by the selected fund managers primarily from independent investors.

The six funds will take stakes in a number of smaller investee funds and cover projects in at least four European countries each. These investee funds will help finance small and medium-sized enterprises (SME) and mid-caps from a range of sectors such as information and communication technologies (ICT), digital, life sciences, medical technologies and resource and energy efficiency.

Commission VP Jyrki Katainen, responsible for Jobs, Growth, Investment and Competitiveness, said, "In venture capital, size matters! With VentureEU, Europe's many innovative entrepreneurs will soon get the investment they need to innovate and grow into global success stories. This means more jobs and growth in Europe."

Exeter University, Flann Pave Way for 5G Communications Revolution

Flann Microwave and the University of Exeter, U.K., have teamed up as part of groundbreaking research which could help pave the way for the next generation of 5G mobile communications. Flann is working with Ph.D. researcher Julia De Pineda-Gutiérrez from the Department of Physics and Astronomy on a four-year project which aims to use metamaterials to revolutionise antenna design for point-to-point radio networks, such as mobile phone networks, with the aim of making these smaller, lighter and cheaper to manufacture and install.

Metamaterials involves materials being treated or engineered to give them special properties not normally found in nature. In the case of the research being carried out by Flann and De Pineda-Gutiérrez, this involves developing surface structures and materials which can be used to manipulate radio waves to form the narrow beams needed for communication between mobile base stations. As demand grows for higher capacity mobile networks, this technology opens the prospect of subtly incorporating antennas into everyday features

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and structures, potentially avoiding the visual clutter associated with conventional antenna types.

Professor James Watts, chief executive of Flann Microwave, said, "This work has implications nationally and internationally in the development of next generation communications networks, which face a considerable challenge in moving from 4G to 5G, much more so than with the step up from 3G to 4G.

"We're delighted to be continuing our association with the University of Exeter, which has a growing reputation in the field of metamaterials research. We are excited at an academic level and by the practical and commercial opportunities which we hope will flow from this project and which could one day become mainstream in network development."

£8M Boost to ICURe Programme for UK Research

An £8 million expansion of the U.K.'s Innovation to Commercialisation of University Research (ICURe) pilot programme will allow even more commercially-promising ideas to get to market more quickly. The funding will see the University of Warwick and Queen's University Belfast join the programme, which is supported by Innovate U.K., part of the new national funding body U.K. Research and Innovation.

ICURe's focus is on training early-career researchers to find the right route to commercialisation and helping them develop the necessary business skills, connections and expertise. It aligns with government's Industrial Strategy, which emphasises the importance of research, innovation and skills to develop a strong economy and ensure Britain leads the high-tech, highly-skilled industries of the future.

With this funding boost, the pilot programme will be able to support an additional 48 research teams nationwide. A total of £3 million of the funding will go towards helping the startups that emerge from the programme to establish their businesses and support future growth.

U.K. Business Secretary, Greg Clark said: "Through the Industrial Strategy, the four grand challenges and the funding, we are helping turn innovative new ideas into products and services which could help change our lives and keep the U.K. as a world leader in developing the products of tomorrow."

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Industrial Connected Sensors Revenue to Grow with 19% CAGR

If sensor suppliers hope to sustain the growth they have started to see with the emergence of the Industrial Internet of Things (IIoT), they must work with other stakeholders in the ecosystem to understand the needs and trends within the IIoT," says Pierce Owen, principal analyst at ABI Research. "Only then can they anticipate the future demands of their customers and meet them with new and innovative sensors and other products."

Increases in the amount, types and variability of sensor data result in higher demand for edge computing and edge analytics, and improved edge analytics results in more use cases for more types of sensors. This virtuous circle benefits manufacturers who get more out of their data, sensor suppliers who sell more sensors and edge computing software companies who continue to innovate. As it stands, most manufacturers do not have the computing power at the edge necessary to analyze the heavy workload that comes with the new volume of sensor data. Sensor suppliers must go to market with gateway suppliers and edge analytics specialists to provide this extra headspace.

The largest sensor suppliers sell automation technology or other industrial equipment as their primary business. Often, they build in sensors to new equipment and provide aftermarket sensors to retrofit legacy equipment. Some of these companies have also built their own IIoT platforms. These suppliers include Rockwell, ABB, Bosch, Honeywell, Ormron, Schneider Electric and Emerson. All the major industrial automation companies also provide sensors, an IIoT platform or both. Because these companies all work on IIoT platforms, they have an opportunity to make purpose-built sensors for IIoT solutions. If end users do not have purpose-built sensors, they face a slow buildup of "garbage in and garbage out."

In addition to the industrial automation companies, IIoT sensor specialists and semiconductor companies have also targeted the manufacturing sector. This includes companies such as 3DSignals, ADI, EpiSensor and Texas Instruments.

"Software companies and platform providers such as PTC, SAP, Siemens and FogHorn will inject themselves into the decision-making processes of their clients to help them achieve greater ROI. These decisions include choosing new sensor suppliers. At this point, most of these companies view sensors as the far end of the 'dumb pipe.' Sensor suppliers should go knock down the doors of these software companies and platform providers to find out how to better serve their needs and change that perception. They need to provide value as a solution partner," concludes Owen.

Next-Generation Smart City IoT Platforms Leveraging Standards, Open Source, AI

In a very crowded IoT platform ecosystem, multiple vendors are targeting the smart cities vertical with optimized and dedicated solutions and vying for dominance in this very promising segment, according to a recent study by ABI Research.

While established players like Cisco and Verizon excel in the width and depth of functionality offered across the value chain and vertical segments, others like IBM and Bosch are embracing next-generation technologies like AI, blockchain and sensor data crowdsourcing to enable a new urban economy based on sharing, service and cognitive business models for smart city services like community-based parking, automated surveillance cams and blockchain-enabled freight tracking.

"To really enable holistic smart city solutions and manage dynamic technology lifecycles, city governments increasingly rely on vendor-agnostic standardized and/or open source platforms," says Dominique Bonte, vice president end markets at ABI Research. "InterDigital's Chordant's adherence to the oneM2M standard and FIWARE's open source API approach offer the promise of flexible, pay as you grow, future-proof solutions enabling yet unknown applications and services. Standardization organizations like ETSI are also actively preparing smart city data and platform standards."

However, many generic, horizontal IoT platforms offered by carriers, network infrastructure vendors and other suppliers are also targeted at the smart cities vertical but often lack specific functionality required by the public sector. At the other end of the spectrum, city platforms built around specific verticals such as energy, buildings, utilities or transportation are offered by players like Itron, Siemens, Schneider Electric, GE and Hitachi. These players are typically focused on OT rather than IT.

Finally, product or technology specific smart city platforms include solutions built around cloud technology (Amazon/AWS, IBM, Microsoft), IT (SAP, NEC, HPE), AI surveillance (NVIDIA), connectivity modules (Telit), cellular connectivity (carriers) and smart lighting (Philips).

Ultimately, no single platform will be able to offer all features for all verticals in a smart city environment characterized by a "platform of platforms" approach, with open, interoperable platforms interacting with and complementing each other in a "system of systems" constellation and open ecosystem.

Forecast Nearly 600M 5G Users by 2023

There will be 9 billion user-linked subscriptions to wireless services by 2023, up from 7.7 billion today, according to new forecasts

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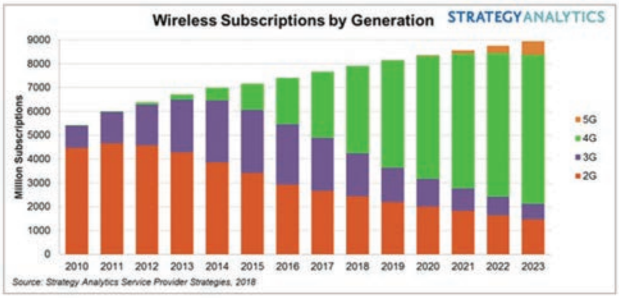
from Strategy Analytics. The new report predicts that 5G adoption will follow a comparable path to that seen by 4G LTE, but warns that there is limited growth left in connectivity revenue for service providers. Key findings include:

- Wireless service revenue will peak in 2021 at US$881 billion, just 3 percent above the level forecast for 2018.
- User-linked mobile 5G connections will grow from 5 million in 2019 to 577 million in 2023 (excluding fixed wireless applications and IIoT). These will account for 10 percent of connectivity revenue in 2018.
- Prior to the launch of 5G services, there is considerable time for 4G LTE platforms to evolve through LTE-Advanced and LTE-Advanced Pro technologies. Combined, they will account for more than half of all 4G LTE connections by mid-2018 and hit 2 billion connections by year end. Even with 5G, many devices will still rely on 4G for roaming outside of 5G coverage areas.

"Competitive pressure has defined the revenue growth of many countries in recent years, including France, India and the U.S., and wireless service providers must work harder to identify growth opportunities," notes Phil Kendall, report author. "The monetization of 4G data traffic has been critical for creating revenue uplift, even in the world's most mature wireless markets like Finland and Japan, and remains a medium term priority for the industry."



Susan Welsh de Grimaldo, director, Service Provider Strategies, adds, "With significant service provider focus on 5G, there are many unanswered questions relating to infrastructure costs and deployment strategies, and to how well service providers can unlock new revenue streams beyond basic connectivity services. The expected early involvement of China in 5G will, however, bring economies of scale to the 5G device market earlier than we typically see with new network technologies, which will be encouraging for operators looking to execute on a clear vision of 5G consumer service opportunities.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

IN MEMORIAM

Tom Brazil, 1952-2018

IEEE Microwave Theory and Techniques Society (MTT-S) President **Thomas J. Brazil** passed on April 13, 2018. Brazil held the chair of Electronic Engineering at University College Dublin (UCD), where he was also head of Electronic Engineering in the UCD School of Electrical & Electronic Engineering. In 1977, he received his Ph.D. from the National University of Ireland, and worked on microwave sub-system development at Plessey Research (Caswell) U.K. from 1977 to 1979.

Brazil was elected a member of the Royal Irish Academy (RIA)—Ireland's highest academic honor—in 2004, served as secretary from 2009 to 2013 and was a member of the RIA Council at the time of his passing. He was IEEE MTT-S Worldwide Distinguished Lecturer in Microwave CAD 1999-2003, was elected an IEEE Fellow in 2003 and was appointed to the Senate of the National University of Ireland in 2012. Brazil acted as chair for both the European Microwave Conference in 2006 and for the European Microwave Integrated Circuits Conference in 2016. Following election by world-wide ballot in August 2010, he became a serving member of the Administrative Committee of the MTT-S and, in October 2016, Brazil was elected president of the MTT-S in 2018. He was serving as President-Elect in 2017 and President from January 2018.

The Memorials Committee is planning to honor Professor Brazil and his contributions to the Society at IMS2018.

MERGERS & ACQUISITIONS

Analog Devices Inc. (ADI) announced the acquisition of **Symeo GmbH**, a privately held company based in Munich, Germany that specializes in radar hardware and software for emerging autonomous automotive and industrial applications. Symeo's innovative signal processing algorithms will enable ADI to offer customers a radar platform with significant improvements in angular accuracy and resolution. Symeo's unique RF and sensor technology enables real-time position detection and distance measurement. The company's technology enables system integrators and original equipment manufacturers (OEM) to offer high precision radar solutions in rough industrial environments, and complements ADI's expanding portfolio of market solutions in this space.

TDK announced that it is buying **Chirp Microsystems**, a startup that developed an ultrasonic sensor that can precisely measure the distance to objects but is small and efficient enough to be embedded in IoT devices—basically a chip that does sonar. With the acquisition, TDK plants its stake in the booming business of sensors that can sense in 3D, detecting hand gestures and following people around a room. For TDK, Chirp's sensors complement its portfolio of sensors and actuators as well as the navigation systems that it acquired in its InvenSense deal.

General Dynamics and **CSRA** announced that they have entered into an amendment to their definitive merger agreement under which General Dynamics will acquire all outstanding shares of CSRA for $41.25 per share in cash, an increase from the prior $40.75 per share offer. The transaction is now valued at $9.7 billion, including the assumption of $2.8 billion in CSRA debt.

COLLABORATIONS

Rohde & Schwarz and **Unigroup Spreadtrum & RDA**, a fabless semiconductor company with advanced technology in mobile communications and IoT, are to establish a joint operator test laboratory in China as part of a memorandum of understanding (MoU) signed at Mobile World Congress 2018 in Barcelona. The two companies will focus on wireless communications and test concepts to better serve their common customers, including the three Chinese network operators and other global operators that Rohde & Schwarz has been serving for many years.

SAT4M2M and **Fujitsu Electronics** are to cooperate on the design, development and production of a new range of IoT low power wide area (LPWA) modules for the booming IoT markets, with communication via satellites. SAT4M2M develops LPWA space-based connectivity to expand the fast growing domains of IoT and benefits from the support of EU, the European Space Agency (ESA), the European Telecommunications Standards Institute (ETSI), DLR (the German Space Agency) and leading industry partners.

Computer Simulation Technology GmbH, part of **SIMULIA**, a Dassault Systèmes brand, and **VPIphotonics** announced their partnership to seamlessly couple full-wave photonic device simulation and overall circuit simulation and analysis of integrated photonic components and subsystems within a single framework. Highly-integrated photonic circuits are on the rise, and this trend is expected to accelerate in the future. The design of complex circuits involves multiple steps, including analysis of the overall circuit simulation and performance, which requires accurate models and realistic characteristics for each embedded element. These circuit elements are typically based on information from Photonics Design Kits (PDK) provided by foundries.

Teledyne Technologies Inc. announced that its subsidiary, **Teledyne DALSA Inc.**, in partnership with **ASML Holding N.V.**, will produce pellicle membranes for use in extreme ultraviolet (EUV) lithography-based semiconductor fabrication. Lithography is a process which patterns the structures on a microchip, and lithography plays an important role in determining how densely chip makers can pack transistors together. As a manu-

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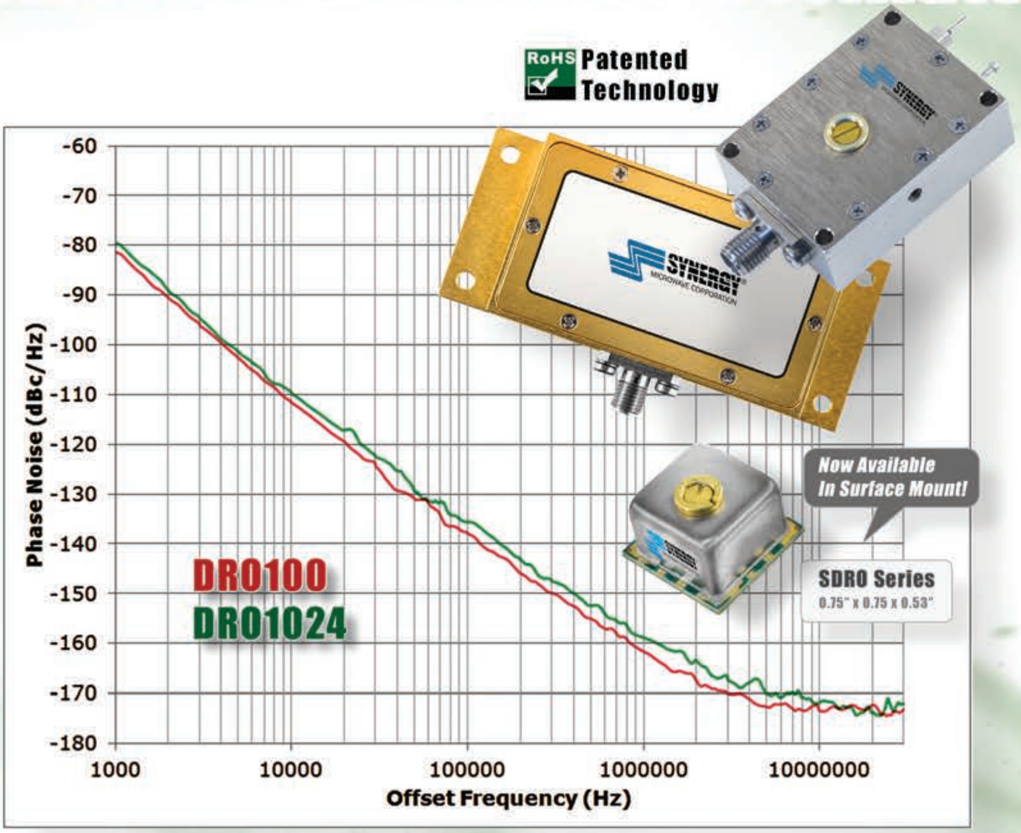

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
SDRO1250-8	12.50	1 - 15	+8 @ 25 mA	-105
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	-109

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facturer of chip-making equipment, ASML has designed the EUV lithography platform as an extendible platform that that will enable the continued progress in microchip manufacturing, delivering chip device cost reductions, power savings and performance improvements well into the next decade.

NEW STARTS

AKON Inc., a supplier of microwave components and integrated microwave assemblies, announced a major addition to the company's website, which is highlighting AKON's new and expanded line of millimeter band components and assemblies, targeted at both the upcoming 5G technology rollout as well as the defense market. AKON products are now available up to 50 GHz. This includes amplifiers, switches, filters, power dividers and frequency multipliers, as well as integrated assemblies such as switched filter banks and frequency converters.

ACHIEVEMENTS

On March 20, 2018 at **EDI CON China 2018**, the conference and exhibition that brings together engineers working on high frequency analog and high speed digital designs, the winners were announced in the EDI CON Innovation Awards. This award program honors products that have had the greatest impact on the industry this year, providing the tools necessary to bring on the next generation of electronic design innovations. Winners were announced by Winson Xing, editor of *Microwave Journal China*, on the exhibit hall floor at EDI CON China at the China National Convention Center in Beijing. Nominations were open to all exhibitors at EDI CON China 2018.

Agile Microwave Technology Inc. has passed the rigorous standards for quality management systems to earn certification to ISO standard ISO 9001:2015, for the design and manufacture of RF and microwave circuits, hybrids, modules, MCMs, multi-function modules and MMIC assemblies, for its new corporate headquarters in the Research Triangle Area at Cary, N.C.

Kymeta announced that the company's KyWay™ satellite terminals are now certified with the world's leading satellite operators, including Intelsat, Telesat, SES and HISPASAT. Antenna certification with these providers means that KyWay terminals successfully connect with the operator's satellite spacecraft and do not cause adjacent satellite interference. Kymeta's satellite terminals operate across a broad range of satellites, and can switch from satellite to satellite, automatically acquiring signals, no matter what operator owns them. The proven ability to establish a link without interference means an entire host of use cases are now possible for fixed and mobile satellite communications.

Triumph Group Inc. announced that its Triumph Fabrications company was recognized with Elite Supplier sta-

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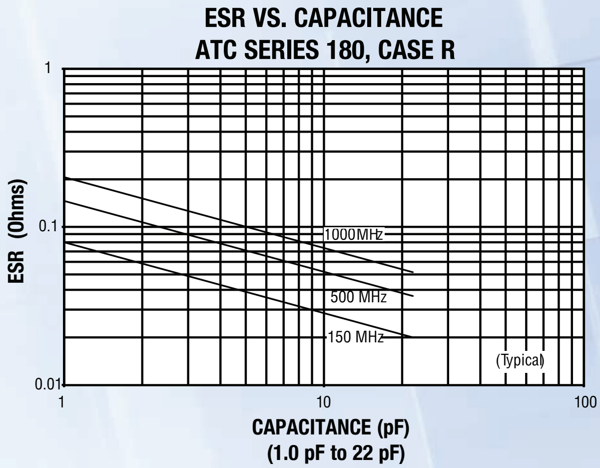
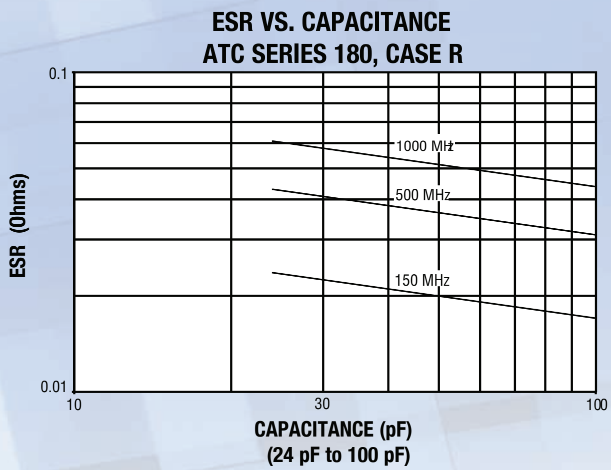
- High Self-Resonance
- Low Noise

Typical Applications:

- RF / Microwave Power Amplifiers
- HDTV Amplifiers
- High Power Filter Networks
- High Power Matching Networks
- Antenna Coupling





Radio tower image courtesy of Tom Rauch, W8JI

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tus by **Lockheed Martin Rotary and Mission Systems** (RMS) for exceptional supplier performance in support of their Sikorsky Aircraft business. Triumph Fabrications, a Triumph Aerospace Structures operating company, produces complex hydroform and stretchform sheet metal components for Sikorsky's UH-60 Black Hawk platform. To attain RMS Elite Supplier status, a company must supply best-in-class performance in quality, delivery, lean and customer satisfaction. This year, Triumph Fabrications achieved a perfect rating of 100 percent in quality, as well as exceptional ratings for on-time delivery, market feedback and performance on Sikorsky's Health Assessment.

A new operational headquarters for the agency that plans, develops, delivers and operates the military's command-and-control capabilities, including defense of secure IT infrastructure in 42 countries, has been honored as among the year's finest engineering projects in Illinois. **The DISA Global Operations Headquarters** at Scott Air Force Base, Ill., includes a secure operations center designed for 24/7 operations and to withstand tornadic winds. The project is winner of a Special Achievement Award from the Illinois chapter of the American Council of Engineering Companies, first in the chapter competition's Building/Technology Systems category.

CONTRACTS

Technica Corp., a provider in high-end systems engineering and operations and maintenance for mission-critical networks and applications, announced that the **U.S. Army's Program Executive Office for Enterprise Information Systems (PEO-EIS)** has selected the company as a provider for the $250 million Army Cloud Computing Enterprise Transformation (ACCENT) Basic Ordering Agreement (BOA). Under ACCENT, Technica will support the Army in transitioning its systems and applications to FedRAMP-certified commercial cloud hosting services or an Army Enterprise Hosting Facility (AEHF). This contract is in direct alignment with the Army's data center consolidation strategy, with goals of a 75 percent reduction by 2025.

BWX Technologies Inc. announced that the **U.S. Naval Nuclear Propulsion Program** has exercised contract options with BWXT subsidiary Nuclear Fuel Services, Inc. (NFS) totaling more than $151 million for fuel manufacture, development activities and decommissioning work in support of the nation's nuclear submarines and aircraft carriers. The contract options were awarded in the fourth quarter of 2017. Work under these contracts has already commenced, and the vast majority of it will be completed during the remainder of 2018. NFS has been the sole manufacturer of nuclear fuel for U.S. Navy aircraft carriers and submarines for decades.

The **U.S. Army** has placed two orders totaling $97 million for **BAE Systems** to provide new night vision goggles and thermal weapon sights, which together

will enable soldiers to rapidly and covertly acquire targets in all weather and lighting conditions. The orders are part of a previously announced five-year contract for the Army's Enhanced Night Vision Goggle III and Family of Weapon Sight-Individual (ENVG III/FWS-I) program. The BAE Systems-developed ENVG III/FWS-I solution features a Rapid Target Acquisition (RTA) Module to greatly reduce target engagement time.

CACI International Inc. announced that it has been awarded an indefinite delivery/indefinite quantity (IDIQ) contract, with a ceiling value of $60 million, to provide advertising and marketing support to the **Army National Guard** (ARNG) **State Media Services Program** (SMSP). This three-year single-award contract represents continuing work in the company's Business Systems market area. The SMSP provides ARNG Retention and Recruitment Commands with access to professional advertising and creative resources to help the ARNG maintain end strength in all 50 states, the District of Columbia and three U.S. territories. Under the contract, CACI will provide ARNG Recruitment and Retention Command with in-depth market research and analysis, digital and traditional advertising strategies, media planning and buying and full-spectrum creative services.

The **Department of the Navy** has awarded **Peraton** a contract to support the efforts of U.S. armed services to detect, locate, remove and secure unexploded ordnance on land and at sea. Peraton will support the Explosive Ordnance Disposal (EOD) Program Management Office. The contract has a ceiling of $40.97 million for one base year and four option years. This is the team's 10th consecutive EOD support contract award since 1983, which covers onsite engineering, logistics and curriculum development and training support services for the Joint EOD Community. The EOD Program Management Office provides the systems, tools and equipment EOD technicians need to locate, identify and neutralize unexploded ground and underwater ordnance, including sea mines, IEDs and other devices.

VSE Corp. was recently awarded a task order under the **U.S. Air Force Contract Field Teams** (CFT) IDIQ contract, supporting the 314th Air Wing at Little Rock Air Force Base in Ark. This task order consists of a one year base period of performance with one one-year option period and an additional six-month option period and total potential value of $28.5 million. Under this task order, VSE will provide organizational maintenance, repair and overhaul services on a fleet of C-130J Super Hercules four-engine turboprop military transport aircraft for the 314th Air Wing at Little Rock Air Force Base.

Mercury Systems Inc. announced it received a $3.1 million order from a manufacturer of commercial space technology solutions for high-reliability RF microelectronics modules designed and screened to space-level performance standards. The order was booked in the company's fiscal 2018 second quarter and is expected to be shipped over the next several quarters. The com-

pany has a 40 year heritage in the design and manufacturing of space-qualified RF and microwave components, modules and highly integrated subsystems for defense prime contractors, government agencies and commercial companies. Mercury's space-qualified RF microelectronics have been successfully deployed in a wide range of applications including satellites, spacecraft and rover vehicles operating on Mars.

Comtech Telecommunications Corp. announced that during its third quarter of fiscal 2018, its Tempe, Arizona-based subsidiary, **Comtech EF Data Corp.**, which is part of Comtech's Commercial Solutions segment, received a $1.6 million order for satellite modems from a major U.S. DoD contractor. The order specified the DMD2050E MIL-STD-188-165A/STANAG 4486 Edition 3 Compliant Universal Satellite Modem, which will be utilized to support the U.S. Army Project Manager Tactical Network. The DMD2050E Satellite Modem is designed to comply with the widest possible range of U.S. government and commercial standards and is compatible with the largest number of satellite modems in the industry.

Leonardo, through its German subsidiary **Selex ES GmbH**, has been awarded a major contract by the **Bureau of Meteorology** to deliver state-of-the-art meteorological radars in Australia. In the long-awaited tender, the Bureau of Meteorology called for quotations for C- and S-Band radar systems and selected Leonardo as the sole supplier of new meteorological radars for the coming years. The deed of supply has an initial term of four years and includes the option to be extended to up to 10 years. The Bureau of Meteorology currently operates 62 meteorological radars in its country-wide network.

PEOPLE

▲ *Tim Filteau*

SemiGen Inc., an ISO and ITAR registered RF/microwave assembly, automated PCB manufacturing and RF supply center, announced the hire of new president, **Tim Filteau**. Filteau is an experienced leader who has held executive-level operational positions at RF, semiconductor and integrated products companies including MACOM, Cobham PLC and Aeroflex Metelics. This announcement comes soon after SemiGen's purchase and expansion into a new 43,000 square foot fabrication facility, formerly the Micrometrics/Aeroflex-Metelics facility, in Londonderry, N.H.

REP APPOINTMENTS

Antenna Systems Solutions S.L. (Celestia Technologies Group), a supplier of antenna measurement systems to the worldwide satellite, defence, wireless and government markets, announced that it has appointed **Flexitron** as its distributor for Sweden and Norway.

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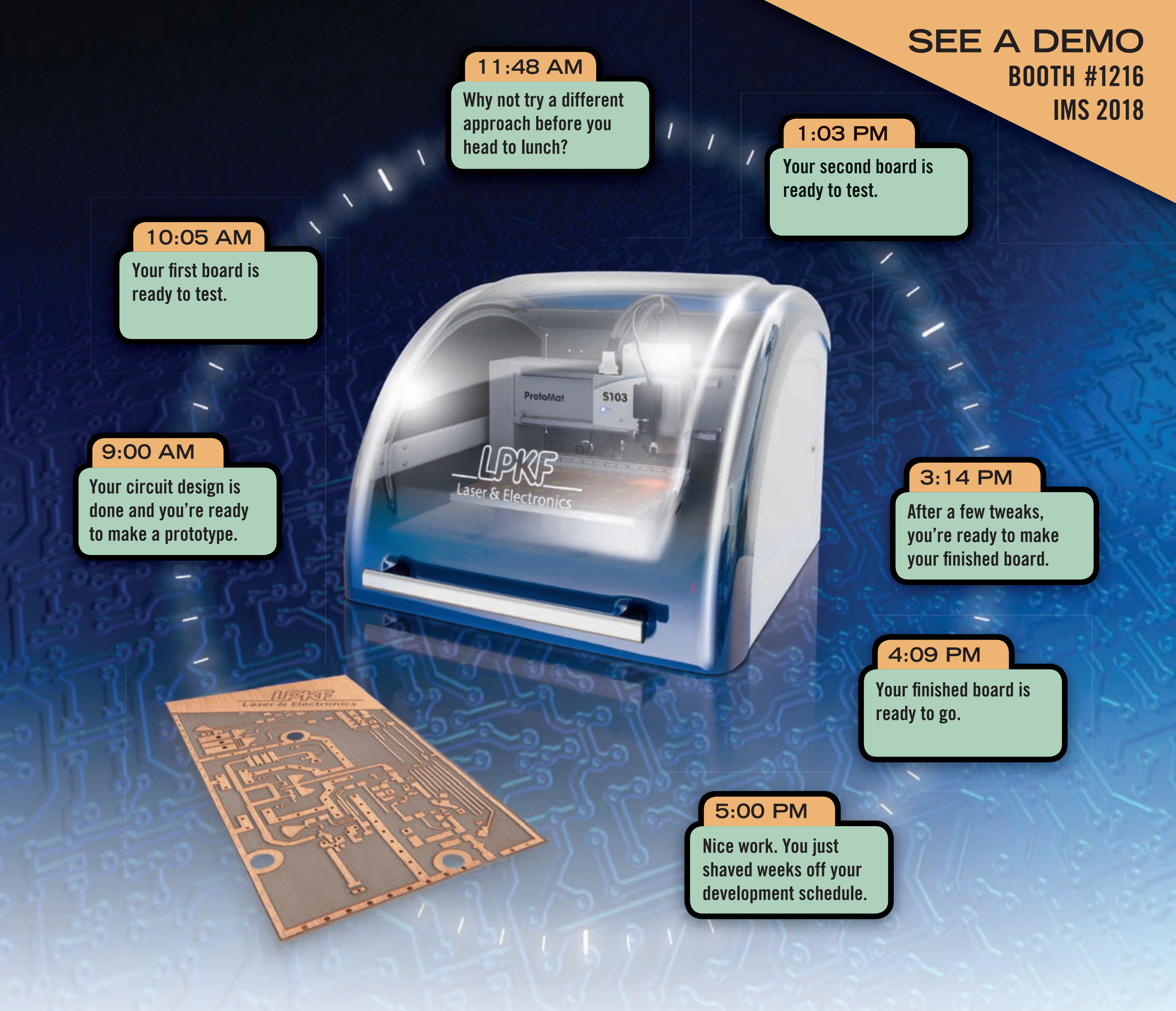
Around the Circuit

Piconics Inc. announced the appointment of **dBm Technical Sales** as its exclusive sales representative for all six New England states. Established in 1963, Piconics is a manufacturer of high quality micro-electronic inductors including broadband conicals, RF and microwave air coils, fixed, tunable and spiral inductors. Founded in 1992, dBm is a team of experienced and dedicated engineers specializing in RF, microwave and fiber optic technologies. Together, Piconics and dBm will bring high quality inductor solutions with unparalleled customer service to the New England market.

Richardson Electronics Ltd. announced a new global distribution agreement with **3Rwave Co. Ltd.**, a manufacturer specializing in microwave ferrite devices including isolators and circulators with frequency ranges up to 40 GHz and 20 kW. Effective January 9, 2018, the agreement aligns with both companies' commitment to partnering with customers by providing the quality and volume to meet their needs.

PLACES

Wurth Electronics Australia Pty was officially opened in Footscray, West Melbourne on February 2, 2018. The change of the company name for the Australian sales office of Würth Elektronik eiSos is the result of the great successes on the Australian continent that the company has achieved since 2011. On the occasion of the opening ceremony, the team, currently comprised of eight staffers, received a visit from Alexander Gerfer, CTO of the Würth Elektronik eiSos Group. The manufacturer of electronic and electromechanical components started in Australia in 2011 with one sales employee.



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50 to 75 GHz, Full V-Band Magic Tee for Test Set Ups and Instrumentation
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50 to 75 GHz, Full V-Band Directional Coupler for Test Set Ups and Instrumentation
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Design of Broadband High Efficiency Power Amplifiers Based on Series Continuous Modes

Qirong Li, Songbai He, Zhijiang Dai and Weimin Shi
University of Electronic Science and Technology of China, Chengdu, China

A series of continuous modes for designing broadband high efficiency power amplifiers (PA) is described and a broadband PA based on this theory is realized. A new theoretical formulation is presented by shaping the drain voltage and current waveforms. In comparison to the classical series of continuous modes, wider design space is obtained, which is benefit for broadband matching network design. To verify this theory, a high efficiency PA is designed, built and tested. Measurement results verify that the objective performance is obtained, while fundamental and harmonics impedances are in good agreement with theory. The fabricated PA delivers 10.9 to 19.5 W saturation output power with a drain efficiency (DE) of 69.5 to 77.9 percent from 2.3 to 3.8 GHz. Gain is 9.8 to 12.3 dB with output power of 40.4 to 42.9 dBm.

PA designers seek broadband performance with high efficiency. Harmonic-tuned PA modes, such as class J and F, have become the primary candidates for obtaining high efficiency.[1] Although these PAs mode can operate with efficiencies higher than 78.5 percent, they are limited to narrow bandwidths due to the requirement for accurate harmonic terminations. To broaden operating bandwidths and simplify matching network design, advanced PAs modes, known as class B to class J continuous[2] and the family of continuous class F,[3] have been proposed. With multiple impedances distributed over the desired bandwidth dynamically, these extended harmonic-tuned PA modes achieve the desired efficiency and output power. Based on these modes, there are various ways to obtain wideband operation.[4-6]

These continuous PA modes, however, simply expand the reactive part of the optimal impedance solution; therefore, the optimal impedance can only change on the constant resistance circle of the Smith chart. Just like the continuous class F mode, pure reactive second harmonic impedances are still required.

The series continuous modes (SCM) concept was presented by Chen et al. in 2014.[7] By combining continuous modes, new modes provide the possibility of realizing a high efficiency broadband PA. The real part of the optimal fundamental impedances ($Z_{(1f,re)}$) can vary from 1 to 1.154, providing greater design freedom.

In this article, new theoretical formulations based on the continuous class F mode and SCMs are presented by shaping the voltage and current waveforms. Compared to SCMs, the real part of novel series continuous modes (NSCM) can vary over a wider range, which significantly relieves the difficulty in broadband matching network design.

NOVEL SERIES CONTINUOUS MODES

Review of the Continuous Class F Mode

From the class F mode, the required unified drain voltage waveforms are defined in Equation 1. In order to sustain a positive voltage, empirical parameter γ is in the range of -1 and 1. The ideal normalized half-rectified drain current waveform[3, 7] is shown in Equation 2.

$$V_{ds} = \left(1 - \frac{2}{\sqrt{3}}\cos\theta\right)^2 \left(1 + \frac{1}{\sqrt{3}}\cos\theta\right)\left(1 - \gamma\sin\theta\right), \quad -1 \le \gamma \le 1 \qquad (1)$$

$$I_{ds} = \frac{1}{\pi} + \frac{1}{2}\cos\theta + \frac{2}{3\pi}\cos 2\theta - \frac{2}{15\pi}\cos 4\theta + K\,K \qquad (2)$$

A DE of 90.7 percent can be maintained while delivering maximum power and optimal impedances can vary on the Smith chart, but with a constant real part.

Review of the SCMs

By combining the continuous class B/J mode, the continuous class F mode and the other continuous modes, the normalized voltage formulation[3,7] is defined by Equation 3 with the same ideal normalized half-rectified drain current waveforms as in Equation 2, formed by the class B bias condition.

$$V_{ds} + \left(1 - \alpha\cos\theta + \beta\cos 3\theta\right)\left(1 - \gamma\sin\theta\right), \quad -1 \le \gamma \le 1 \qquad (3)$$

To keep V_{ds} positive, the relationship between α and β is shown in Equation 4.

$$\alpha - \beta = 1 \qquad \text{for } \alpha \le \frac{9}{8} \qquad (4)$$

$$\alpha\left[\left(\frac{2}{3} + \frac{2\beta}{\alpha}\right)\sqrt{\frac{1}{4} + \frac{\alpha}{12\beta}}\right] = 1 \qquad \text{for } \frac{9}{8} < \alpha \le \frac{2}{\sqrt{3}}$$

The theoretical DE varies from 78.5 percent (the continuous class B/J mode) to 90.7 percent (the continuous class F mode). The real part of the normalized fundamental optimal impedance varies from 1 to 1.154 ($1 \le \alpha \le 2/\sqrt{3}$), which is good for realizing wideband operation.

Novel Series Continuous Modes

Starting from the continuous class F mode, the continuous class F^{-1} mode is obtained by shaping the current waveforms while maintaining a constant voltage waveform. This expands the design space. Then, by multiplying the factor $(1 - \gamma\sin\theta)$ with the drain voltage waveform, SCMs offer increasing flexibility. Evolving from the continuous class F mode and SCMs, the NSCMs perform shaping of the voltage waveform and the current waveform simultaneously as described by Equations 5 and 6.

$$V_{ds} + \left(1 - \frac{2}{\sqrt{3}}\cos\theta\right)^2 \left(1 + \frac{1}{\sqrt{3}}\cos\theta\right)\left(1 - \gamma\sin\theta\right), \quad -1 \le \gamma \le 1 \qquad (5)$$

$$I_{ds} = 1 + \alpha\cos\theta + \beta\cos 2\theta \qquad (6)$$

To work successfully, it is worth noting that non-zero crossing voltage and current waveforms are essential. So the γ parameter varies from -1 to 1, and the relationship between the α and β is as follows:

$$\alpha - \beta = 1 \qquad \text{for } \alpha \le \frac{4}{3} \qquad (7a)$$

$$\frac{\alpha^2}{8\beta} + \beta = 1 \qquad \text{for } \frac{4}{3} < \alpha \le \sqrt{2} \qquad (7b)$$

The various combinations of α and β map to different continuous modes. When $\alpha = \sqrt{2}$ and $\beta = 1/2$, the quasi-continuous class F^{-1} mode is obtained. When α =

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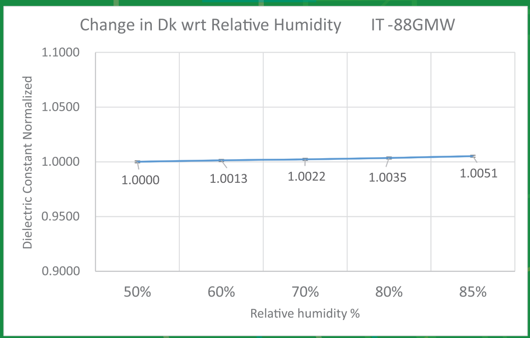

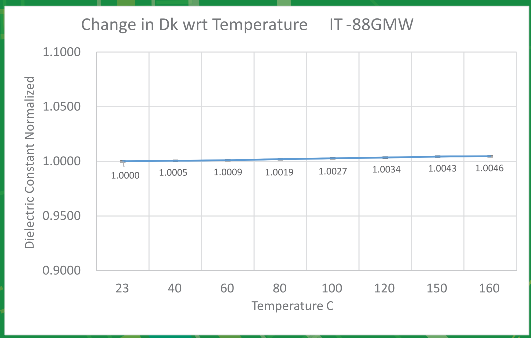

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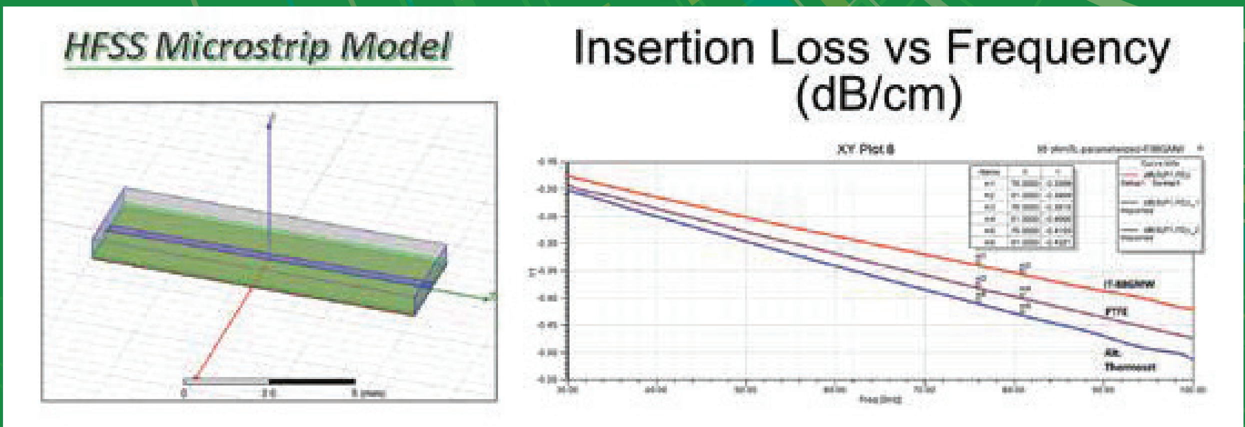

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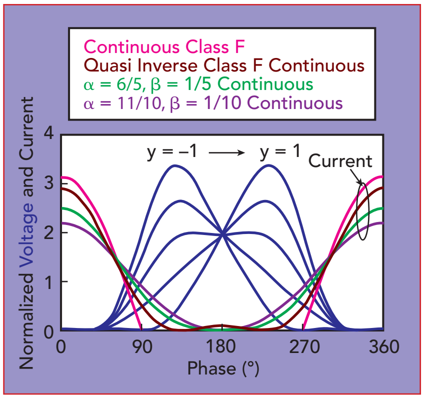
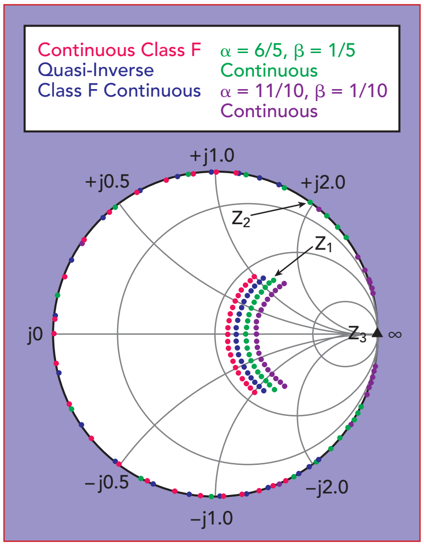


▲ Fig. 1 Normalized drain voltage and current of the novel series continuous modes.



▲ Fig. 2 Impedance design space.

5/4 and β = 1/4, another continuous mode is achieved. The voltage and current waveform of α = 11/10 and β = 1/10 corresponds to another new continuous mode as well. The voltage and current waveforms when α = 11/10, 5/4 and √2 are depicted in ***Figure 1***. The current waveform of continuous class F is also plotted in Figure 1 for comparison.

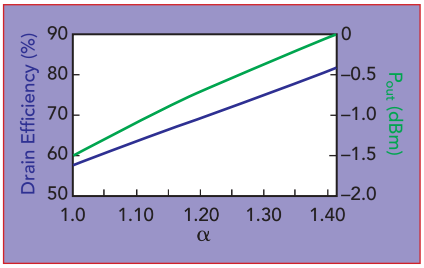
The fundamental and harmonic optimal impedances, normalized to R_{opt}, are given in Equation 8. $R_{opt} = 2\cdot(V_{ds} - V_{knee})/I_{peak}$ is the optimal fundamental impedance for class B operation, corresponding to all harmonics short circuited.

$$Z_1 = \frac{\pi}{\sqrt{3}\alpha} + j\frac{\pi\gamma}{2\alpha} \quad (8a)$$

$$Z_2 = -j\frac{\pi}{2\sqrt{3}\beta}\left(\gamma + \frac{1}{6}\right) \quad (8b)$$

$$Z_3 = \infty \quad (8c)$$

This novel design concept provides more abundant optimal impedances solutions. The parameter α varies from 1 to √2, and the corresponding normalized real part of the fundamental optimal impedance ($Z_{(1f,re)}$) varies from 1.28 to 1.81. ***Figure 2*** shows optimal fundamental and harmonic impedances of the NSCMs when α = 11/10, 5/4 and √2. The quasi-continuous class F^{-1} mode corresponds to $Z_{(1f,re)}$ = 1.28. The optimal impedances of the continuous class F mode are also shown in the Figure 2 (the red dot area where $Z_{(1f,re)}$ = 1.154). The design space between the quasi-class F^{-1} continuous mode and the standard continuous class F mode is the space where high order current elements need to exist for positive current waveforms.



▲ Fig. 3 Theoretical normalized output power and drain efficiency.

From Equations 5 and 6, the power at dc (P_{dc}), fundamental RF (P_{RF}) and the DE η are computed:

$$P_{dc} = \frac{1}{\pi} V_{ds} I_{peak} \quad (9a)$$

$$P_{RF} = \frac{\alpha}{\sqrt{3}\pi} V_{ds} I_{peak} \quad (9b)$$

$$\eta = \frac{\alpha}{\sqrt{3}} \quad (9c)$$

DE and output power normalized to the continuous class F mode are illustrated in ***Figure 3***. The DE of the NSCMs ranges from 57.7 to 81.6 percent when α changes from 1 to √2. When α = √2, the DE of the quasi-continuous class F^{-1} is 81.8 percent which is same as the DE of the typical continuous class F^{-1} mode. Compared to the quasi-

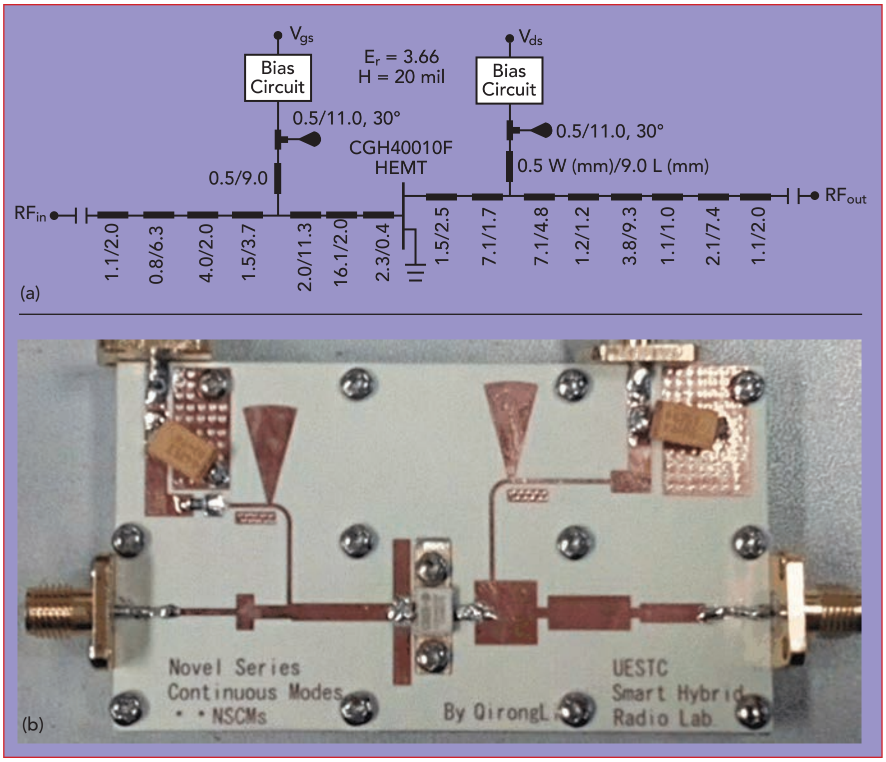


Fig. 4 PA matching network (a) and fabricated amplifier (b).

class F^{-1} continuous mode, output power of the NSCMs declines by about 0 to 1.5 dB, but good performances is still achieved.

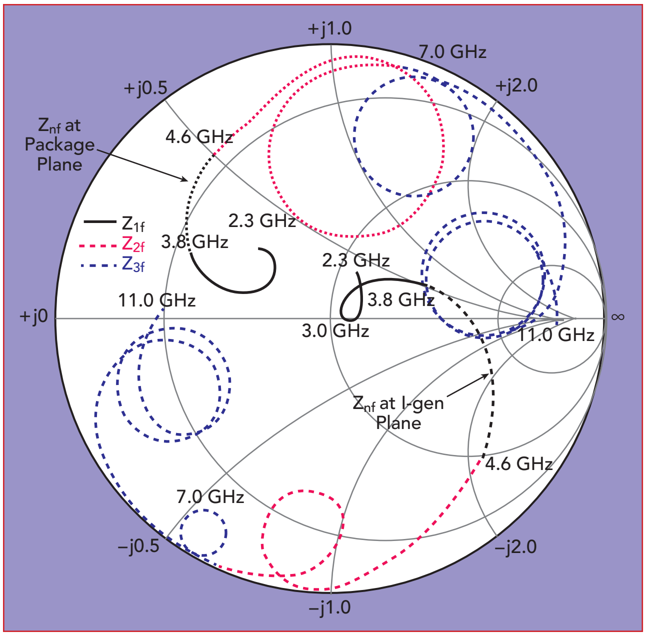
From Figures 2 and 3, it is clear that the design space of the NSCMs covers a wider area where $Z(_{1f,re})$ is between 1.28 and 1.81 and α is between 1 and $\sqrt{2}$. This offers significantly more design freedom compared to traditional continuous modes. For example, if a DE above 70 percent is desired, an α parameter greater than 6/5 is chosen; for a DE above 60 percent, an α parameter greater than 1.04 is used.

BROADBAND HIGH EFFICIENCY PA DESIGN BASED IN NSCMS

A broadband (2.3 to 3.8 GHz) high efficiency PA employing a 10 W Cree (Wolfspeed) GaN HEMT device (CGH40010F) is designed to experimentally verify the design concept. From the last section, we know that when $\alpha > 6/5$, a 70 percent DE can be sustained. An approximate CGH40010F large-signal package model from Chen et al.[6] is employed together with an output matching network (OMN) to achieve optimal impedance matching.

When exploiting the nonlinear device capacitance, it can dominate the third harmonic band response;[5] so, in the OMN design, emphasis is placed on fundamental and second harmonic matching while keeping third harmonic impedances in the high efficiency region. Real frequency technology[8] and stepped-impedance filter matching are the most common methods used in the matching network design. A stepped-impedance microstrip-line filter network is utilized in this work.

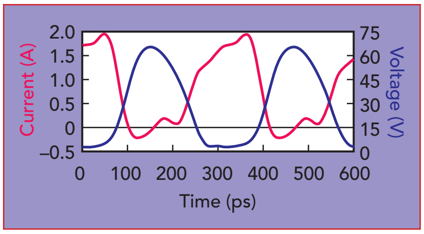
Figure 4a shows the final matching network with dimensions. A photo of the fabricated PA circuit implemented on a Rogers 4350B PCB with H = 20 mils is shown in ***Figure 4b***. With the approximate package model of the device and the final OMN, we obtain the impedance trajectories normalized to R_{opt} at the package plane and current generator (I-gen) plane, as shown in ***Figure 5***. It is clear that the impedances at the I-gen plane lie within the predicted region.



▲ **Fig. 5** Impedance trajectories of the output matching network at the package and I-gen planes.

The measured results, including output power, DE and power-added efficiency (PAE), are shown in ***Figure 7***. Simulation results are given for comparison.

From the simulated results, we can see that the DE from 2.3 to 3.8 GHz is from 71 to 75.8 percent with a PAE of 65 to 74 percent, and the gain is from 10.2 to 12.6 dB over the entire bandwidth. The output power ranges from 40.2 to 42.6 dBm.



▲ **Fig. 6** Simulated 3.5 GHz voltage and current waveforms at the I-gen plane.

The de-embedded simulated intrinsic drain voltage and current, when the PA is biased at V_{ds} = 28 V and V_{gs} = -2.8 V at 3.2 GHz, is shown in ***Figure 6***. The half-sinusoidal voltage and quasi-half sinusoidal current waveforms corresponding approximately to the waveforms in Figure 1 are obtained.

EXPERIMENTAL RESULTS

The PA is measured under the stimulus of a single-tone continuous waveform signal swept from 2.3 to 3.8 GHz in 0.1 GHz steps.

From the measured results, a DE of 69.5 to 77.9 percent with a PAE of 63.5 to 73.4 percent is achieved in the band of 2.3 to 3.8 GHz. Across the band, the measured gain and P_{out} are 9.8 to 12.3 dB and 40.4 to 42.9 dBm respectively. Measurement agrees well with simulation.

A performance comparison of this PA with other state-of-the-art continuous PAs is summarized in ***Table 1***. The modified FE[6] and ITRS PA FoM[9] are used to evaluate PA performance and provide a complete comparison with previously published work. FE denotes the frequency-weighted average efficiency. The ITRS PA FoM includes both output power and gain in addition to the DE and frequency. Considering these measures, the NSCM provides excellent performance.

CONCLUSION

Emerging from the classical continuous class F mode and SCMs, the NSCMs are obtained by shaping drain voltage and current waveforms simultaneously. These modes enable expansion of the real part of optimal impedances solutions, providing greater design flexibility for improved performance.■

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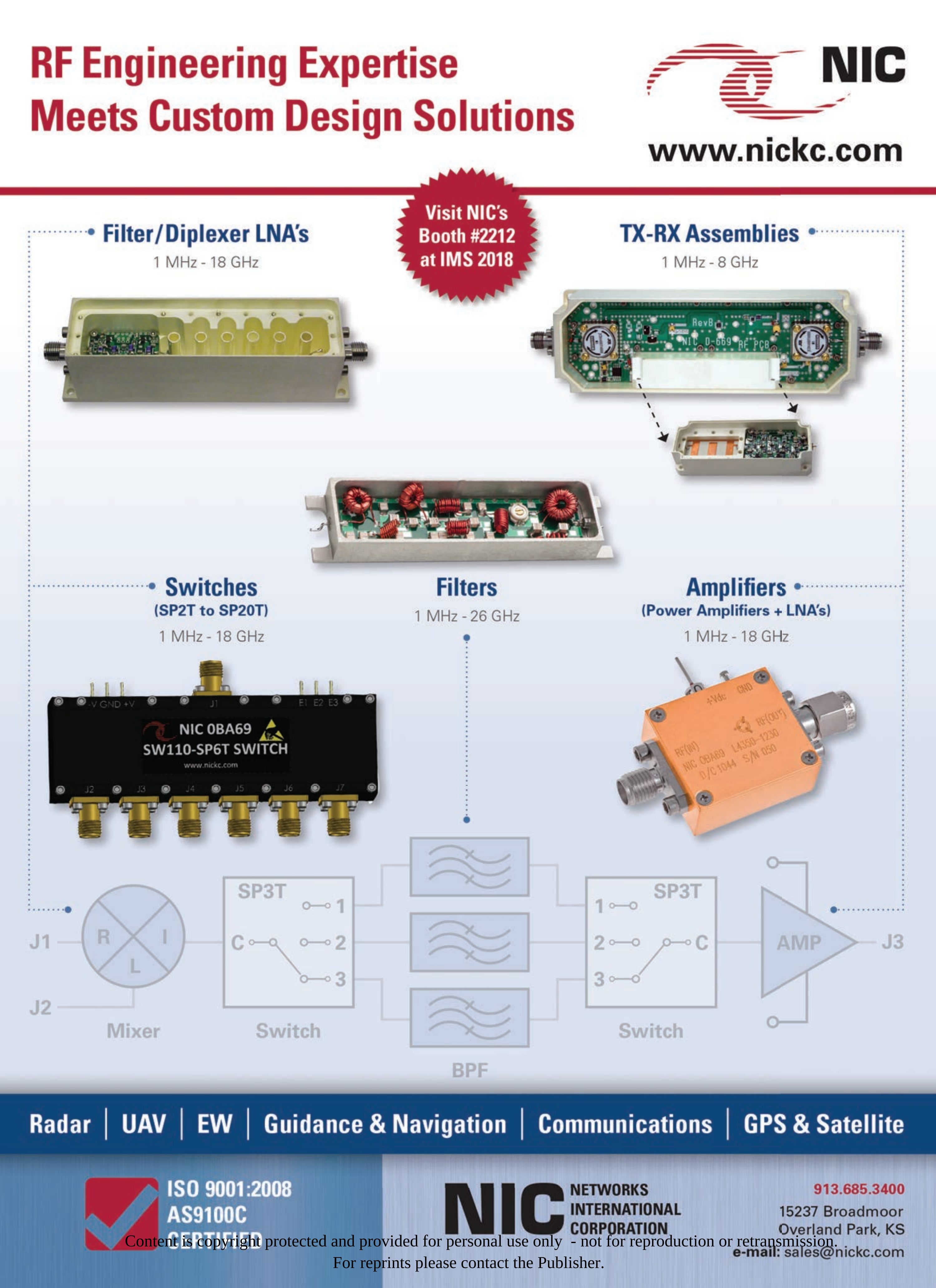

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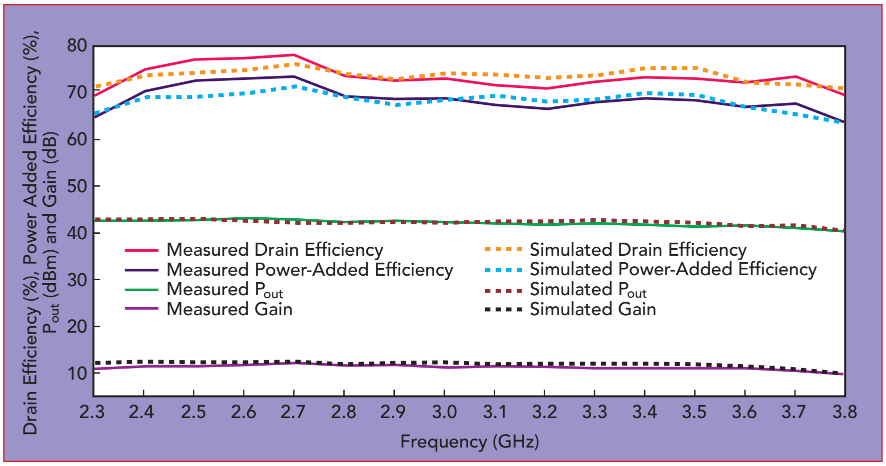

Fig. 7 Measured and simulated drain efficiency, power-added efficiency, gain and output power of the broadband PA.

TABLE 1

PERFORMANCE OF STATE-OF-THE-ART BROADBAND PAs

Reference	Bandwidth (GHz)	Output Power (W)	Drain Efficiency (AE) (%)	Gain (dB)	FE	FOM	Design Type
4	1.5 to 2.5	9 to 11.5	60 to 70 (65)	10.2 to 12.2	77.3	298.5	Class J
5	1.45 to 2.45	11 to 16.8	70 to 81 (75.5)	10 to 12.6	89.2	462.6	CF
6	1.3 to 3.3	10 to 15	60 to 83 (72.7)	10 to 13	89.5	552.8	CF/ CF^{-1}
7	1.6 to 2.7	10.2 to 17.8	70.3 to 81.9 (76.4)	11.9 to 15.2	92.5	669.9	SCMs
This Work	2.3 to 3.8	10.9 to 19.5	69.5 to 77.9 (72.1)	9.8 to 12.3	95.3	1126.5	NSCMs

Notes:
FE = AE*$f_c^{0.25}$, where AE = Average Drain Efficiency and f_c = Center Frequency
FoM = f_c^2*AE*AP*AG, where AP = Average Output Power and AG = Average Gain

CF = Continuous F
CF^{-1} = Continuous F^{-1}
SCMs = Series of Continuous Modes
NSCMs = Novel Series of Continuous Modes

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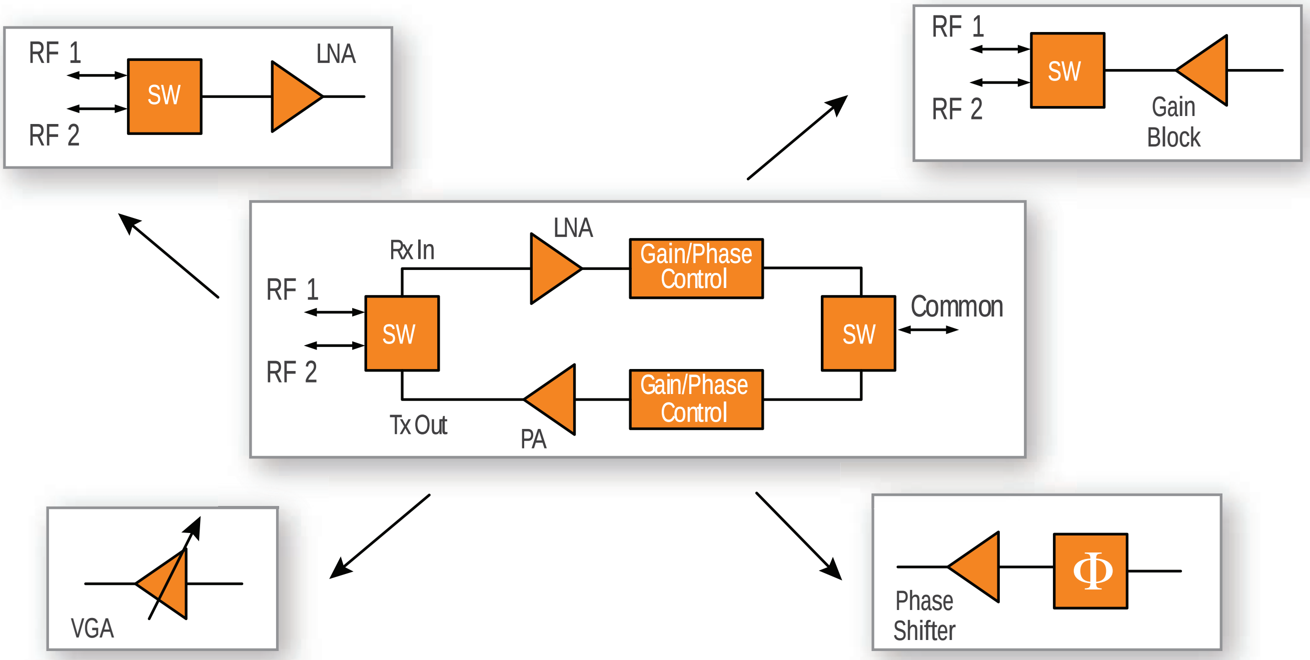

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			AWMF-0157	5G Tx/Rx Quad Core IC
	39 GHz	Silicon Core IC	AWMF-0123	5G Rx Quad Core IC
			AWMF-0125	5G Tx Quad Core IC
			AWMF-0156	5G Tx/Rx Quad Core IC
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			AWS-0103	Dual Beam High IIP3 Tx/Rx Quad Core IC
			AWS-0104	Single Beam Low NF Tx/Rx Quad Core IC
			AWS-0105	Single Beam High IIP3 Tx/Rx Quad Core IC
		RF Front End IC	AWMF-0106	Medium Power Front End MMIC
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			AWMF-0112	8-element Rx Quad Core IC
	Ka-Band	Silicon Core IC	AWMF-0109	4-element Dual Pol Tx Quad Core IC
			AWMF-0113	8-element Tx Quad Core IC
		PA IC	AWP1102	3W High Power Amplifier MMIC
Multi-Market	Ku-Band	Silicon Core IC	AWMF-0117	Single Channel Multi-Function Tx/Rx Core IC
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A Compact Microstrip Lowpass Filter with Harmonic Suppression

Chun-Ping Ge and Yong-Qin Liu
Weinan Normal University, Weinan, China

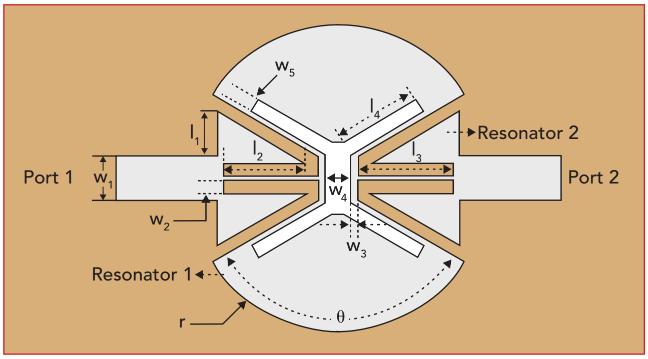
Yan Dou
Weinan Normal University, Weinan, China and University of Electronic Science and Technology of China, Chengdu, China

A compact microstrip lowpass filter with harmonic suppression exhibits ultra-wideband rejection. It is based on triangular patch resonators and a butterfly patch resonator with two 120 degree radial "wing" patches. A filter of this design with a 3 dB cutoff frequency at 1.78 GHz achieves a harmonic suppression bandwidth of 158 percent, enabling it to suppress the twelfth harmonic response. Its small size of 14.5 mm × 18 mm corresponds to 0.133 λg × 0.165 λg, where λg is the guided wavelength at 1.78 GHz.

Planar lowpass filters with compact size and high performance are frequently required in microwave communication systems to suppress harmonics and spurious signals. Conventional design methods utilize high and low impedance lines with shunt stubs and semi-lumped elements. These methods, however, yield low stopband rejection and relatively flat roll-off characteristics while large in size.[1-2]

Techniques to reduce size and enhance performance have been widely studied in recent years.[3-7] Li et al.[3] cascaded multiple stepped-impedance hairpin resonators to realize a sharp roll-off and wide stopband suppression, at the cost of large size and high passband loss. Hayati and Lotfi[4] cascaded multiple, semi-circular and semi-ellipsoid patch resonators to achieve wide stopband suppression, but faced a tradeoff between size and performance. To further improve stopband performance, Ma et al.[5] proposed a lowpass filter of cascaded LC resonant structures and transformed radial stubs, but this resulted in large circuit size and increased design complexity. Ma and Yeo[6] replaced conventional low impedance stubs with radial stubs to realize wide stopband rejection, but roll-off performance was not ideal and stopband bandwidth could be improved. Defected ground structures and multilayer techniques have also been used,[7] at the price of increased design complexity.

In this article, a microstrip lowpass filter with compact size and harmonic suppression is described. Both triangular patch and



▲ Fig. 1 Microstrip lowpass filter structure.

butterfly patch resonators are used in the design to achieve compact size and ultra-wideband rejection. Meander transmission lines are also employed to further reduce size. The resulting filter exhibits a harmonic suppression band from 2.83 to 21.6 GHz with better than 15 dB suppression, less than 0.3 dB passband insertion loss and a compact size of 0.133 λg × 0.165 λg, where λg is the guided wavelength at 1.78 GHz.

FILTER DESIGN

Figure 1 shows the filter layout. It consists of high and low impedance microstrip main transmission lines and two types of resonators. Resonator 1 is composed of a high impedance transmission line and a butterfly patch connected in series. Resonator 2 is a triangular patch. To illustrate the design theory, the frequency responses of the two resonators are discussed individually. ***Figure 2a*** shows the simulated frequency response of the lowpass filter with resonator 1, only. With the exception of a parasitic response in a narrow band around 7.5 GHz, the filter has wide harmonic suppression characteristics. To eliminate this parasitic passband a triangular patch resonator is introduced. As shown in ***Figure 2b***, the simulated frequency response of the lowpass filter with resonator 2 has a wide stopband response. It has one transmission zero in the vicinity of 7.5 GHz, which can be adjusted by controlling the size of the structure. Both resonators are used to achieve wide stopband performance, shown in ***Figure 2c***, which shows the lowpass filter response of resonators 1 and 2.

The microstrip filter (see ***Figure 3***) was fabricated on an RT/Duroid 5880 substrate with a dielectric con-

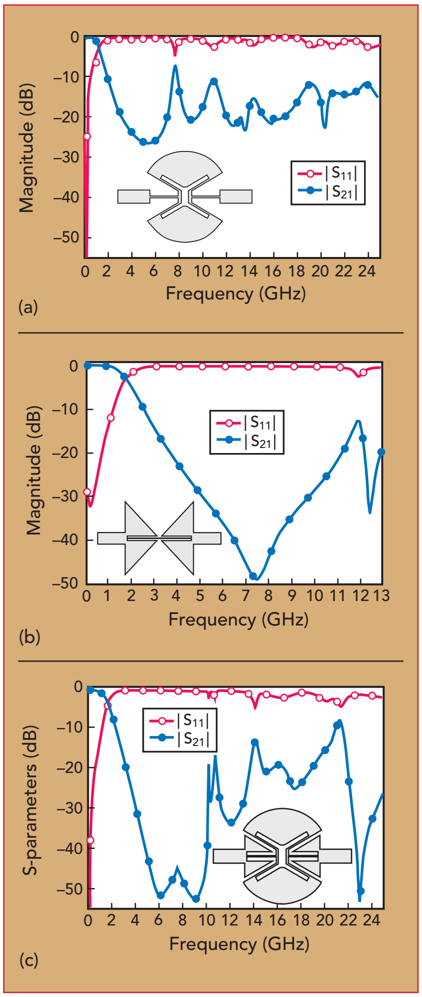
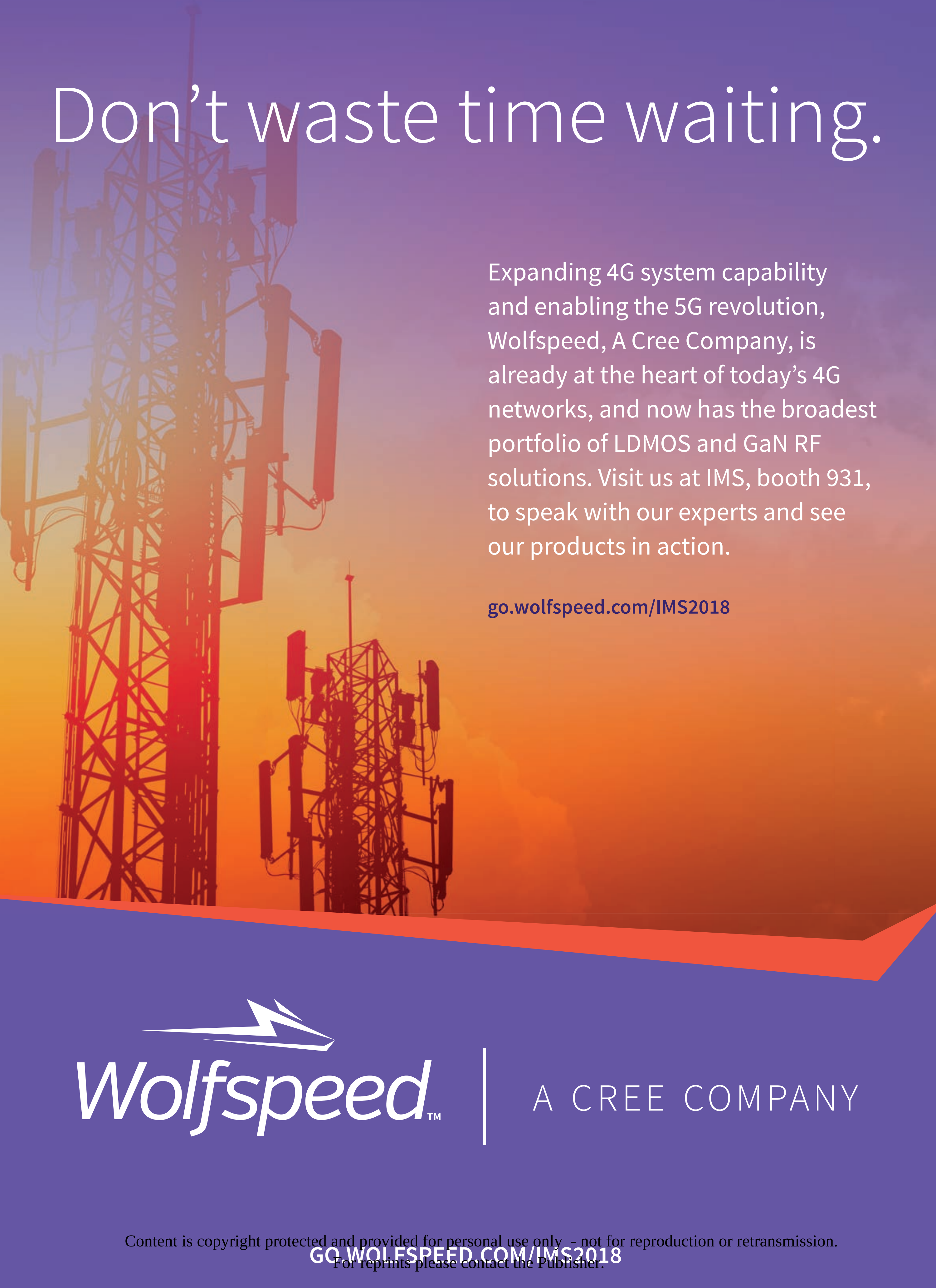


Fig. 2 Simulated lowpass filter response with only resonator 1 (a), only resonator 2 (b) and both resonators 1 and 2 (c).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stant of 3.38, thickness of 0.813 mm and loss tangent of 0.0027. The dimensions (shown in Figure 1) are: l_1 = 2.4 mm, w_1 = 2.6 mm, w_2 = 0.4 mm, w_3 = 0.5 mm, w_4 = 1.5 mm, w_5 = 0.5 mm, l_2 = 5.1 mm, l_3 = 5.6 mm, l_4 = 3.9 mm, r = 8.5 mm and θ = 120 degrees.

SIMULATION AND MEASUREMENT

The filter's performance was measured with a Keysight N5244A vector network analyzer. The measured and simulated responses, shown in ***Figure 4***, are in good agreement. The measured 3 dB cutoff frequency is 1.78 GHz (see ***Figure 5***). The filter suppresses up to the twelfth harmonic, as spurious frequencies are suppressed greater than 17 dB from 2.37 to 18.20 GHz. For comparison, ***Table 1*** summarizes the performance of this and several other previously published lowpass filter designs.

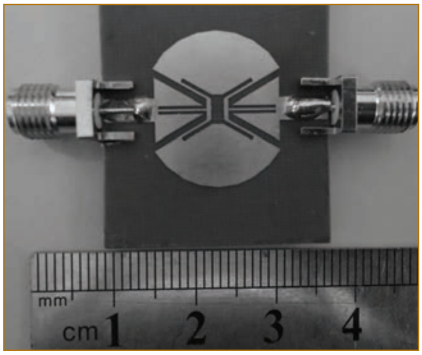

Fig. 3 Fabricated microstrip lowpass filter.

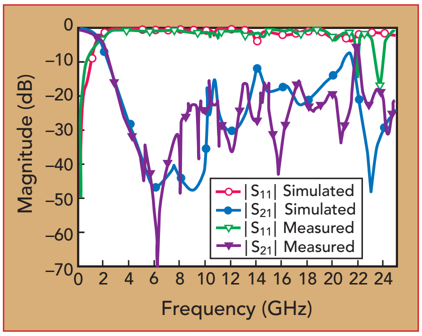

Fig. 4 Simulated vs. measured lowpass filter performance.

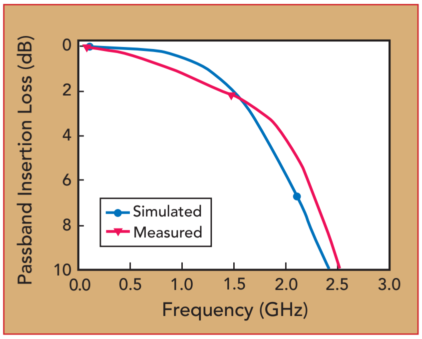

Fig. 5 Simulated vs. measured passband insertion loss.

TABLE 1

FILTER COMPARISON

Ref.	Circuit Size (λg)	Maximum Passband Insertion Loss (dB)	Harmonic Suppression
2	0.08 × 0.08	0.5	9th
3	0.11 × 0.36	1.0	10th
4	0.23 × 0.31	0.3	6th
5	0.15 × 0.40	0.4	7th
6	0.24 × 0.31	1.5	13th
8	0.07 × 0.12	0.3	11th
This Work	**0.13 × 0.17**	**0.3**	**12th**

SUMMARY

A microstrip lowpass filter with a cutoff frequency of 1.78 GHz and good harmonic suppression was designed, fabricated and measured. The demonstrated filter achieved very good performance: low insertion loss in the passband and compact size. The filter design has a very wide stopband, able to suppress the twelfth harmonic. With this performance, the proposed structure has potential applications in modern communication systems.■

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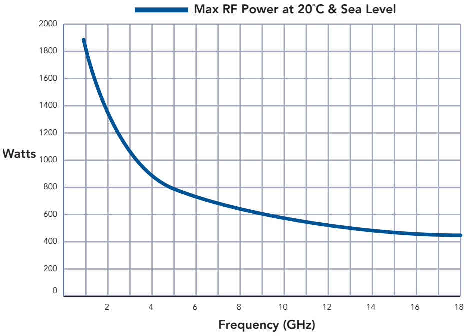
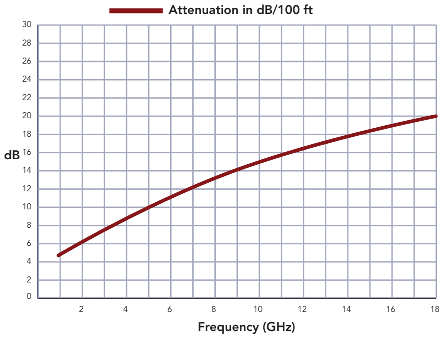


Attenuation in dB/100 ft



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UWB 16-Way Hybrid Coaxial/Ring Cavity Power Divider with Low Insertion Loss

Yu Zhu, Kaijun Song, Shunyong Hu and Yong Fan
University of Electronic Science and Technology of China, Chengdu

An ultra-wideband (UWB) 16-way ring cavity power divider uses a symmetrically coaxial taper. To extend its operating bandwidth, stepped-impedance matching is employed. Measured return loss is better than 10.8 dB from 5.8 to 18.4 GHz. Average insertion loss is about 12.5 dB, including the 12 dB divider loss. Amplitude and phase imbalances are approximately ±0.7 dB and ±7 degrees, respectively, across the entire operating frequency range.

To address the rapidly developing demands of RF/microwave industrial and military applications, UWB radiating systems are attracting industry attention. In all radar and communications systems, the output power of the transmitter is a major determinant of operating range. To achieve higher output power over wide bandwidths, various multi-way power combiners/dividers have been described.[1-20] These include substrate integrated waveguide power dividers,[1] rectangular waveguide power dividers,[3-5] radial waveguide power dividers,[6-7] conical power dividers[8-9] and coaxial waveguide power dividers.[10-12] With an increasing number of ports, the radius of a radial waveguide[6-7,13] or a conical line[8] increases. This introduces higher-order modes that cannot be effectively suppressed. Bandwidth and insertion loss are also important considerations as the structure becomes larger and more complex.

In this article, a UWB 16-way ring cavity power divider, also suitable as a power combiner, is described. It consists of a coaxial taper transition, an oversized coaxial waveguide with a stepped inner conductor and a ring cavity with 16 coaxial probes. A coaxial taper feed port provides uniform excitation[12] for excellent amplitude and phase balance. Measurements agree closely with

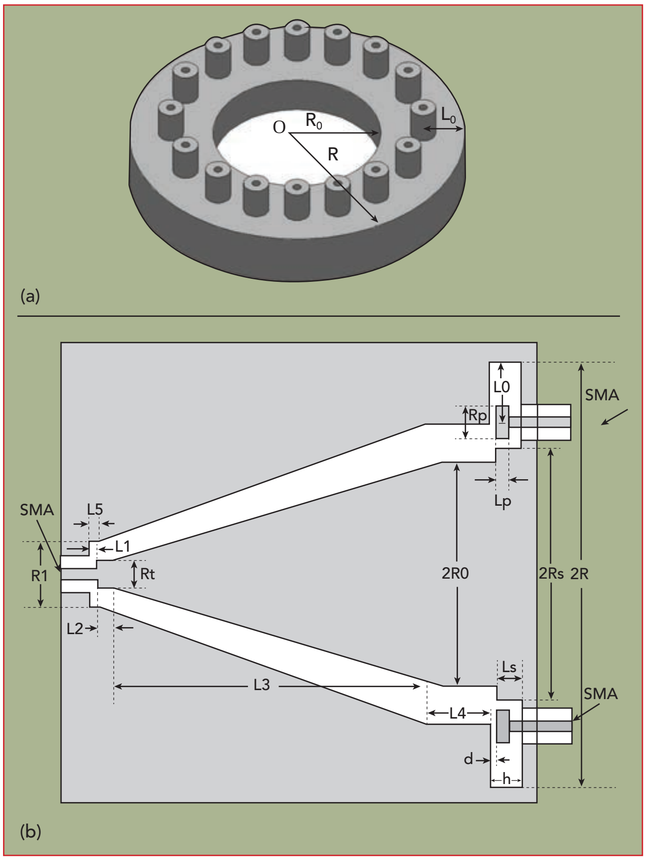

Fig. 1 16-way ring cavity power divider: ring cavities with output ports (a) and power divider (b).


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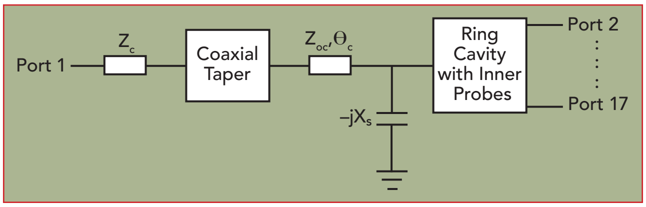


Fig. 2 Power divider equivalent circuit.

simulation. Such a structure can be extended to large numbers of power-dividing ports.

POWER DIVIDER DESIGN

Figure 1 shows the hybrid, coaxial/ring cavity, 16-way power combiner/divider terminated by SMA connectors (coaxial ports). The input signal is fed to the left input connector and then divided into 16 equal output signals, where each output connector is fed in parallel from an oversized coaxial waveguide. A coaxial taper feed port provides axially symmetric electromagnetic field excitation for the ring cavity power divider and maintains good output port amplitude and phase balance. It also provides good impedance matching to the input port to the ring cavity. A stepped inner conductor further improves wideband impedance matching. In general, to provide proper impedance matching, the length of each coaxial probe should be about λg/4, where λg is the waveguide wavelength at the center frequency; however, the length of the capacitively-loaded coaxial probe is less than λg/4.[12]

As shown in Figure 1, the length of L_0 is maintained at about λg/4 to make the outer side of the ring cavity the short wall. When the number of ports increases, the radii R and R_0 increase, but the width of the ring cavity ($R-R_0$) is kept constant. That is, when the number of probes increases, only the perimeter of the ring cavity increases; the section of the ring cavity is kept constant, preventing higher-order modes from propagating. This power-dividing structure is, therefore, suitable for large numbers of ports for high-power, active power-combining systems.

The approximate equivalent circuit of the 16-way ring cavity power divider is shown in ***Figure 2***. The stepped discontinuity from the output port of the coaxial taper to the ring cavity is modeled as a capacitive reactance $-jX_S$. $-jX_S$ can be altered easily by changing L2, L5, R1 and Rs; the adjustability of $-jX_s$ facilitates impedance matching. The charac-

TABLE 1

OPTIMIZED DIMENSIONS OF THE RING CAVITY POWER DIVIDER (mm)

Rt	Rp	d	h	Lp	L1	L2
3	3.8	0.4	4	2	0.5	1.8
L3	L4	L5	R	Rs	R0	R1
68.3	7.7	0.4	31.3	21.2	19.7	5.6

teristics of the proposed structure can be analyzed with microwave network theory. According to Hu et al.,[12] for an N-port lossless reciprocal network

$$\begin{cases} \sum_{k=1}^{N} S_{ki}S_{ki}^{*} = 1 \\ \sum_{k=1}^{N} S_{ki}S_{kj}^{*} = 0, i \neq j \end{cases} \quad (1)$$

The ring cavity, 16-way power combiner/divider structure is axially symmetric. Port 1 is the input port and the remaining n ports are the output ports. Assuming that the input port is impedance matched, the S-parameter matrix is given as

$$S = \begin{Bmatrix} 0 & S_{1n} & S_{1n} & \cdots & S_{1n} \\ S_{1n} & S_{22} & S_{23} & \cdots & S_{2n} \\ S_{1n} & S_{32} & S_{33} & \cdots & S_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ S_{1n} & S_{n2} & S_{n3} & \cdots & S_{nn} \end{Bmatrix} \quad (2)$$

If this structure is lossless, this is the unitary matrix. So that

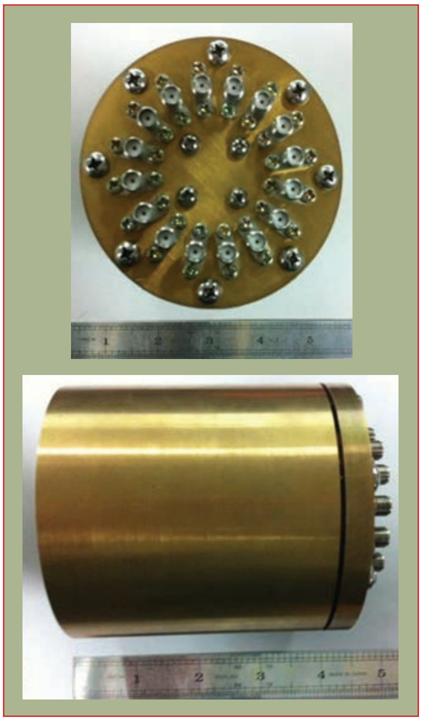
$$\left|S_{ij}\right|^2 = \frac{n-1}{n^2} \quad i \neq 1, i \neq j \quad (3)$$

For this ring cavity, 8-way power combiner/divider, n is equal to 16, so the average value of isolation and return loss of the output ports is

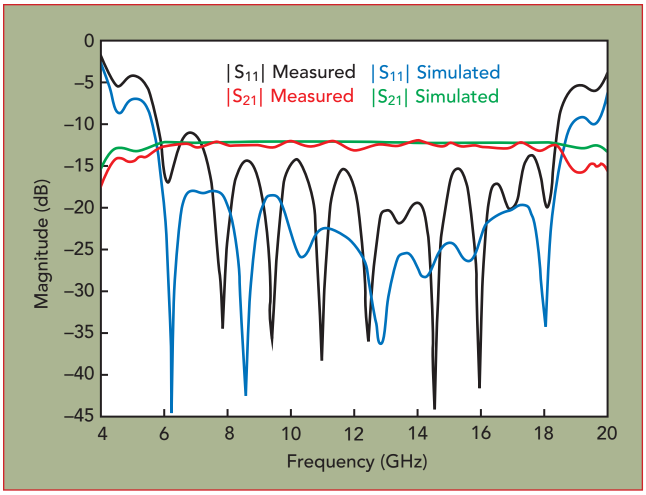
$$10\lg\left(\left|S_{ij}\right|^2\right) = -12.3 \text{ dB}$$
$$(n = 16, i \neq 1, i \neq j) \quad (4)$$

SIMULATION AND MEASUREMENT

Using this analysis, the 16-way ring cavity power divider was designed, simulated and optimized using the electromagnetic simulation tool Ansoft-HFSS. The optimized dimensions are listed in ***Table 1***, and the fabricated power divider is shown in ***Figure 3***. The power divider was measured using a Keysight network analyzer, and the measured S-parameters are compared with the simulated in ***Figure 4***. The average insertion loss is around 12.5 dB, including the ideal 12.04 dB power-dividing loss. ***Figure 5*** shows the measured transmission characteristics. A maximum amplitude imbalance of ±0.7 dB and a phase imbalance of ±7 degrees are achieved over the entire band. These imbalances are attributed to fabrication errors.



▲ Fig. 3 **Fabricated power divider.**



▲ Fig. 4 Simulated vs. measured $|S_{11}|$ and $|S_{21}|$ performance.

CONCLUSION

A UWB 16-way ring cavity power divider contains a large number of power-dividing ports while exhibiting UWB performance. Measurements demonstrate good amplitude and phase balance, low loss and agree with the simulation. Based on this performance, the design has the potential to be a useful building block in power-combining amplifier networks.■

ACKNOWLEDGMENT

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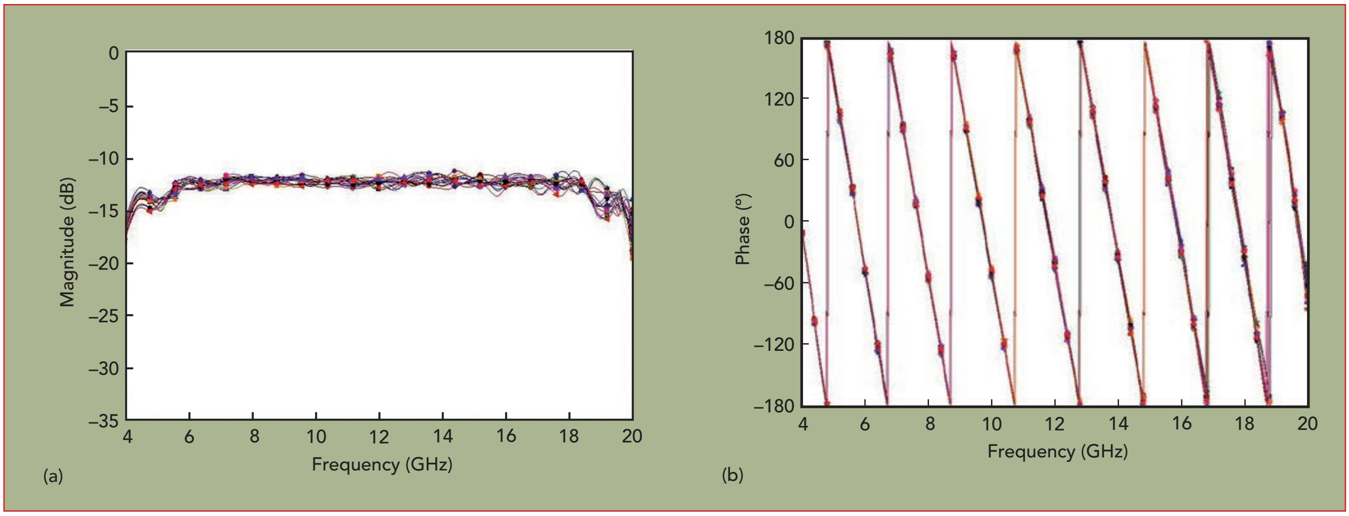

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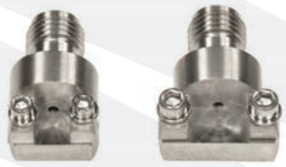

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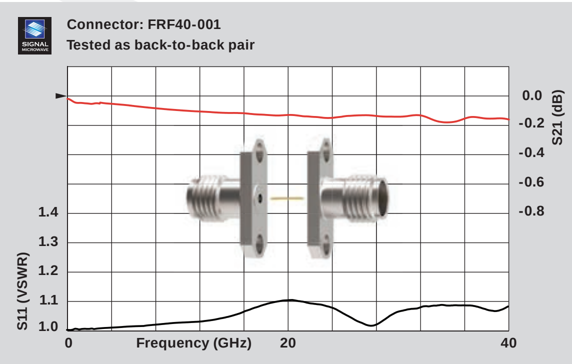

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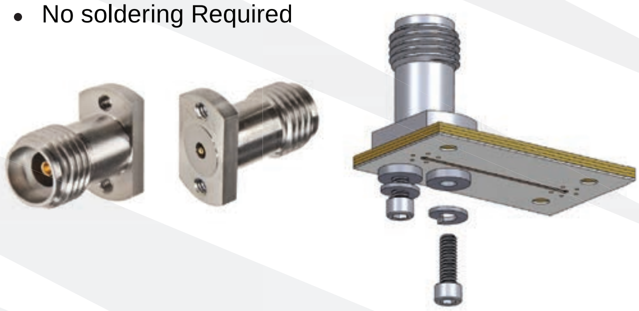

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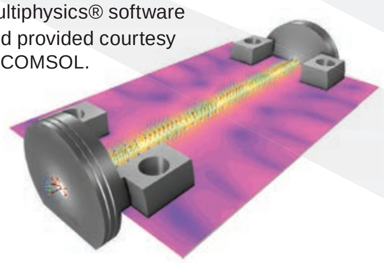

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Yu Zhu *received his B.S. degree in electrical information engineering from Southeast University Chengxian College in 2014 and is working toward his M.S. degree in electrical engineering at the University of Electronic Science and Technology of China (UESTC). His research interests include mmWave techniques with a focus on RF/microwave passive devices.*

Kaijun Song *received his M.S. degree in radio physics and a Ph.D. in electromagnetic field and microwave technology from UESTC in 2005 and 2007, respectively. Since 2007, he has been with the EHF Key Laboratory of Science in the School of Electronic Engineering at UESTC, where he is a full professor. His research fields include microwave and mmWave/THz power-combining technology, UWB circuits and technologies, microwave/mmWave devices, circuits and systems and microwave remote sensing technologies.*

Shunyong Hu *received his B.Sc. degree in applied physics from Shandong University of Science and Technology in 2010 and is working toward his Ph.D. in electromagnetic fields and microwave technology at UESTC. His research interests include microwave and mmWave power-combining technology and microwave passive component design.*

Yong Fan *received his B.E. degree from Nanjing University of Science and Technology in 1985 and his M.S. degree from UESTC in 1992. He is a senior member of the Chinese Institute of Electronics. His research interests include mmWave communication, electromagnetic theory, mmWave technology and mmWave systems.*

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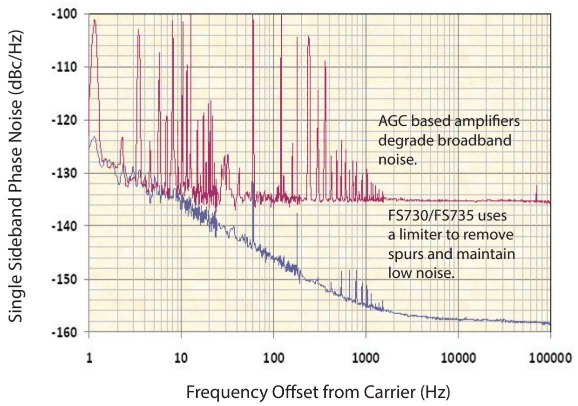

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An Interview with CEO Stefan Wolff by JT Konstanturos

Stefan Wolff is someone who tells it like it is. The pragmatic CEO of pSemi™, a company with 30 years of RFIC history and backed by electronics giant Murata, speaks with passion and a deep understanding of what is expected to attract top engineers in today's competitive marketplace. Wolff's direct, no-nonsense demeanor makes a strong case for anyone looking for a workplace that encourages people to reach their highest potential while working on products that will shape our connected world.

JTK: Thanks for taking the time to speak to me. Tell me about the new name, pSemi, and what the future holds.

SW: The pleasure is mine. I thrive on the exciting time this is for pSemi, and it is a privilege being its CEO. pSemi was formed to provide focus and resources to take semiconductors to the next level. Our new name is derived from Peregrine Semiconductor and reflects its proud 30-year RFIC history. Fast-forward to the present: We are a Murata company with the backing and integrity of that electronics giant. Murata has challenged us to broaden our scope, increase our IP and grow on a global scale to support inventions that are coming in our not-so-distant future.

JTK: What sets pSemi apart from other semiconductor companies, and what's different now?

SW: We are innovation junkies—pure and simple. With well over 500 issued and pending patents, our patent portfolio was named one of the technology world's most valuable portfolios by the *IEEE Spectrum* "Patent Power Scorecard" for the last two years. What that says is our patents are not only innovative but very useful to the industries we serve. So, what is different now? The industries we serve are growing. Smaller, faster, lighter is the mantra we hear all the time from inventor companies, and we are rising to meet that challenge through very novel and intelligent semiconductor integration and packaging.

JTK: Sounds like quite a challenge. When will you reach your goal?

SW: The honest answer to that question is never. You can't stand still in this time of electronic revolution. You have to keep moving forward at all times to succeed. We have never shied away from the tough challenges, and now is not the time to start.

JTK: What does pSemi have to offer the best and brightest engineers?

SW: We are growing, and we are hiring. pSemi offers an engineering-driven environment with fascinating projects for challenging applications like 5G, IoT and battery management. Since our inception, we have invented breakthrough technologies for emerging markets, such as switches and antenna tuners for smartphones in the 2000s, and today, we are spearheading Murata's efforts in new semiconductor growth markets. The foundation of our whole-person support is a work-hard, play-hard philosophy. Yes, that means we have wellness programs, parties and special-recognition dinners, and yes, our headquarters are near beautiful beaches with the perfect San Diego lifestyle. And yes, we do take full advantage of it all! Even beyond San Diego, pSemi has offices around the world—and plans to have offices—wherever there is a hub of semiconductor talent that supports our growing "dream team."

JTK: How do you plan to build your "dream team" of engineers?

SW: Well, we are already making it happen. With the right people, we will get there even faster. This year alone, we have acquired businesses and hired entire teams. Chip designers frequently do not leave a job they hate because they love their team. We say, "No problem. We will take the entire team too if they are the right fit." We are leaning on our "dream team" to design the products of the future. Think smartphones, small cells, portable computing, data centers, smart homes, electric vehicles and healthcare. It is an exciting time in our industry, and we are grateful to have the backing and support of Murata in this next chapter.

"We are growing, and we are hiring. pSemi offers an engineer-friendly environment with fascinating projects…and a work-hard, play-hard philosophy."

JTK: Any last words?

SW: Definitely! I do not pretend to know everything about our industry; no one does. I ask a lot of questions, and I really want to hear what our employees think. I do have a few expectations of our employees. First and foremost is respect. We expect it at all levels. Not far behind is integrity. That means we tell the truth. You can expect me to tell the truth, and I will expect the same. The truth has no politics and no taboo subjects. If it will make the company better, it should be talked about candidly. Third is quality and customer satisfaction. We strive for it in everything we do. Our customers expect it, our parent company is known for it, and it makes us proud of our efforts. Last, but not least, is teamwork. Without it, we can't do any of this. We are so fortunate that our parent company not only shares these values but has weaved them into every aspect of their business.

If you would like to join our team, I would like to hear from you. Please send your resume to Stefan@psemi.com. For more about pSemi and our innovative products, please go to psemi.com.

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A 20 GHz Low Phase Noise Push-Push VCO in InGaP GaAs HBT Technology

Jincan Zhang, Bo Liu, Leiming Zhang and Ligong Sun
Henan University of Science and Technology, Luoyang, China

Yuming Zhang, Hongliang Lu and Yimen Zhang
Xidian University, Key Laboratory of Wide Band-Gap Semiconductor Materials and Devices, Xi'an, China

A 20 GHz low phase noise voltage-controlled oscillator (VCO) uses InGaP GaAs heterojunction bipolar transistor (HBT) technology. A push-push negative g_m VCO configuration taking its output signal from a capacitive base common node of the cross-coupled transistors is employed to achieve a high oscillation frequency and low phase noise. The VCO oscillates from 19.44 to 20.04 GHz. Measured phase noise is -111.8 dBc/Hz at 1 MHz offset from a 19.78 GHz carrier. It consumes 31 mW from a 5 V supply and occupies an area of 0.514 mm × 0.622 mm. Its figure of merit is -182.8 dBc/Hz.

The increased demand for high data-rate wireless communication is driving the development of RFIC to higher frequency bands. For high frequency RFICs, InGaP GaAs HBT technology is a good candidate. Compared with CMOS, InGaP GaAs HBTs have the advantages of potentially higher f_T, higher transconductance and lower 1/f noise. In addition, InGaP GaAs HBTs have been shown to have inherent radiation hardening, making them well suited for the applications in the space environment.[1-2]

In transceiver systems, VCOs are key components, and most systems require low phase noise and jitter, which degrade system performance by reducing accuracy and increasing errors. At RF frequencies, two VCO topologies (cross-coupled[3-6] and Colpitts[7-10]) are widely used. From Andreani et al.,[11] it can be concluded that both topologies are capable of very good phase noise; however, it also has shown that a cross-coupled VCO can achieve lower phase noise than a Colpitts.

In order to extend the output frequency range, a frequency doubler combined with a VCO may be used, but this increases circuit complexity and power consumption. An alternative is the so called push-push oscillator,[12-13] which extracts the second harmonic of the VCO core. In this type of oscillator, the desired frequency tuning range is twice that of the VCO core and there is potentially less power consumption. Depending on the node from which the second harmonic is extracted, three architectures are found in the literature. The extracting node can be the collector common node,[14] base common node[13] or the emitter common node.[15] Compared with the collector common node and emitter common node, the base common node is most efficient at extracting all the available second harmonic from the tank.[13] In this article, we describe a 20 GHz push-push negative g_m VCO that takes its output signal from a capacitive base common node of the cross-coupled transistors.

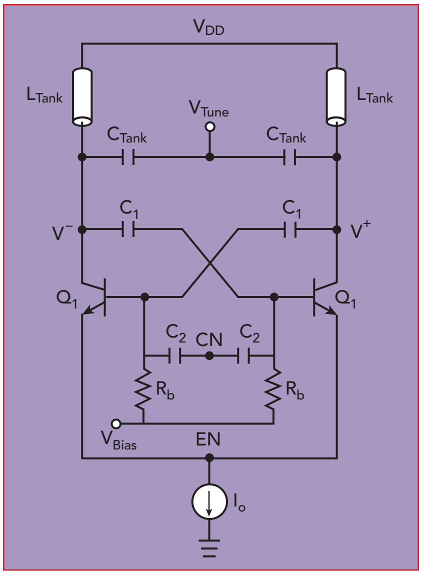

Fig. 1 Negative g_m differential VCO.

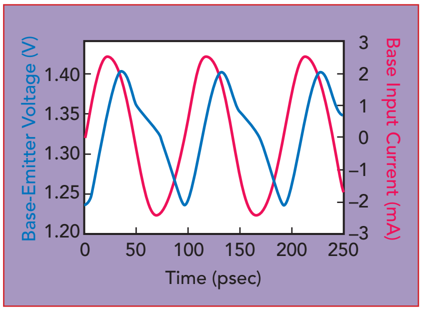

Fig. 2 Base-emitter voltage and base current waveforms.

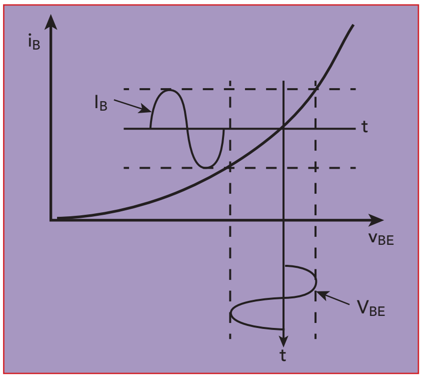

Fig. 3 Base-emitter voltage waveform distortion.

CIRCUIT DESIGN

Architecture

The circuit schematic of a conventional negative g_m differential oscillator is shown in ***Figure 1***. The cross-coupled transistors (Q_1 and Q_2) generate a negative g_m to overcome tank loss. The capacitive voltage divider, composed of C_1 and C_2 + C_{BE} (C_{BE} is the base-emitter junction capacitor of Q_1), is designed to attain an approximate loop gain of three in order to maximize the tank swing and simultaneously optimize signal amplitudes at the base nodes to feed back from the collectors of Q_1. It is known that phase noise degrades rapidly if the base-voltage swing becomes larger than a certain optimum value since Q_1 enters deep saturation.[16]

The common node (CN) of the capacitive voltage divider can be regarded as a virtual ground for the fundamental frequency (ω_o) just like the emitter common node (EN), but that CN could be a very effective summing node for the second harmonics ($2\omega_o$) of the fundamental signals (V+, V-) of the VCO core. Note that the CN can be regarded as a base common node compared with the conventional emitter or collector common node. The advantage of using the CN for output extraction is that it does not require any additional circuitry such as frequency doubler to create $2\omega_o$, other than the conventional negative g_m oscillator circuit, and does not reduce the common-mode impedance at node EN. It has been reported that an additional inductance inserted between node EN and the tail current source I_o can increase the common-mode impedance and the signal swing at node EN, but it is at the cost of an additional bulky inductor.

Operating Principle

The mechanisms responsible for second harmonic generation at the VCO core are investigated to understand circuit operation. A simple 20 GHz VCO is designed based on the circuit schematic of Figure 1 with a 10 GHz LC tank. The first is the nonlinear switching characteristics of the base-emitter junction diode. Although the circuit operates nonlinearly, it is helpful to use linear circuit analysis when appropriate.

Figure 2 illustrates the simulated waveforms of the base-emitter voltage (V_{BE}) and the base input current (I_B) of Q_1. The base current leads the base-emitter voltage by 90 degrees due to the base input capacitance, and the upper half period of V_{BE} is distorted compared with the undistorted sinusoidal waveform. The distortion is due to the exponential current-voltage relationship

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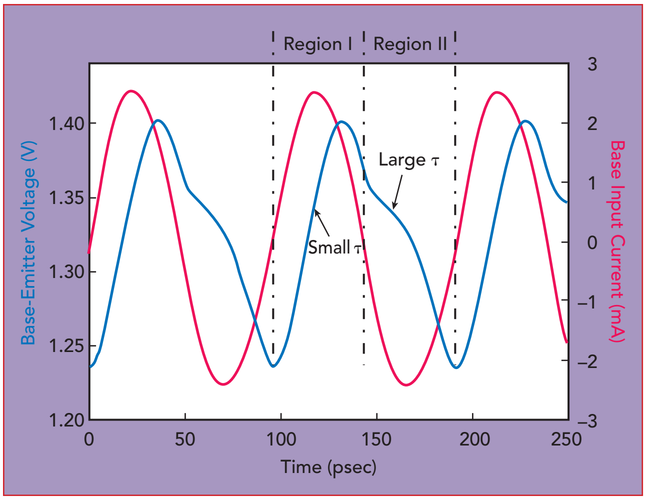

Fig. 4 Rise and fall times of the base-emitter voltage vs. τ.

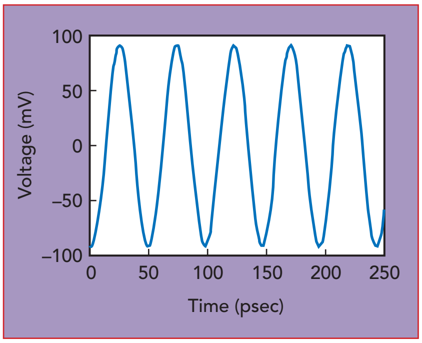

Fig. 5 Voltage at the capacitive common node (CN).

of the base-emitter junction diode given by

$$I_B = I_S\left(e^{V_{BE}/V_T} - 1\right) \quad (1)$$

where I_s is the saturation current and V_T is the thermal voltage. ***Figure 3*** illustrates conceptually how the upper half period of V_{BE} is distorted by voltage clipping when the base current is a large sinusoidal signal.

The second cause for second harmonic generation is the different time constants involved in charging and discharging the base-emitter junctions in the circuit. Again, a linear circuit analysis provides an intuitive understanding. The time constant at the base-emitter nodes is given by

$$\tau = R_B\left[\frac{C_1(C_2 + C_{BE})}{C_1 + C_2 + C_{BE}}\right] \quad (2)$$

where R_B is the base input resistance. As shown in ***Figure 4***, in region I, I_B is high, i.e., R_B is small, so that the corresponding τ is small. This results in a fast rise time. The inverse occurs in region II.

These two mechanisms, together, contribute to second harmonic generation in the base-voltage waveform. When they are summed at the capacitive CN, the fundamental components at ω_o cancel out due to their 180 degree phase difference and only the second harmonic components add constructively. This results in $2\omega_o$ at the output as shown in ***Figure 5***. Moreover, the amplitude of the voltage waveform at the capacitive CN is not divided down by the capacitive divider. By contrast, the differential-mode fundamental signals V^+ and V^- are reduced by the same capacitive divider. Therefore, the CN node is capable of extracting all the available second harmonic components very efficiently from the tank.[13]

MEASUREMENT RESULTS

The technology used in this work is the InGaP GaAs HBT process from WIN Semiconductors Corporation. The process offers four types of NPN transistors, Q1H051B1, Q1H101B1, Q1H151B1 and Q1H201B1, with different emitter lengths (5, 10, 15 and 20 μm, respectively). Main electrical properties for NPN transistors are the collector-emitter breakdown voltage BV_{CEO} = 9 V, the maximum unity current gain frequency f_T = 65 GHz and the maximum unity power gain frequency f_{max} = 80 GHz. Passive components, including two metal layers, two types of capacitors, resistors, varactor diodes and inductances, as well as back side via holes are available in the process. Passive and active device models have been implemented and validated by simulation with Keysight Advanced Design System (ADS) software.

Figure 6 shows a micrograph with a chip area of 0.514 mm × 0.622 mm, including all test pads. The circuit is measured on wafer. An HP4142B voltage and current source is used to supply the DC

voltages and the output is connected through a ground-signal-ground probe to the Keysight N9030A spectrum analyzer with a phase noise measurement utility and a 50 Ω load. The VCO is biased with V_{DD} = 5 V and I_{DD} = 6.2 mA. It consumes 31 mW of DC power.

The oscillation frequency variation as a function of control voltage is plotted in ***Figure 7***. When the control voltage is tuned from 0 to 5 V, the VCO operates from 20.04 to 19.44 GHz. That is, the VCO exhibits a tuning range of 3.04 percent based on a 19.74 GHz center frequency. The measured oscillation frequency (20.04 to 19.44 GHz) of the VCO is shifted down slightly as compared to the simulated oscillation frequency (20.92 to 20.2 GHz). The difference between the simulated and measured results can be attributed to the fact that all the passive elements and wiring of circuit were modeled with the quasi 3D electromagnetic simulation of

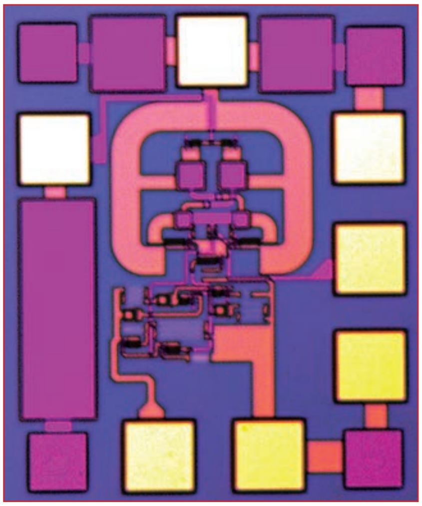

Fig. 6 VCO IC.

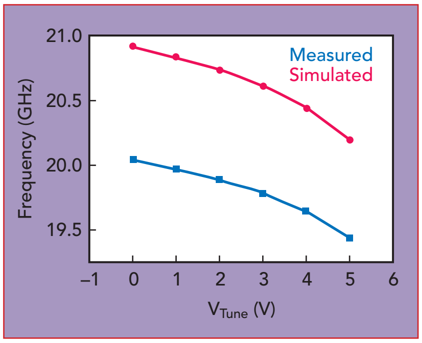

Fig. 7 Simulated and measured VCO frequency vs. tuning voltage.

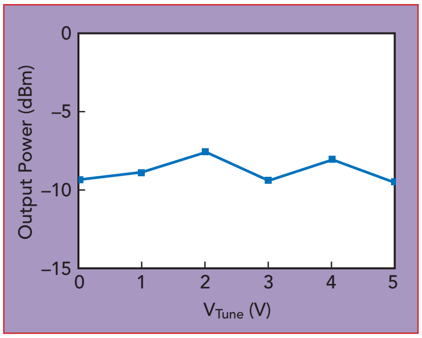

Fig. 8 Measured VCO output power vs. tuning voltage.

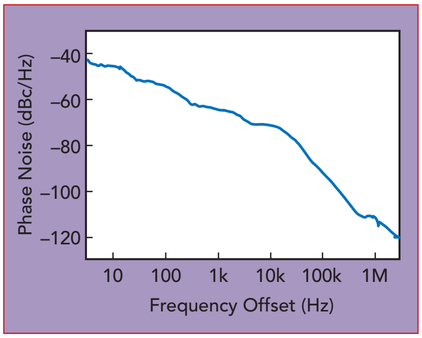

Fig. 9 Measured VCO phase noise.

TABLE 1

COMPARISON OF K- AND KA-BAND VCOs

Ref.	f_{osc} (GHz)	Phase Noise at 1 MHz (dBc/Hz)	Tuning Range (%)	P_{VCO} (mW)	Technology	Figure of Merit (dBc/Hz)
4	23.1	-94	5	2.5	0.18 µm SiGe BiCMOS	-177.3
5	20.89	-97.2	10.5	40	0.13 µm SiGe BiCMOS	-167.6
6	24.27	-100.3	2.2	7.8	0.18 µm CMOS	-179.1
7	21.89	-108.2	N/A	32	0.18 µm CMOS	-180
8	25	-103.1	2.4	13.2	0.18 µm CMOS	-179.9
9	19	-112	11	200	0.13 µm SiGe BiCMOS	-174.6
This Work	19.74	–111.8	3.04	31	1 µm InGaP GaAs HBT	-182.8

momentum electromagnetic (EM) simulator in ADS. It is difficult to set the substrate parameters to be the same as those fabricated from the list in the library. ***Figure 8*** shows the measured signal output power, which is above -10 dBm over the output frequency range.

Phase noise of the VCO is difficult to measure, due to spectrum jitter caused by noise from supply and tuning voltages. In this work, the phase noise is roughly measured using the Keysight N9030A phase noise utility. ***Figure 9*** shows the measured results. VCO phase noise is -111.8 dBc/Hz at 1 MHz offset from the 19.78 GHz carrier frequency.

Table 1 compares this performance with that of previously reported VCOs in K- and Ka-Band. The commonly used figure of merit (FOM), which accounts for phase noise (PN), oscillation frequency (f_{osc}), frequency offset (Δf) from f_{osc}, and power dissipation (P_{VCO}) as depicted in Equation 3,[6] is used for the comparison.

$$FOM = PN - 20\log\left(\frac{f_{osc}}{\Delta f}\right) + 10\log\left(\frac{P_{VCO}}{1mW}\right) \quad (3)$$

It is evident from Table 1 that, the VCO reported in this work has an excellent FOM compared with the other oscillators processed in SiGe BiCMOS or CMOS technology. Furthermore, its power consumption is remarkably low, only 31 mW, compared with other VCOs realized in the same InGaP GaAs HBT technology.[17-18]

CONCLUSION

A K-Band VCO in InGaP GaAs HBT technology operates at a high oscillation frequency with low phase noise. It employs a push-push negative g_m architecture, which takes its output signal from a capacitive base CN of the cross-coupled transistors. Measurements demonstrate an oscillation frequency range from 19.44 to 20.04 GHz. Phase noise is -111.8 dBc/Hz at 1 MHz offset from 19.78 GHz carrier.■

ACKNOWLEDGMENT

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Jincan Zhang *received his M.S. degree and Ph.D. degrees from Xi'an University of Technology in 2010 and 2014, respectively. He is currently a lecturer at Henan University of Science and Technology. His research is focused on modeling of HBTs and the design of very high speed integrated circuits.*

Hongliang Lu *received her M.S. and Ph.D. degrees in microelectronics engineering from Xidian University in 2003 and 2007, respectively. Since 2010, she has been a professor in the School of Microelectronics at Xidian University. Her work involves modeling and experiments on SiC MESFETs and other devices.*

Yuming Zhang *received his M.S. and Ph.D. degrees in microelectronics engineering from Xidian University and Xi'an Jiaotong University in 1992 and 1998, respectively. From 1999 to 2000, he was with Rutgers University as a postdoctoral fellow. Since 2001, he has been a professor at the Microelectronics Institute, Xidian University. His research is in the design, modeling, fabrication and electrical characterization of SiC electronic devices for high temperature and high-power operation.*

Yimen Zhang *is a professor of the School of Microelectronics, Xidian University. He has been a visiting scholar and senior visiting scholar at Arizona State University, Tempe, and Yale University, respectively. His research interests are in the areas of wideband semiconductor devices, semiconductor devices modeling, TCAD for VLSI and quantum well devices.*

Bo Liu *received his B.E., M.S. and D.E. degrees in electronic engineering from the University of Kitakyushu, Japan in 2005, 2008 and 2012, respectively. Since 2012, he has been an associate professor at Henan University of Science and Technology. His research interests include VLSI layout design and process variation analysis for analog IC design for manufacturability.*

Leiming Zhang *received his M.S. degree at the University of Electronic Science and Technology of China in 2008. He is currently a lecturer at Henan University of Science and Technology. His research is focused on device modeling of CMOS and design of mixed signal integrated circuits.*

Ligong Sun *received his M.S. degree from Henan University of Science and Technology in 2006. He is currently an associate professor in Henan University. His research is focused on AI and robot, computer application technology and the design of mixed-signal integrated circuits.*

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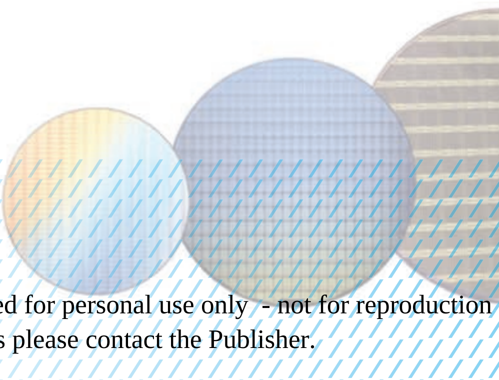

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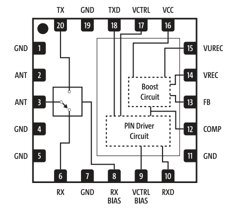

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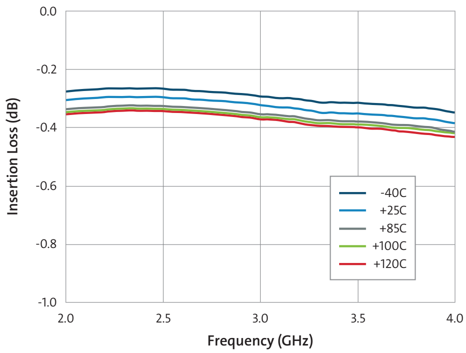

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Metamaterial-Based Planar Compact MIMO Antenna with Low Mutual Coupling

Jie Li, Jia-Bei Zhao, Jia-Jun Liang, Lin-Lin Zhong and Jing-Song Hong
University of Electronic Science and Technology of China, Chengdu, China

A metamaterial structure placed in the space between two symmetrically printed 5.8 GHz MIMO antenna elements provides an effective means of limiting the surface waves between them in order to reduce mutual coupling. Greater than 24 dB isolation is observed while demonstrating good radiation patterns, efficiency and gain.

MIMO technology has been shown to improve wireless link transmission rates and reliability.[1-2] However, when multiple antennas are spaced in close proximity, performance is degraded by mutual coupling. Researchers have introduced different methods to minimize the mutual coupling between antennas. For example, Farahani et al.[3] and Coulombe et al.[4] used electromagnetic band-gap (EBG) structures. Others have introduced defecting ground structures (DGS), or slits, in the antenna ground.[5-7] Tang et al.[8] and Liu et al.[9] used decoupling structures between two closely spaced radiating elements to reduce the mutual coupling for UWB applications.

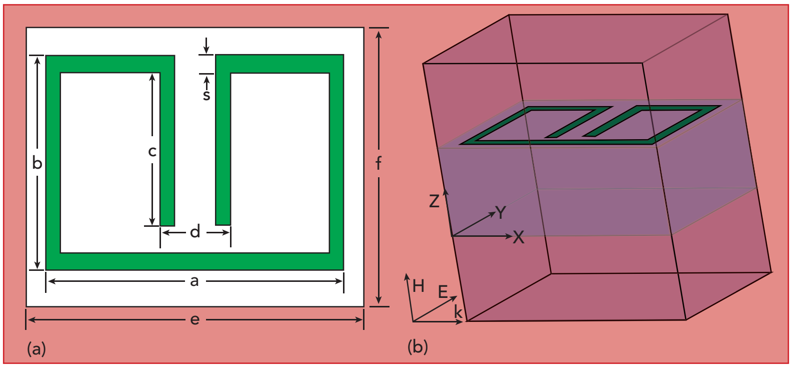


Fig. 1 Metamaterial unit cell; 2D view (a), 3D view (b).

Metamaterials, possessing distinctive electromagnetic properties, have attracted much interest over the last decade. Metamaterial units are usually repeatedly arranged with a scale of a sub-wavelength. At the macroscopic level, negative values of dielectric permittivity, magnetic permeability or both can be achieved by carefully choosing the shape of the metamaterial units and adjusting structural dimensions.[10]

Recently, metamaterial structures have been exploited in the design of MIMO antennas. For example, a waveguide metamaterial was inserted between two microstrip patches by Yang et al.,[2] and the mutual coupling between the two antenna elements was reduced by about 6 dB from 3.5 to 3.55 GHz. With a rectangular loop resonator, good isolation between two monopoles and three monopoles at 2.45 GHz was achieved by Ketzaki and Yioultsis.[10] A complementary split ring resonator (CSRR) was proposed for antenna miniaturization in a 2.45 GHz ISM band application,[11] and a metamaterial spiral resonator at 5.5 GHz reduced MIMO system performance degradation caused by strong mutual coupling among four patch elements.[12] In this article, a compact MIMO antenna uses a rectangular loop resonator as the metamaterial unit.

ANTENNA DESIGN

First introduced by Pendry,[13] the split ring resonator (SRR) has been utilized in many forms in the design of MIMO antennas due to its property of negative magnetic permeability. We use a split rectangular loop structure for this purpose. By altering the geometry and dimensions of this particular kind of metamaterial cell, it exhibits better controllability of the gap capacitance than other resonators.

Rectangular Loop Resonator Design

In ***Figure 1*** a unit cell is etched on a 1.6 mm thick FR-4 epoxy substrate with relative permittivity ε_r = 4.6 and loss tangent tan δ = 0.019 at 5.8 GHz. Figure 1a shows a two-dimensional view of the unit cell with dimensions: a = 4.2 mm, b = 2.4 mm, c = 1.7 mm,

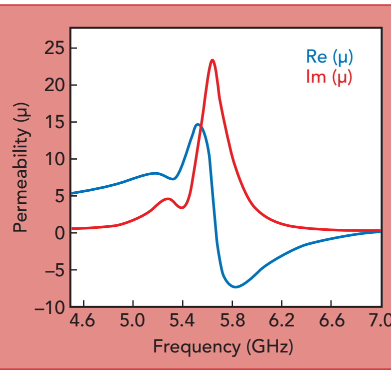


Fig. 2 Metamaterial permeability, real and imaginary parts.

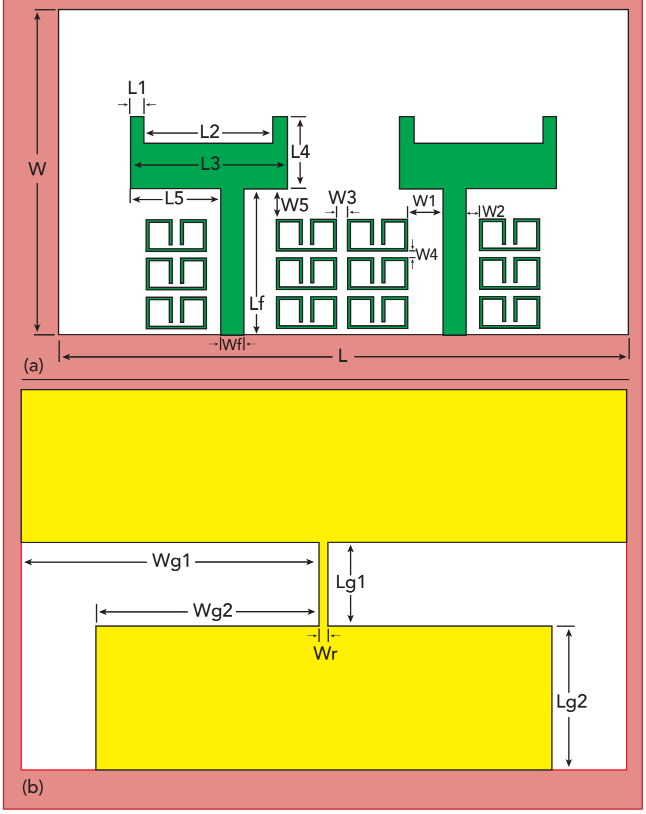


Fig. 3 Antenna geometry; top view (a), bottom view (b).

TABLE 1
OPTIMIZED ANTENNA PARAMETERS

Parameter	Values (mm)	Parameter	Values (mm)
L	40	W_3	0.8
L_1	1	W_4	0.6
L_2	9	W_5	2.4
L_3	11	L_f	11.3
L_4	5.5	L_{g1}	5.5
L_5	6.7	L_{g2}	9.5
W	25	W_f	1.6
W_1	2.3	W_{g1}	19.8
W_2	1	W_{g2}	14.8

d = 1 mm, e = 4.8 mm, f = 3 mm and s = 0.2 mm. Figure 1b shows unit cell dimensions of 3 × 4.8 × 1.6 mm^3 on an xyz axis. An incident plane electromagnetic wave propagates in the x direction towards the unit cell with the magnetic field of the wave oriented along the z-axis and the electric field oriented along the y-axis. The boundary walls along the y-axis (at the xz-oriented sides) are considered perfect electrical conductors.

The effective magnetic permeability is determined using the parameter retrieval technique.[10,14] As shown in ***Figure 2***, the real part of the permeability at 5.8 GHz is negative.

Metamaterial-Based MIMO Antenna

The microstrip array antenna (see ***Figure 3***) consists of a ground plane with two open L-shaped slots (bottom view) and two U-shaped patch elements (top view) on an FR-4 substrate. Four rows of split rectangular loop resonators are used to minimize mutual coupling between the two radiating elements. Each row contains three elements. The single SRR structure of Figure 1 is sufficient to provide a perfect inductance, but is still small enough to satisfy the condition of having subwavelength dimensions. ***Table 1*** lists the dimensions of the MIMO antenna in Figure 3.

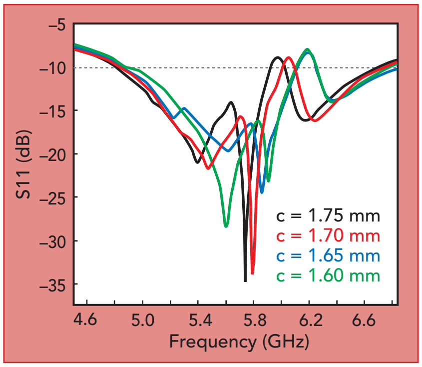
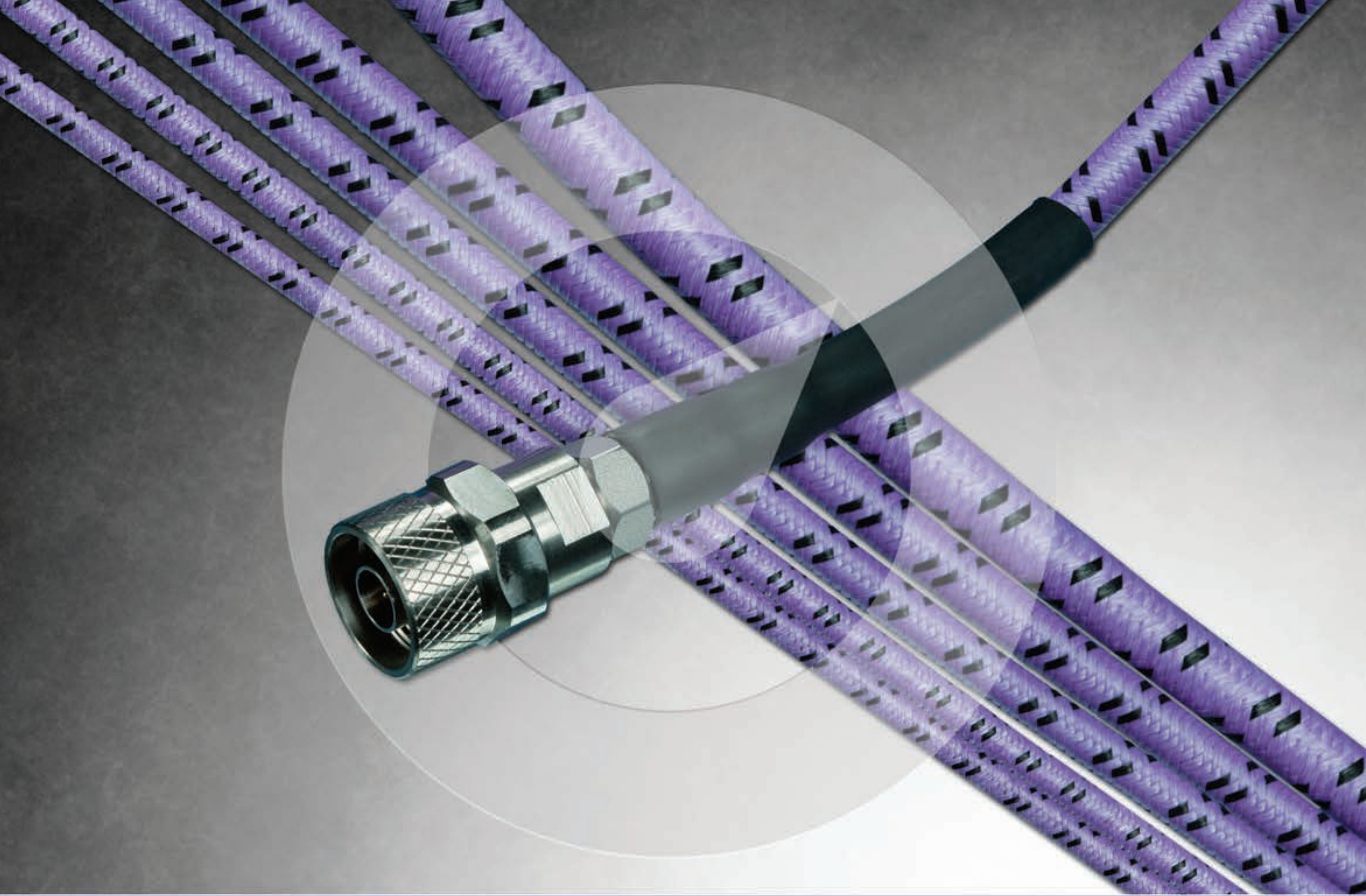


Fig. 4 Reflection coefficient for various lengths of c.

EXPERIMENTAL RESULTS

The antenna is modeled in HFSS. SRR dimensions are fixed values ex-



cept for the gap capacitance, which is controlled by the length of c. ***Figure 4*** shows the reflection coefficient for various lengths of c from 1.6 to 1.75 mm. The resonant frequency changes, correspondingly. When c = 1.7 mm, resonance occurs at 5.8 GHz.

Characteristics of the antenna (see ***Figure 5***) are measured in an anechoic chamber and compared with simulation, demonstrating good agreement. The fabricated antenna resonates at 5.8 GHz with a reflection coefficient of -32.7 dB in the simulation and at 5.82 GHz with a reflection coefficient of -26.2 dB in the measurement. The antenna has an impedance bandwidth of approximately 1040 MHz (4.93 to 5.97 GHz) at 10 dB return loss.

In ***Figure 6***, simulated and measured isolation of the two-element MIMO antenna are shown. At 5.8 GHz, isolation is 15.3 dB without the SRRs. With the SRRs placed between the two antenna elements, isolation is increased to 27.5 (simulated) and 24.6 dB (measured); i.e., coupling is reduced by approximately 12.2 and 9.3 dB, respectively. The small frequency shift between measured and simulated results in Figures 5 and 6 is attributed to manufacturing tolerances.

In ***Figure 7***, measured and simulated radiation patterns of the MIMO antenna in the x-z (H) and y-z

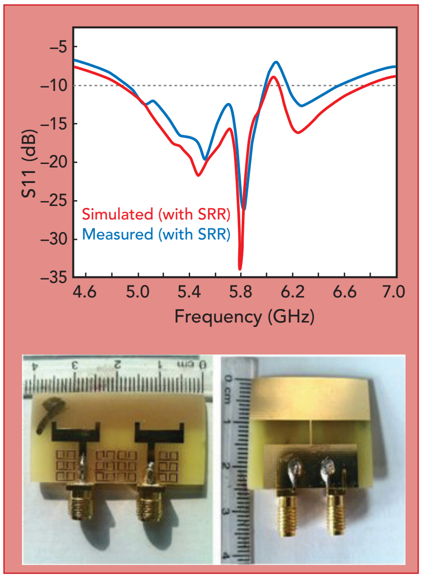


Fig. 5 Measured and simulated reflection coefficient vs. frequency.

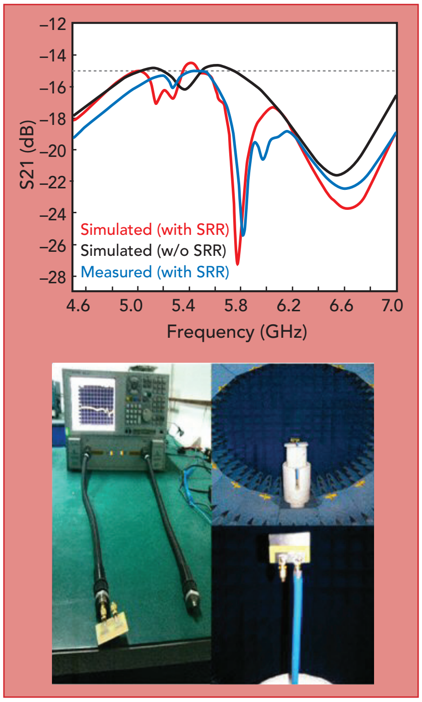
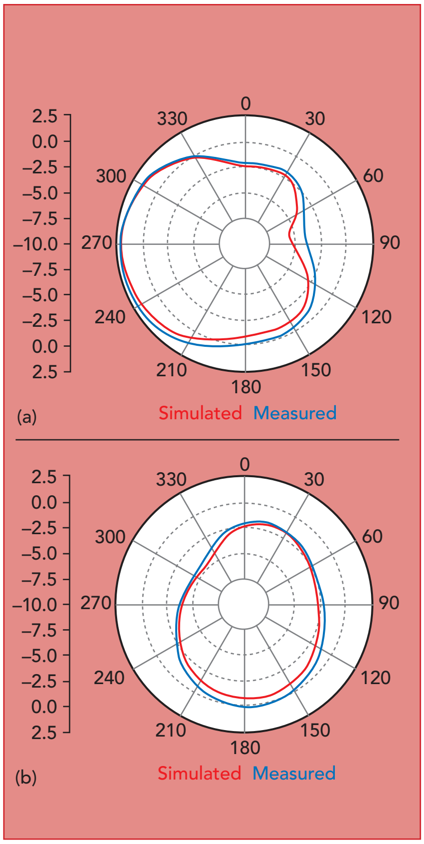


Fig. 6 Measured and simulated isolation.

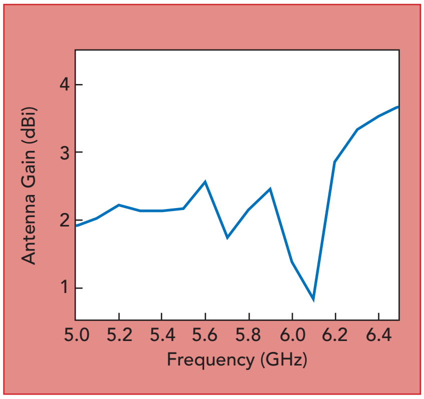
(E) planes at 5.8 GHz are compared when one port is excited the other port is terminated with a 50 Ohm load. The results show that the antenna radiates with a quasi-omni-directional characteristic. Again, measured results agree well with simulation. The measured peak gains of the antenna are shown in ***Figure 8***. The gains are about 1.9 to 3.7 dBi in the 5 to 6.5 GHz band and 2.14 dBi at 5.8 GHz. Measured radiation efficiency (see ***Figure 9***) is 71 percent at 5.8 GHz.

CONCLUSION

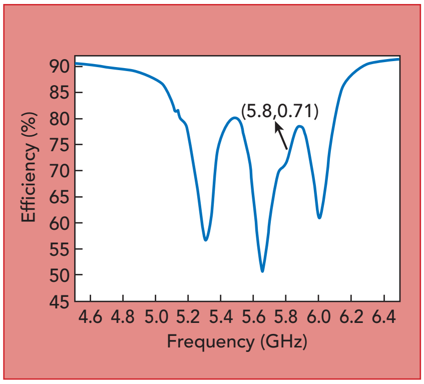
A small sized (25 × 40 × 1.6 mm^3) printed microstrip-fed slot antenna has been designed and demonstrated. Within a small available space (0.166λ) between the MIMO radiating elements, a metamaterial-based negative permeability structure is placed as a means to reduce



▲ **Fig. 7** Measured and simulated radiation patterns at 5.8 GHz; x-z plane (a), y-z plane (b).



▲ **Fig. 8** Measured antenna gain.



▲ **Fig. 9** Measured radiation efficiency.

mutual coupling. With this technique, mutual coupling is reduced by 9 dB at the operating frequency. It compares favorably with other decoupling techniques in providing an effective approach for controlling propagation between closely spaced microstrip patches. In addition, full planarity of the MIMO antenna is preserved, while employing a simple and straightforward fabrication process.■

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MV336 10 MHz, +12V
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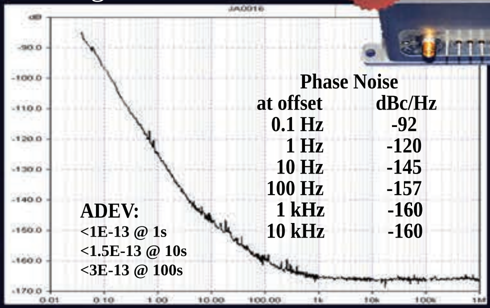
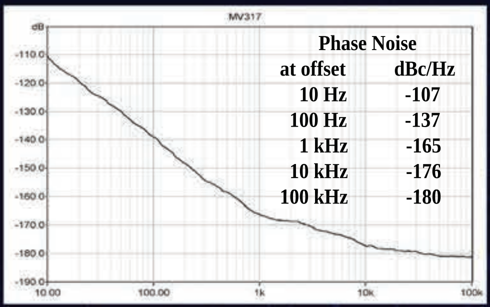
- Package: 92x80x50 mm



Phase Noise at offset	dBc/Hz
0.1 Hz	-92
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-160

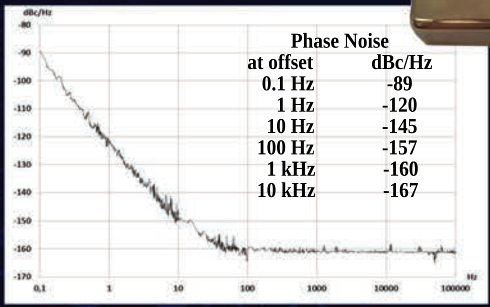
ADEV:
<1E-13 @ 1s
<1.5E-13 @ 10s
<3E-13 @ 100s

MV317 100 MHz, +5V/+12V
- Temperature Stability: 1E-8
- Aging: ±1E-7 per year
- Package: 25.8x25.8x10.3 mm



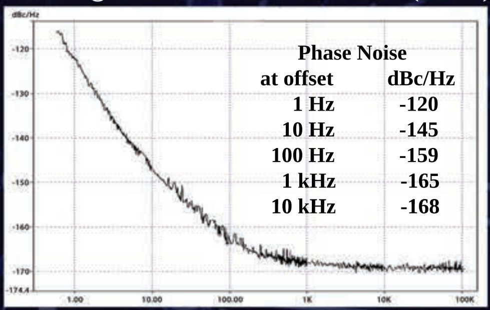
Phase Noise at offset	dBc/Hz
10 Hz	-107
100 Hz	-137
1 kHz	-165
10 kHz	-176
100 kHz	-180

MV341 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <2E-13 per sec.
- Package: 50.8x50.8x12.7 mm



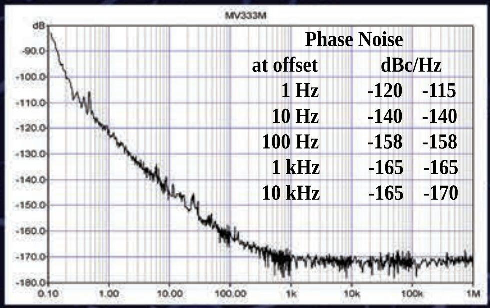
Phase Noise at offset	dBc/Hz
0.1 Hz	-89
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-167

MV272M 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <4E-13 per sec.
- Package: 41.0 x 30.0 x 17.0 mm (SMD)



Phase Noise at offset	dBc/Hz
1 Hz	-120
10 Hz	-145
100 Hz	-159
1 kHz	-165
10 kHz	-168

MV333M 10 MHz
- Temperature Stability: 3E-9
- Allan Deviation: <5E-13 per sec.
- Package: 25.8x25.8x12.7 or 36x27x16 mm



Phase Noise at offset	dBc/Hz	
1 Hz	-120	-115
10 Hz	-140	-140
100 Hz	-158	-158
1 kHz	-165	-165
10 kHz	-165	-170

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INVITED PAPER

Precise Frequency Sources Meeting the 5G Holdover Time Interval Error Requirement

A. Kotyukov, Y. Ivanov and A. Nikonov
Morion Inc., Russia

Synchronization is an essential prerequisite for all mobile networks to operate. It is fundamental to data integrity; without it, data will suffer errors and networks can suffer outages. Radio base stations rely on having access to reliable and accurate reference timing signals in order to generate radio signals and maintain frame alignment. Effective synchronization also permits hitless handover of subscriber connections between adjacent radio base stations. The measurement of time interval error (TIE) is a method for evaluating reference timing signals. This article describes the process.

Historically, frequency synchronization has been provided either by a Global Navigation Satellite System (GNSS) or derived from the transport network to which the network device requiring synchronization was connected. Public GNSS provides an accurate and stable synchronization source, but the financial cost to equip every site in a network with a GNSS-derived synchronization source may be prohibitive because of the requirement to install and manage additional equipment. Cost concerns for GNSS synchronization are more prevalent for small cell sites where the number of sites is increased compared with macro sites.

Telecommunication networks rely on the use of highly accurate primary reference clocks which are distributed network-wide using synchronization links and synchronization supply units. Primary reference clocks (PRC) or primary master clocks must meet the international standards requirement for long term frequency accuracy. To achieve this performance, atomic clocks or GPS disciplined oscillators are normally used.

Synchronization supply units (SSU) are used to ensure reliable synchronization distribution. They have a number of key functions:

- Filter the synchronization signal they receive to remove the higher frequency phase noise.
- Provide distribution with a scalable number of outputs to synchronize other local equipment.
- Provide a capability to carry on producing a high quality output even when their input reference is lost. This is referred to as holdover mode.

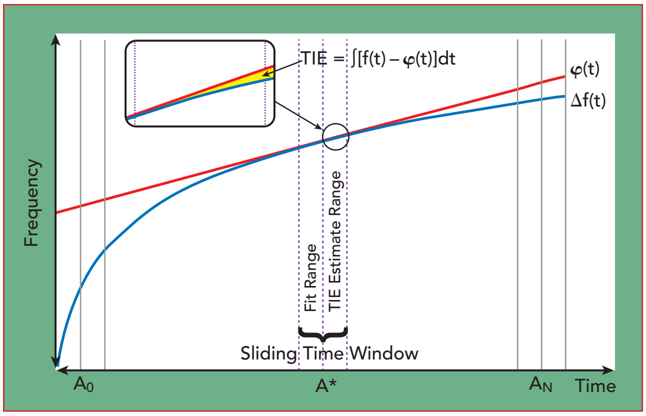

Fig. 1 TIE estimation algorithm.

5G REQUIREMENTS

5G backhaul networks have higher requirements for frequency and time synchronization when compared to all previous generations. As mobile networks eventually migrate from LTE Advanced (LTE-A) to 5G, there are three fundamental changes that will have the most significant upstream impact:

- 10- to 15-fold increase in capacity (from LTE/LTE-A capacity of ~100 Mbps to ~10 Gbps in 5G).

- Ultra-low latency of ~1 ms (round trip).
- Ultra-dense nature of the network setting unprecedented requirements for the synchronization of the cell sites as small and overlapping cell sites proliferate.

For 5G, higher accuracy time synchronization requirements are increased due to new services, technologies and the network architecture:

- New services
  – High accuracy positioning service; high accuracy location capability of less than 3 m on 80 percent of occasions in traffic roads and tunnels, underground car parks and indoor environments.
- New technologies
  – Carrier aggregation; carrier aggregation enables the use of multiple carriers in the same or different frequency bands, to increase mobile data throughput.
  – Coordinated multi-point technologies.
  – 5G frame structure.
- New network architecture
  – Back-haul and front-haul.

Carrier aggregation technologies require the time error between the base stations to be less than 260 ns. The 5G new frame structure under study may require as high as ±390 ns accuracy for the air interface to avoid interference. The 5G network will combine centralized radio access networks (C-RAN) and distributed radio access networks (D-RAN). The time synchronization should be achieved in both the back-haul and front-haul transport network.[1]

Time interval error (TIE) is the metric to specify clock accuracy/stability requirements in telecommunication standards. Of specific interest is the TIE of a network clock in holdover mode (not locked) for mobile networks. The key requirement for 5G communication networks is a TIE of 100 to 400 ns in holdover mode for 4 to 24 hours.[2]

Frequency stability versus temperature and long-term stability (aging) are the key parameters of precision frequency sources that have the greatest influence on TIE in holdover mode. This article covers measurements and some results obtained for precision frequency sources ensuring a TIE of 100 to 400 ns for 4 to 24 hours.

TIE MEASUREMENT PROCEDURE

TIE measurements are done for 3 to 7 days with periodic temperature changes. A measurement duration of 3 to 7 days is necessary to count and compensate for frequency drift due to aging. In general, it may be possible to compensate for aging in holdover mode in case there is a long term record of frequency output of a precise frequency source obtained while synchronized to an external reference. It is possible to create learning systems capable of aging compensation basing on data from the last 2 to 3 days of operation.

TIE estimation, which takes into account compensation for aging, is carried out as follows (see ***Figure 1***):

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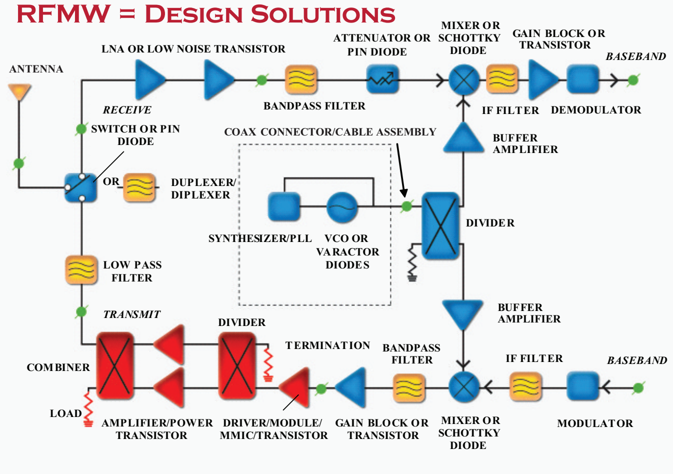

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- Choose the beginning of TIE estimation (start of the "sliding" time window). The sliding time window, moving with some step (1 to 4 hours), is applied to the data. This window consists of two parts: Fit range and TIE estimate range.
- Approximate aging. The frequency aging approximation φ(t) is built basing on readings situated inside the fit range. The fit range lasts 24 hours. According to our research, this is most optimal for the aging approximation.
- TIE estimation. Readings situated inside of the TIE estimate range are used for determining the subject time error. The time error in this range is determined by the difference between the frequency readings and the aging approximation:

$$TIE = \int \left[f(t) - \varphi(t) \right] dt \quad (1)$$

The TIE estimate range is 4 to 24 hours.

A TIE of 100 to 400 ns in holdover mode for telecom and mobile networks is used primarily for grand masters, which are installed in environmentally conditioned rooms. This means that the temperature change during the day usually does not exceed 5 Centigrade degrees.

Different temperature profiles can be used for TIE estimation. Two are

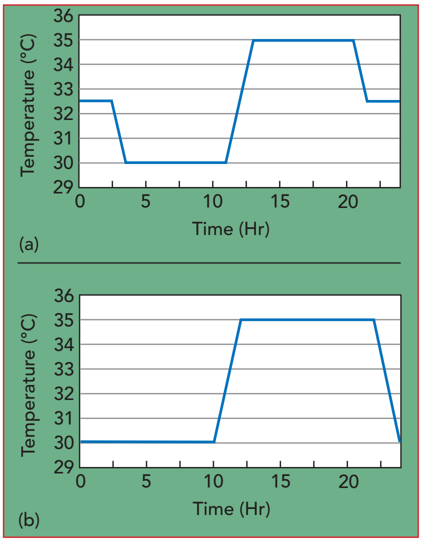

Fig. 2 Temperature profiles for TIE estimation: symmetrical (a) and asymmetrical (b).

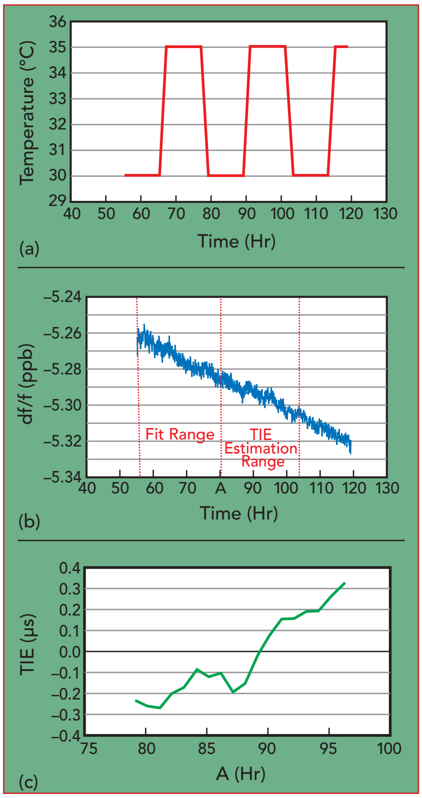

Fig. 3 24-hour TIE for a DOCXO: temperature profile during the test (a), measured frequency (b) and estimated TIE (c).

presented in ***Figure 2***. It should be mentioned that the profile of Figure 2a is symmetrical with respect to the average temperature change. Thus, the time error accumulated over 24 hours along this profile should be equal to 0 (under ideal conditions). The profile shown in Figure 2b does not have symmetry, so even under ideal conditions there is a net time error accumulated over 24 hours.

For TIE estimation we use the temperature profile from Figure 2b because it models the worst case operation of a precise frequency source. An example of TIE estimation for a double oven controlled crystal oscillator (DOCXO) using the measurement procedure described above is shown in ***Figure 3***. TIE estimation results are obtained as outlined below:

- The initial "sliding" window position (A) for the calculated approximation line is based on frequency counts situated in the fit range.
- Data inside the TIE estimation range is used for determining the time error, TIE_A, per Equation 1.
- The calculated TIE_A value is shown in Figure 3c.
- The sliding time window is stepped by 1 hour and all calculations are repeated.
- The procedure continues while the TIE estimation range is within the measurement length.

TIE MEASUREMENTS

Even negligible frequency changes influence TIE estimation results. Sources of errors should be taken into account in order to obtain reliable values of TIE. These include mutual synchronization of the frequency of individual oscillators and frequency measurement instability.

Mutual Synchronization

Mutual synchronization of oscil-

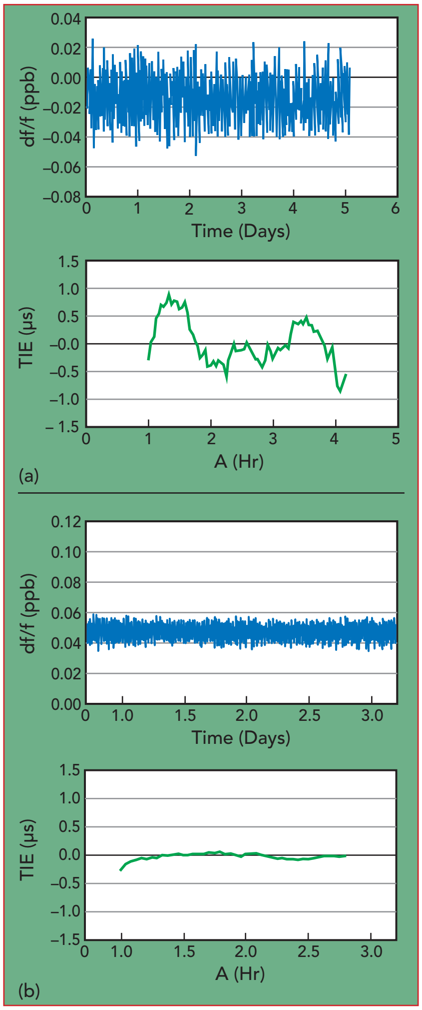

Fig. 4 Frequency and TIE estimation for a rubidium oscillator before (a) and after (b) measures to prevent mutual syntonization of frequency.

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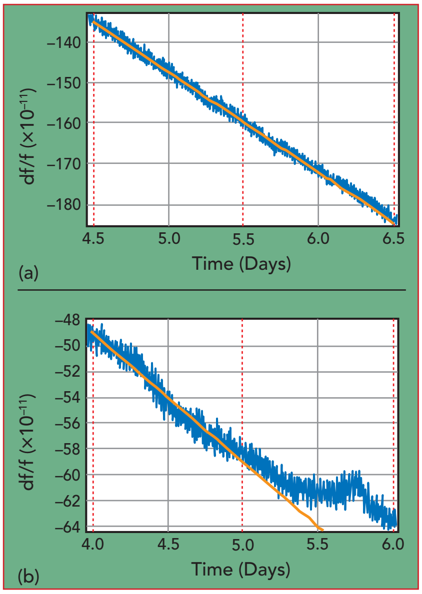
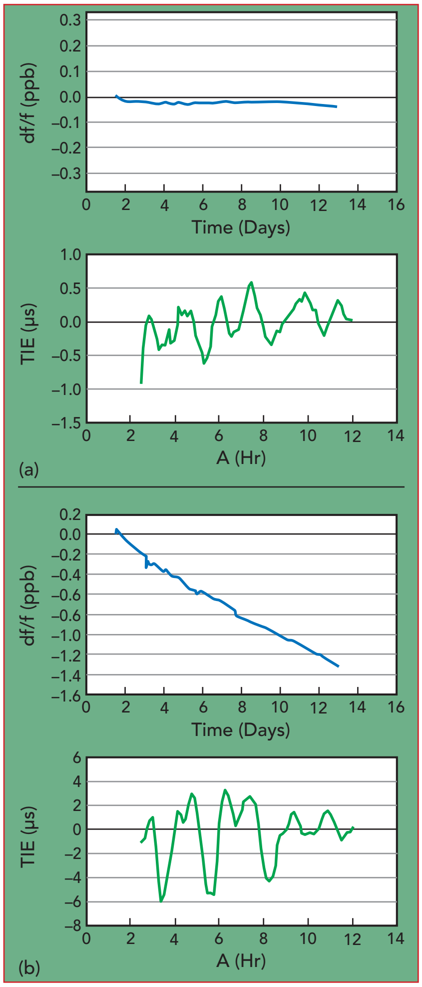
lators at close frequencies is one of the most important sources of errors for frequency measurement. This effect may be easily seen in volume production when, simultaneously, a large number of oscillators are measured. To prevent this effect, it is necessary to minimize all possible ways oscillators can influence on each other, e.g., on the common grounds of power circuits and circuits of frequency switchers, through electromagnetic coupling and through reverse signal transmission through the open channels of the switcher. As an example, ***Figure 4*** shows the results of rubidium oscillator TIE measurements before and after the implementation of the above measures.

Frequency Measurement Instability

For precision frequency sources to meet the TIE 100 to 400 ns requirement, it is extremely important to have aging curve monotonicity of about 1 to 2E-11/day. In other words, there should be no jumps or any other irregular frequency



▲ **Fig. 5** Aging curve meeting the 100…400 ns TIE requirement (a) vs. "standard" aging curve (b).



▲ **Fig. 6** Frequency and TIE for quartz oscillator without (a) and with (b) "short-term" frequency changes.


CORNING

changes. ***Figure 5*** compares aging that meets the TIE 100 to 400 ns requirement with one that does not. The reasons for "short-term" frequency changes may be explained by either contact phenomena, stability of the reference source or errors caused by internal issues in the precision frequency source.

To separate internal issues from the other phenomena, good quality connectors and precision reference sources should be used. During initial measurements we found that some precision rubidium oscillators, regardless of the manufacturer, dramatically changed frequency in increments ranging from 5E-12 to 5E-11. Knowing this, we now use a hydrogen frequency standard for 100 to 400 ns TIE measurements. A TIE measurement for a quartz oscillator with and without "short-term" frequency changes is shown in ***Figure 6***.

TIE measurements will be reliable if all factors listed above are taken into account. Examples of TIE measurements over 4, 8, 16 and 24 hours are shown in ***Figure 7***.■

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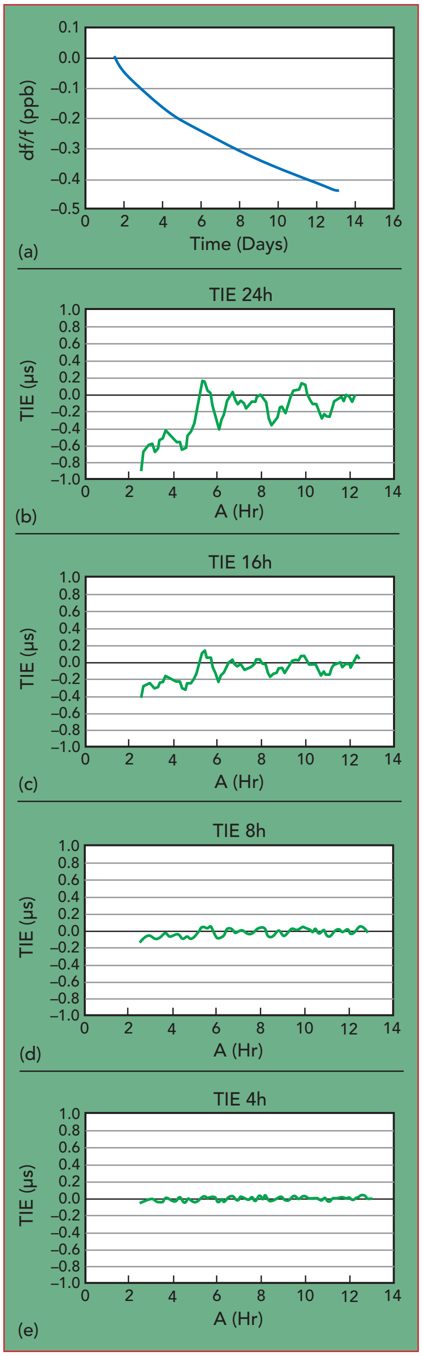
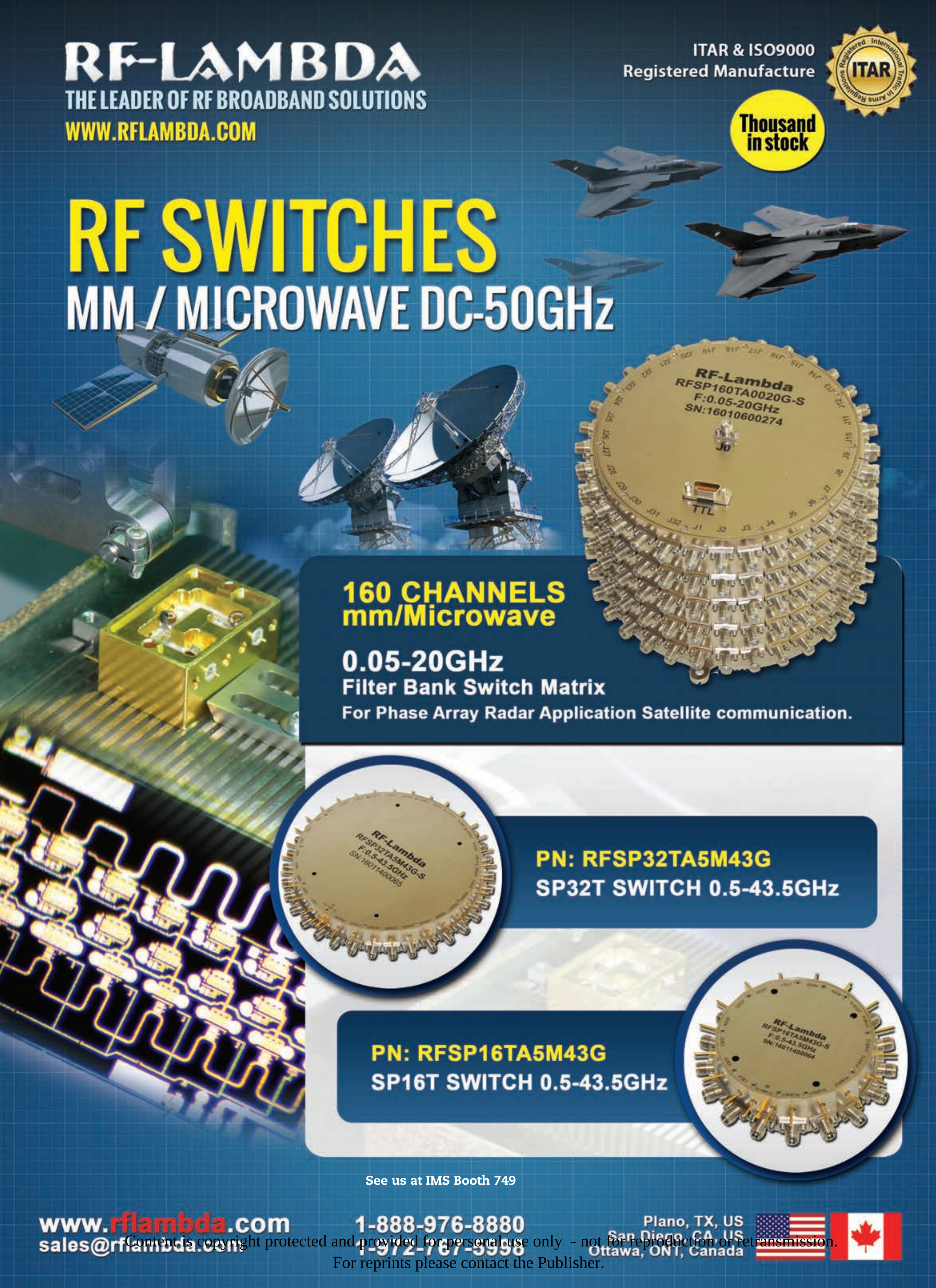


▲ **Fig. 7** TIE measurements at 24, 16, 8 and 4 hours.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INVITED PAPER

RF GaN on Si Meets CMOS Manufacturing

Tim Boles
MACOM, Lowell, Mass.

Ferdinando Iucolano
STMicroelectronics, Catania, Italy

Since its inception, GaN has shown the potential to transform the RF technology landscape, promising major disruptions across multiple markets. Carefully nurtured from fledgling technology to widescale deployment, GaN's inherent performance advantages over legacy technologies gained early traction for military applications, where performance far outweighs cost considerations.

GaN's pathway to mainstream RF commercialization hinges on its ability to support the volume and cost requirements of end applications, including 4G and 5G base stations and emerging RF energy applications—cooking, lighting, industrial heating and drying, medical, pharmaceutical and automotive ignition systems. Cost sensitivities are compounded by the growing need for more integrated components, e.g., MMICs, particularly for dense architectures like massive MIMO antenna systems for 5G base stations. Integrated packaging introduces additional cost that must be offset by lower semiconductor manufacturing costs.

The sheer volume of GaN production required by price-sensitive commercial RF applications and the demands these markets place on the semiconductor supply chain eliminate GaN on SiC as a viable contender, given SiC's extremely slow ingot growth rate and the present inability to scale GaN on SiC wafer production beyond 6 in. wafer diameter. This leaves GaN on Si technology as the only viable way forward for the commercial development of GaN. However, to meet the volume, cost and surge capacity requirements for mainstream RF commercial markets, GaN on Si production must be ported from III-V compound semiconductor foundries to mainstream CMOS manufacturing lines.

PROCESS DISCIPLINE

In addition to supporting higher production volumes and wafer diameters up to 12 in. on a fully automated platform, CMOS fabs offer the opportunity to exploit strict process controls to achieve more repeatable performance and extremely high line yield, which will drive additional cost reduction. The equipment used in CMOS fabs is more automated and advanced, and the existing silicon manufacturing infrastructure offers opportunities to spread overhead costs for volume microwave GaN on Si production, further reducing the overall cost structure.

To make the jump from III-V to CMOS-based GaN on Si fabrication, considerable effort is required to conform

to standard CMOS process nodes—which produce thousands of wafers in a single week. The respective process modules employed in III-V and CMOS wafer fabrication are significantly different. While III-V allows for a degree of flexibility in the workflow, CMOS production flows require strict adherence to distinct and individually optimized modules. There is simply no allowance for individual adjustment to the workflow outside of these highly defined modules.

The rigidity of this approach fulfills an expectation that all processes will work in production the first time and every time—a core philosophy for high volume fabrication. These stringent process controls are designed to produce robust processes that will meet the required fine-line photolithography processes commonly employed in CMOS fabs, with no ability to rework process steps. This approach to wafer fabrication contrasts sharply with typical III-V manufacturing, where in-line wafer scanning electron microscopy is routinely used to adjust fine-line photolithography parameters in an attempt to "inspect in" quality. With CMOS, process disciplines must be airtight from the beginning, or yield and cycle time will suffer.

MAJOR CHALLENGES

Semiconductor surface passivation is a key consideration when transitioning GaN on Si from III-V to CMOS fabrication, given the different surface chemistries each process platform uses. Fortunately, because the properties of GaN on Si HEMT technology are, in many respects, more closely related to silicon than GaAs, industry standard silicon cleans and surface treatments can be used, with more aggressive mixtures of mineral acid/peroxide or hydroxyl/peroxide solutions to prepare the surface for subsequent process steps.

CMOS-based GaN on Si fabrication also takes advantage of advanced atomic layer deposition (ALD) and atomic layer etching (ALE) technologies that are not typically found in III-V fabs. Commercial ALD/ALE systems are capable of depositing high density films with excellent material quality and exceptional uniformity, thickness control and reproducibility, forestalling the possibility of surface damage by avoiding the use of plasma enhancement during the deposition. Films as thin as 50 Å and up to 1.0 μm thickness are routinely applied to silicon with a host of metal oxides and nitrides.

The hardest challenge porting GaN on Si to a CMOS fab is the use of gold for device metallization. Gold has been universally used for all GaN production in III-V fabs because of its low electrical bulk resistivity and excellent electromigration properties. In CMOS fabs, gold is never used in front-end processes because it causes electron recombination traps that destroy the fundamental electron mobility in the device structure. This means that all metallization used in GaN on Si high


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frequency devices to form the gate—the heart of the device—must be changed to different metals, which impacts the chemicals employed in the process, with significant implications for surface characteristics and overall device performance. Intensive R&D in this area yielded new metallization solutions to overcome this challenge and make it viable for GaN on Si to be produced in CMOS fabs without using gold. This is possible using non-gold ohmic contacts, nickel aluminum gate metallization and interconnects formed from either aluminum or copper.

Wafer thickness is another critical consideration when porting GaN on Si production to a CMOS fab. Wafers produced in III-V fabs for high frequency devices must be as thin as 50 µm, for thermal and electrical performance, and are manually mounted and dismounted. Significant wafer bow—up to several millimeters—creates a high risk of wafer breakage, leading to yield loss and higher cost. In contrast, wafers produced in CMOS fabs can produce wafers in the 50 to 60 µm range, in which the mounting and dismounting is fully automated. Strict process controls were developed for the CMOS fab to ensure that ultra-thin GaN on Si wafers do not suffer from "potato chip" curling and wafer breakage. It is now possible to produce GaN on Si wafers that measure 2 µm in flatness across the 6 in. wafer, by leveraging the CMOS fab processes, and new techniques were developed to allow source vias to be formed from the backside of the GaN on Si wafer in a manner consistent with III-V performance requirements.

PERFORMANCE AND RELIABILITY

MACOM and STMicroelectronics' (ST) joint development effort to port the GaN on Si process yielded CMOS-manufactured, high frequency GaN on Si devices that exhibit equivalent performance to GaN on Si devices produced in III-V fabs (see ***Figure 1***). RF load-pull of 600 µm test structures at 2.5 GHz achieve essentially identical output power, high frequency gain and power-added efficiency, comparing ST wafer fabrication facilities with a III-V fab.

In terms of reliability, RF GaN on Si devices produced in the CMOS fab meet the fabs' reliability standards and, in some cases, outperform the reliability achieved with legacy semiconductor technologies—with a path to meet more demanding reliability requirements. Qualification testing of GaN on Si

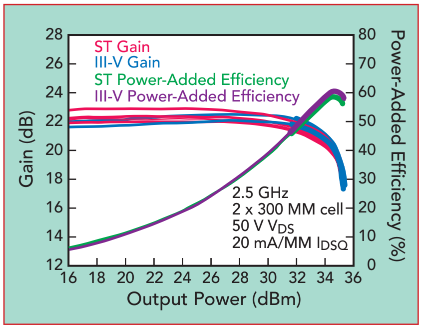

Fig. 1 Load-pull measurements at 2.5 GHz, comparing 600 µm test structures fabricated on STMicroelectronics' 6 in. silicon fab and MACOM's 4 in. III-V fab.

has been successfully accomplished across a wide range of tests, including highly accelerated stress tests (HAST), high temperature operating life (HTOL), high temperature reverse bias (HTRB), accelerated life testing (ALT) and routine testing for electrostatic discharge (ESD), intermittent operating life (IOL), temperature cycling, mechanical shock and vibration and destructive physical analysis (DPA). ***Figure 2*** shows the stability of RF output power for a population of microwave GaN on Si devices subjected to HAST, and ***Figure 3*** shows minimal change in RF power for 231 devices after HTOL testing.

OPPORTUNITY AWAITS

MACOM and STMicroelectronics collaborated for well over a year to port high frequency GaN on Si production to ST's CMOS wafer fabs, with sample production planned to begin in 2018. The ability to manufacture microwave GaN on Si devices in a CMOS fab opens the door to a new world of possibilities, including the homogenous integration of GaN and CMOS-based high frequency devices on a single chip. These multi-function RF devices will combine GaN's power and high frequency benefits with digital control. The R&D to enable this is already underway. High-power digital-to-analog converters, microprocessors and on-wafer wireless transmitters are among the many candidates for single-chip integration.

With the successful porting of RF GaN on Si production to CMOS fabs, GaN on Si technology is uniquely positioned to meet the performance, cost structure, manufacturing capacity and supply chain flexibility requirements of 4G and 5G wireless base station infrastructure, expanding to address solid-state RF energy applications. While the process challenges that were overcome to achieve this goal were myriad and significant, with a small margin for error, the advantages far outweighed the limitations and have enabled a new era in RF technology to begin.■

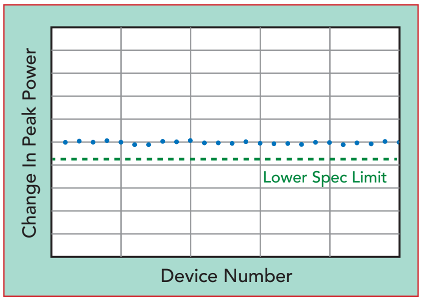

Fig. 2 Change in peak output power following HAST on a sample of 25 GaN on Si devices fabricated by STMicroelectronics' 6 in. silicon fab.

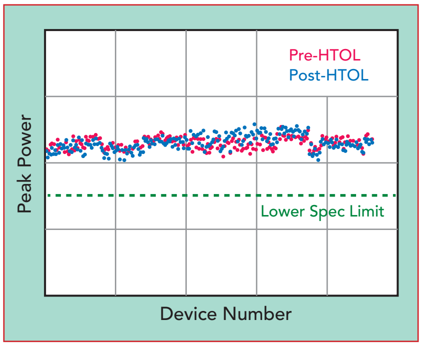

Fig. 3 Peak output power before and after HTOL testing for 231 GaN on Si devices fabricated by STMicroelectronics' 6 in. silicon fab.

INVITED PAPER

Advanced GaAs Integration for Single Chip mmWave Front-Ends

David Danzillio
WIN Semiconductors, Taoyuan City, Taiwan

The next generation mobile network, 5G, is envisioned as a flexible, efficient and resourceful platform offering advanced capabilities that will form the core of future use cases and new businesses opportunities. While these future applications are impossible to predict, they will depend on connectivity to a new radio access network that provides higher bandwidth, ultra-high reliability and low latency. Today, only a few 5G services have been identified; the most promising are fixed wireless access (FWA) and enhanced mobile broadband (eMBB) services.

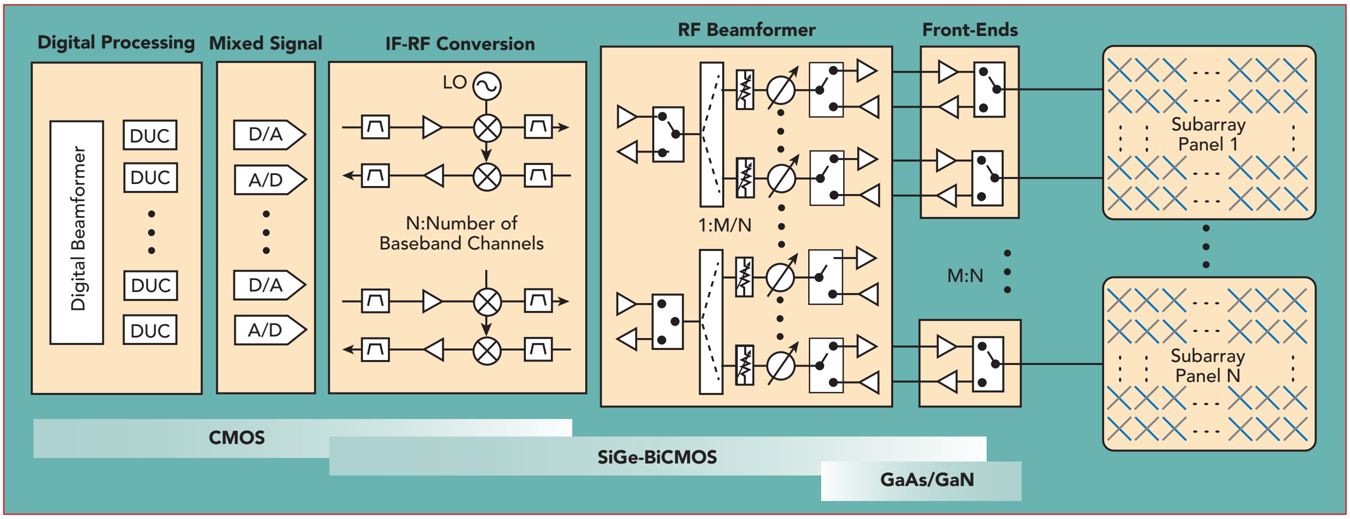

Fig. 1 Simplified block diagram of mmWave phased array using hybrid beamforming.

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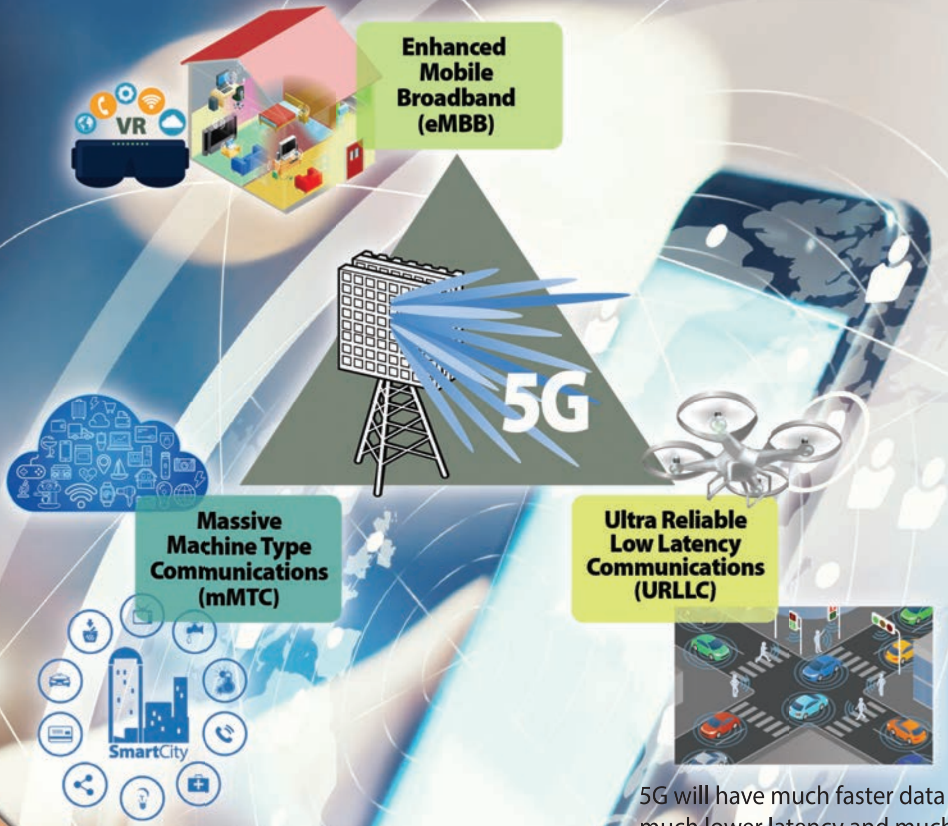

Circuit materials for the next generation of wireless communications

The next generation of wireless communications is the Fifth Generation (5G). 5G will have much faster data rates, much higher capacity, much lower latency and much higher connection density. It will enable many new use cases, such as 4K/8K video, AR/VR, industry robots, remote diagnostic, autonomous driving cars, and billions of IoT connections across various vertical industries. 5G will far outperform current 4G LTE-A networks, but the transition to 5G will require more advanced RF components to operate across low, mid and high frequencies. These RF components start with high-performance circuit materials from Rogers Corporation.

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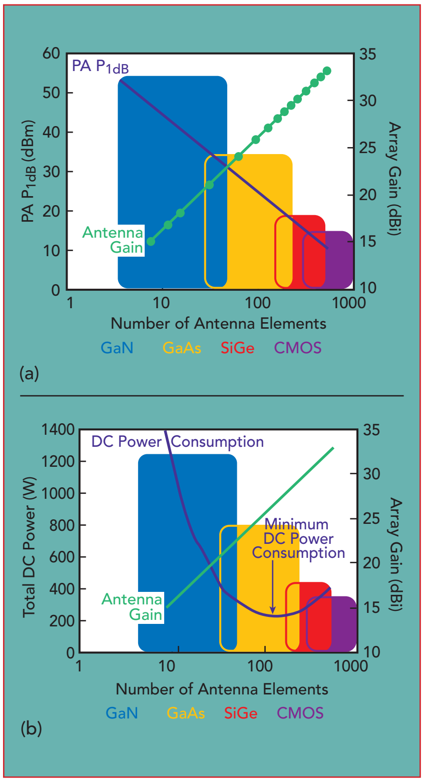

Fig. 2 Phased array trade-offs: PA output power (a) and array DC power consumption (b) vs. number of antenna elements to achieve 60 dBm EIRP, with overlay of semiconductor technology capabilities.

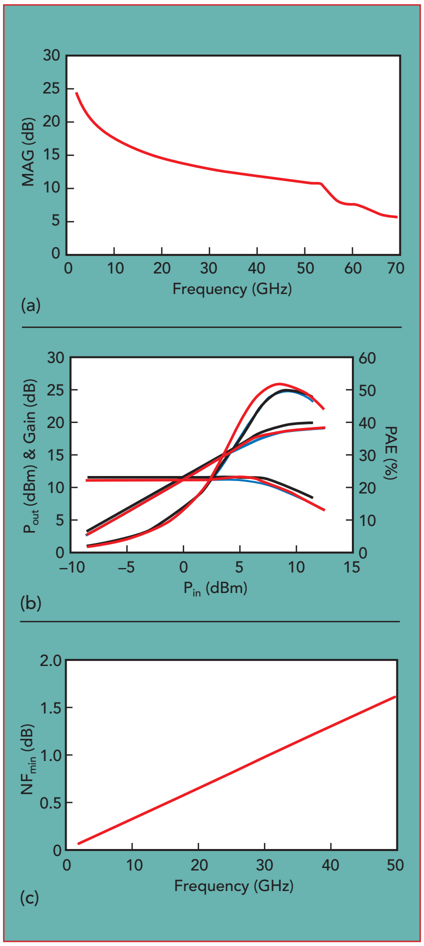

Fig. 3 PIH1-10 GaAs process performance: MAG of 2 x 50 μm PHEMT unit cell with V_D = 4 V and V_G at 100 mA/mm I_D (a); 2 x 75 μm unit cell gain, output power and PAE vs. input power at 29 GHz, with V_D = 4, 5 and 6 V (b); 4 x 25 μm PHEMT noise figure vs. frequency with V_D = 2 V and V_G at 100 mA/mm I_D (c).

To meet the multiuser demands of FWA and eMBB, network operators are planning to deploy microcell/picocell access points that use active antenna arrays and beamforming to precisely control high bandwidth connections. These active array solutions rely on multiple RF transmit/receive (Tx/Rx) chains to form and scan the beams, with the spacing between each antenna one-half the wavelength (λ/2). With increasing transmit frequency, the spacing between antennas becomes quite small; e.g., for a 28 GHz antenna array, the spacing is 5 mm. The limited area for component placement and the Tx/Rx performance requirements for mmWave antenna arrays creates an entirely new set of challenges for the semiconductor technology used in the front-ends.

HYBRID BEAMFORMING

The literature contains numerous studies evaluating digital, analog and hybrid beamforming architectures, offering multiple perspectives.[1-3] Ultimately, the architecture choice depends on the power consumption, cost and performance requirements for the access point. Hybrid beamforming is emerging as the favored architecture for mmWave active antennas, as it enables using the optimum semiconductor technologies across the system. A simplified block diagram of such a system[2] is shown in ***Figure 1***, which also shows the preferred semiconductor technologies for the functional blocks.

An important trade-off is between array size (the number of antennas) and total array power consumption. This trade-off is driven by the transmit power of each antenna element, determined by the semiconductor technology employed for the front-end power amplifier (PA). An excellent illustration of this is shown in ***Figure 2***, which repre-


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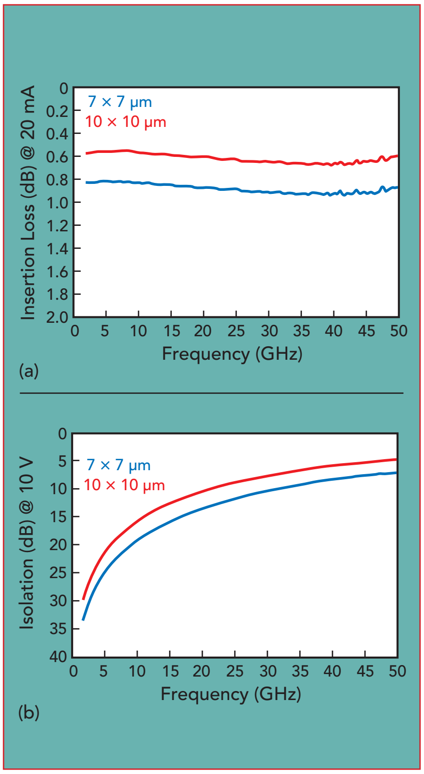


Fig. 4 Insertion loss (a) and isolation (b) vs. frequency of single, shunt PIN diodes, comparing 7 x 7 and 10 x 10 μm diodes.

sents a 28 GHz system with 60 dBm effective isotropic radiated power (EIRP).[1] The takeaways from these graphs are:

- The target EIRP can be satisfied with a wide range of PA power levels, as shown in Figure 2a,
- Antenna gain increases with the number of elements, also shown in Figure 2a and
- As the number of antenna elements increases, with lower transmit power per element, the total array DC power decreases, reaching a minimum at approximately 128 elements, then increases, as shown in Figure 2b.

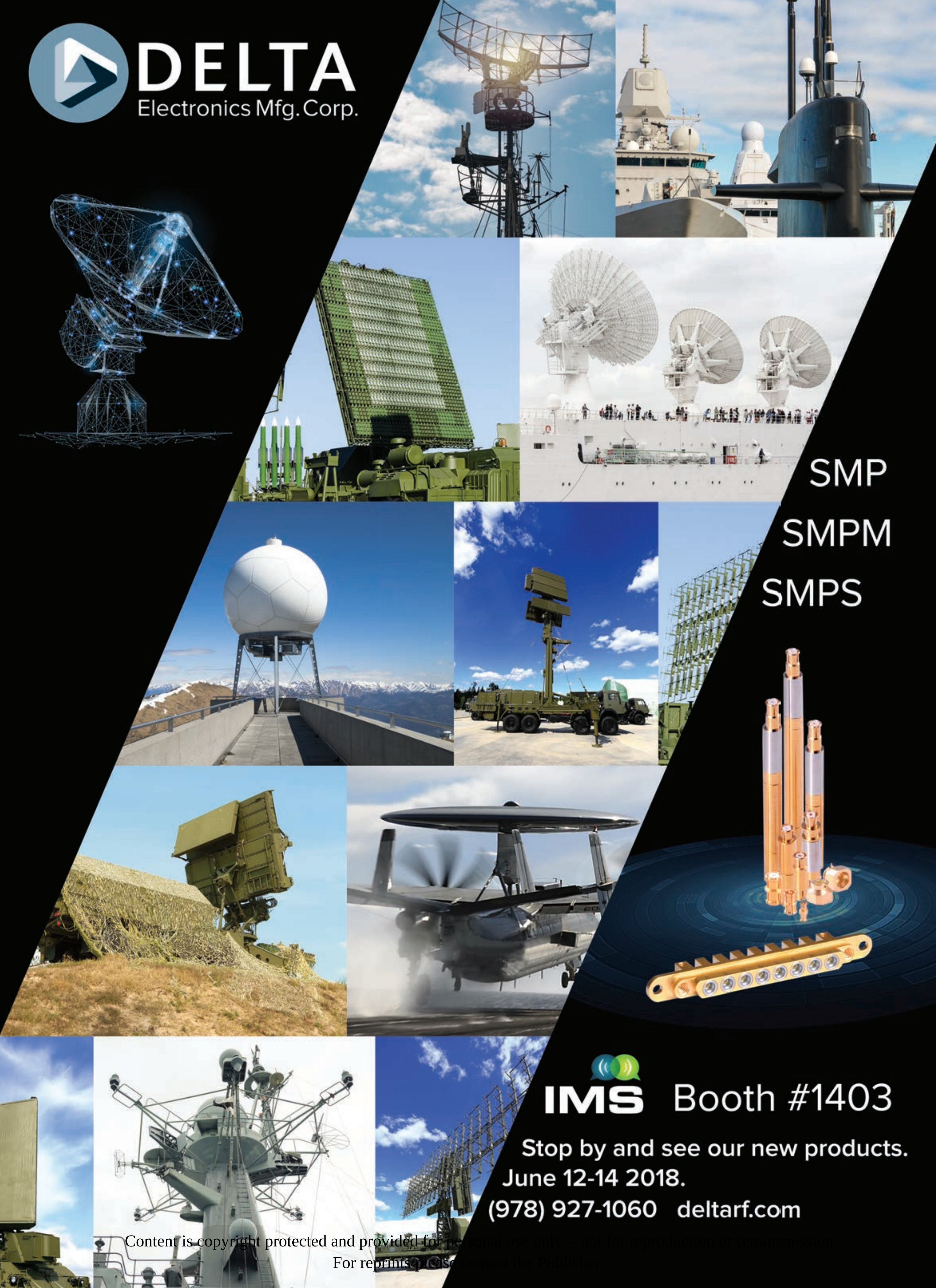
As more antenna elements are added to accommodate the lower P_{1dB} available from SiGe and CMOS PAs, more power is consumed by the front-ends and beamformer ICs that feed and control these channels. One example of this is a fully integrated, dual polarized, 28 GHz, SiGe beamformer IC with 16 elements.[4] With a die size over 160 mm^2, the majority of which is the front-end, this component consumes a considerable amount of silicon. One may extrapolate this to an array of several hundred antenna elements and quickly realize the cost, size and assembly challenges that result from a suboptimal choice of front-end semiconductor technology.

This analysis of the effect of front-end semiconductor technology on the total power consumption of the array shows that a GaAs PA will result in the minimum power consumption. The cited literature contains additional studies of active array antenna systems and reaches similar conclusions that GaAs represents the optimum technology choice for mmWave front-ends. These references acknowledge GaAs can provide the optimum range of PA performance but claim GaAs cannot fit within the λ/2 antenna spacing of the antenna elements (e.g., 5 mm at 28 GHz). Historically, multifunction integration has been a weakness for GaAs technology, particularly for short gate length processes used at mmWave.

INTEGRATED GaAs

Owing to its dominant share of cellular and Wi-Fi RF front-ends used in mobile devices, GaAs manufacturing continues to advance and now offers best-in-class performance and the integration required for mmWave active antenna systems.

Long ago, the mmWave performance of GaAs PHEMT devices exceeded the optimum power levels needed for FWA active antenna arrays; however, a more advanced platform was required to satisfy the spacing requirements. To meet the size requirements of mmWave active antenna arrays and provide additional capabilities for more complex applications, advanced compound semiconductor manufacturers now offer innovative GaAs PHEMT technologies that monolithically integrate the Tx PA, Rx LNA and low loss PIN switch in a single chip mmWave front-end. In addition to these functions, platforms like WIN Semiconductors' PIH1-10 provide a linear Schottky diode for power detectors and mixers, low capacitance PIN diodes for ESD protection and optimized E/D transistors for logic interfaces. This suite of capabilities comes in a hu-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midity-rugged back-end, available with a copper redistribution layer and copper pillar bumps to reduce die size and allow flip chip assembly, enabling GaAs front-ends to fit within 28 and 39 GHz antenna lattice spacing.

mmWAVE PERFORMANCE

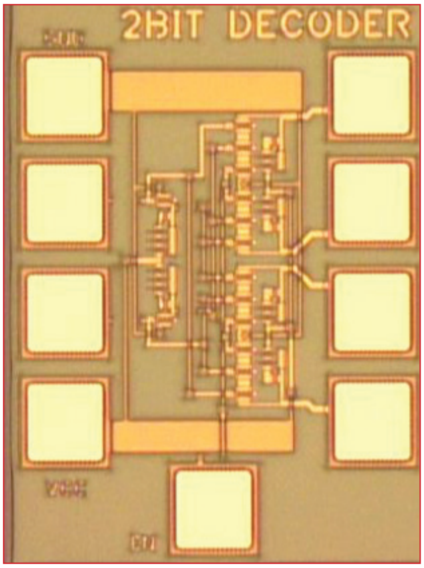
The core of these integrated technologies is a versatile enhancement-mode PHEMT transistor that provides excellent power, gain, power-added efficiency (PAE) and noise figure at mmWave frequencies and is biased from a single positive supply. ***Figures 3a*** and ***b*** show measurements of the maximum available gain (MAG) and 29 GHz load-pull taken at V_D of 4, 5 and 6 V. The MAG is stable to 50 GHz, confirming the device can cover both the 28 and 39 GHz 5G bands. The enhancement-mode PHEMT can be biased up to 6 V, where it provides a P_{1dB} power density of over 0.7 W/mm and a typical peak PAE of 50 percent. Noise performance is shown in ***Figure 3c***, demonstrating the versatility of the mmWave enhancement-mode PHEMT. The transistor exhibits less than 1 dB noise figure at 28 GHz and approximately 1.3 dB at 38 GHz.

As noted, the PIH1-10 platform provides a monolithic PIN diode to realize an on-chip T/R switch. ***Figure 4*** shows the insertion loss and isolation for a single diode in a shunt configuration; two diode sizes are measured (7 x 7 and 10 x 10 μm), exhibiting insertion losses of approximately 0.6 and 0.9 dB, respectively.

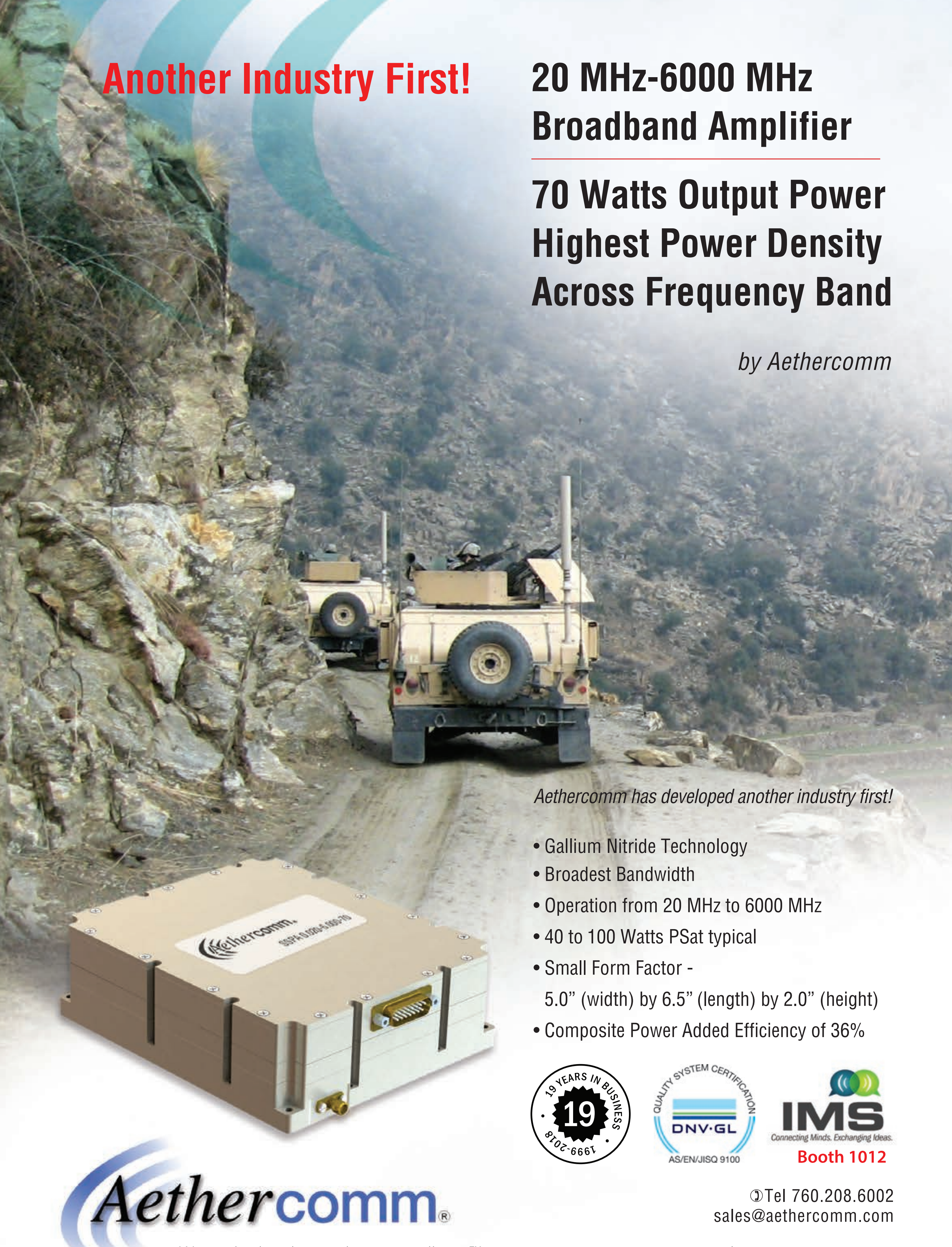
ADDED FUNCTIONS

To meet the requirements of mmWave front-ends, the chosen process platform must provide excellent power and noise performance and have a low loss switch capability. However, that is not enough to provide a truly integrated front-end solution. To extend the feasibility of GaAs, several historic weaknesses of PHEMT technology must be addressed: adding multiple diode types for ESD protection, mixers and power detectors and standard logic cells and circuits for biasing and control interfaces.

The availability of on-chip logic is particularly important for active



▲ **Fig. 5** 2-bit decoder logic function, one of several logic cells available in E/D PHEMT GaAs process.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antenna arrays, as it simplifies the interface with the beamformer IC. A library of logic solutions, such as the 2-bit decoder shown in ***Figure 5***, is available and continually expanding with more logic functions. These capabilities have been incorporated into the baseline PHEMT technology and are provided to the user as process options to meet application requirements. By adding libraries of logic cells and ESD reference circuits, GaAs technology offers users an entirely new toolset to support high performance mmWave front-ends.

In addition to functionality, the GaAs PHEMT platform must enable compact front-ends that fit within the 5 mm antenna spacing at 28 GHz or the 3.75 mm at 39 GHz. As excessive transmission losses at these frequencies are costly, the front-end components should be close to the antenna elements. The industry's expectation is for the front-end MMICs to be attached directly to the antenna boards, which requires a chip scale package. To enable this assembly capability and minimize MMIC size, advanced platforms such as PIH1-10 incorporate a copper redistribution layer with copper pillar bumps. With the inherent humidity resistance of the technology, a chip scale, mmWave front-end can be realized.

SUMMARY

mmWave access points using active antenna arrays will play an important part in the development of 5G network services. As the industry adopts hybrid beamforming, designers will have more flexibility when choosing semiconductor technologies to meet specific use cases. Stringent performance specifications demand best-in-class semiconductor technology for front-end PAs and LNAs. Advanced and highly integrated GaAs PHEMT platforms will be a competitive technology to lower hardware costs and enable high performance, single chip, mmWave front-ends.■

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Integrated Dual Polarized Scalar Horn Antenna Covers 24–42 GHz

SAGE Millimeter Inc.
Torrance, Calif.

In the race to develop 5G mmWave hardware, accurate and efficient tools for measuring antenna performance are required to keep pace. SAGE Millimeter's model SAF-2434231535-358-S1-280-DP is a dual polarized, scalar, feed horn antenna assembly that covers all 5G frequency bands in the range from 24 to 42 GHz. An integrated orthomode transducer (OMT) yields orthogonal wave components when the antennas is used as a receiver and delivers full polarization agility when used as a transmitter. Both modes benefit from 15 dBi of mid-band gain, with 35 dB port isolation and 35 dB cross-polarization rejection.

POLARIZATION DIVERSITY

As a receiver (see ***Figure 1***), the antenna assembly can be combined with a pair of down-converters driven from a common local oscillator (LO). The down-converted signals are fed to a vector signal analyzer or a dual-channel oscilloscope to simultaneously resolve horizontal and vertical wave components and their phase relationship, providing polarization information. When used as a signal source (see ***Figure 2***), the antenna can be combined with a pair of up-converters that are fed from a common LO and driven by a vector signal generator. This configuration can generate any linear, circular or elliptical polarization.

Highly repeatable results are obtained when adjustments are made electronically, rather than more commonly switching antennas and other hardware to change polarization and frequency. As a result, the integrated antenna saves both time and cost, avoiding additional antennas, cables, fixtures and electronic components.

Applications for the dual polarized antenna assembly include characterizing mobile and fixed antennas and measuring propagation effects in complex environments. Such assessments are essential to maximize 5G system performance over the full range of operational settings. The feed's dual polarization and wide bandwidth are also well suited for advanced frequency-agile radar systems and high speed data communications.

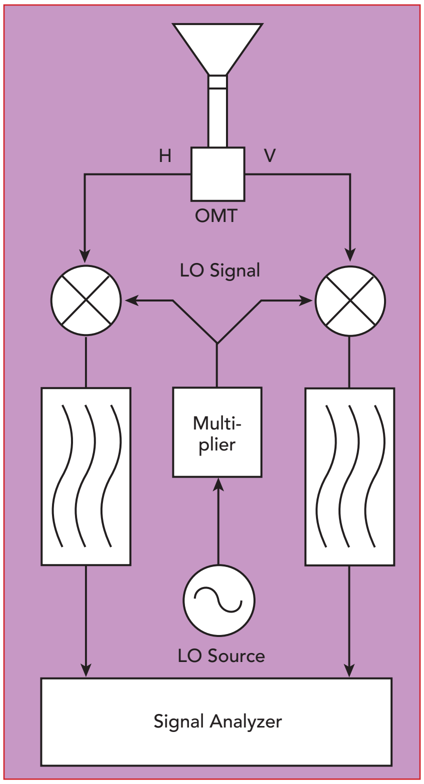

Fig. 1 The amplitude and polarization of a received signal can be determined using two down-converters, a common LO and vector signal analyzer.

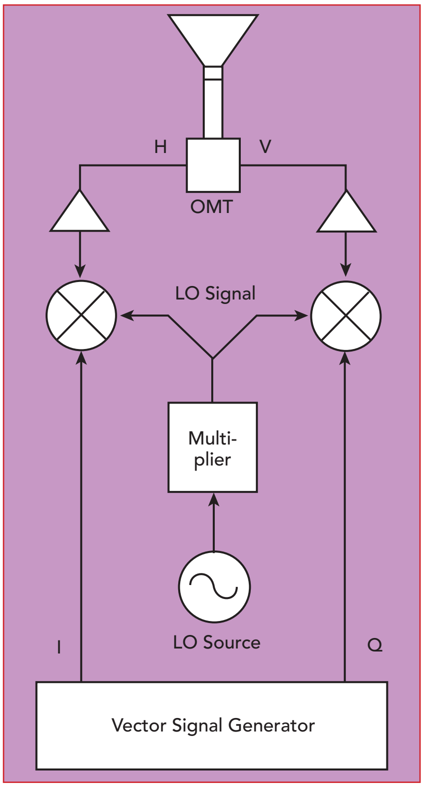

Fig. 2 A signal with adjustable amplitude and polarization can be generated using two up-converters, a common LO and vector signal generator.

CONSISTENT PERFORMANCE

The E- and H-plane antenna patterns have sidelobe levels below -25 dB across the full operating spectrum (see ***Figure 3***). The feed achieves good quiet-zone performance in anechoic chambers with limited size and absorption characteristics, making it a good fit for cost-sensitive antenna ranges. The antenna's 3 dB beamwidth is matched at 35 degrees for both the E- and H-planes. Return loss for the OMT ports is better than 20 dB, typically 25 to 30 dB (see ***Figure 4***).

Constructed from gold-plated aluminum and brass, the antenna operates from -40°C to +85°C. Both ports are standard WR28 waveguide with UG-599/U flanges and 4-40 threaded holes. The overall length of the assembly is 4.1 in. (104 mm). The horn's maximum diameter is 1.6 in. (40.6 mm).

INTEGRATED SOLUTIONS

Good cross-polarization rejection, important for accurately controlling antenna polarization, relies on a high degree of symmetry in

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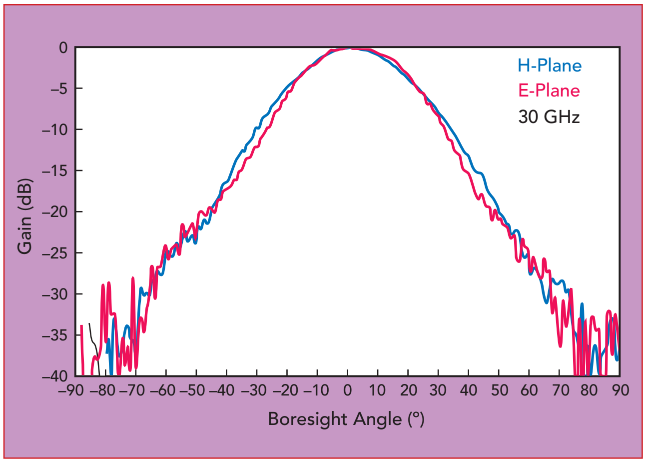

Fig. 3 **From 24 to 42 GHz, the antenna typically achieves 15 dBi gain with a 3 dB beamwidth of 35 degrees.**

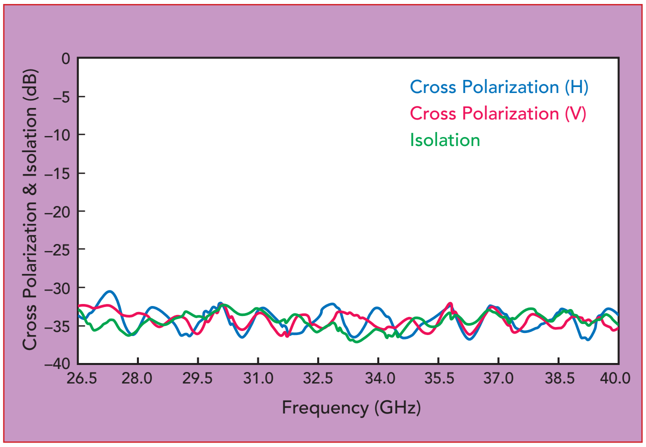

Fig. 4 **Low cross-polarization and high isolation between OMT ports enable good control of the antenna's transmit and receive polarizations.**

the construction of the OMT and the scalar horn, with minimal mechanical gaps or misalignments between the components. As an integrated assembly, the antenna maximizes performance while allowing users to avoid the difficult tasks of separately purchasing a feed horn and OMT, then assembling precisely, testing in a calibrated antenna range and adjusting to optimize performance.

To meet a wide range of test and measurement needs, the antenna can be integrated with a variety of off-the-shelf components, including signal sources, variable attenuators, phase shifters, frequency converters, filters and customized instrumentation. The antenna can be combined with a dielectric lens or a Cassegrain reflector to achieve higher gain for radar and communication applications.

VENDOR**VIEW**

SAGE Millimeter Inc.
Torrance, Calif.
www.sagemillimeter.com

VNA Test Port Adaptors to 70 GHz

Rosenberger
Fridolfing, Germany

When testing, as well as selecting the right test equipment to do the task efficiently and effectively, it is just as important for the adaptors and cables used to connect to the device under test (DUT) to be equipped and suitable for the job, with minimum loss and secure connections. They also need to be rugged and adaptable for testing a variety of applications, such as telecommunications, data systems, medical electronics, industrial electronics, test and measurement, aerospace and automotive electronics.

With these requirements in mind, Rosenberger has revised and expanded its product range of high-quality, ruggedized test port adaptors for vector network analyzer (VNA) test applications, to provide the connection required when using network analyzers with various test devices and equipment. The product range now covers RPC-3.50, RPC-2.92, RPC-2.40 and RPC-1.85 in-series and inter-series test port adaptors for frequencies up to 70 GHz. Inter-series adaptors RPC-3.50, RPC-2.92 and RPC-2.40 to RPC-N and RPC-7 are also available.

RUGGEDIZED CONSTRUCTION

Of particular importance is the ruggedized construction of the adaptors, reducing mechanical abrasion to a minimum and ensuring reliable protection of VNA test ports. Designed to connect directly with a ruggedized coupling nut to the VNA test port, these high-quality test port adaptors offer significant, practical features. For instance, they are usable for all common VNAs, offer reliable protection of VNA test ports and provide cost savings by reducing VNA down-time and minimizing repair costs. They are claimed to deliver excellent measurement performance due to restricted connection dimensions on the adaptor DUT side, as well as providing reliable measurements of solely the devices and not of the complete test setup.

Figure 1 shows the typical insertion loss and return loss of these test port adaptors, illustrated by the RPC-3.50 female to male configuration. The female versions are mateable with all common VNA test ports and all common standard series. Similarly, the male versions are mateable with all common standard series, for example with ruggedized and non-ruggedized female connectors.

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Remcom's Device Design Workflow

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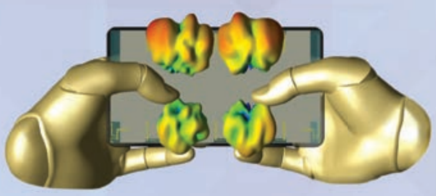

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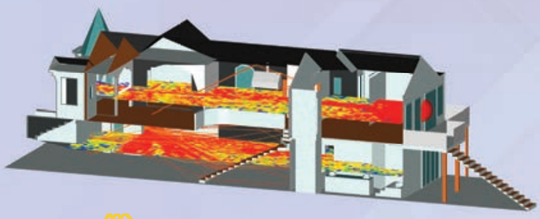

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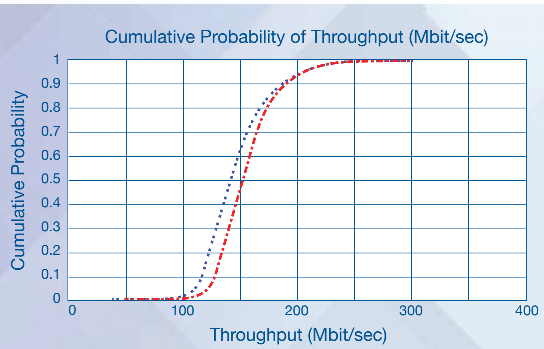

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Taking each of the range of adaptors in turn, the RPC-3.50 test port adaptors (see ***Figure 2***)—interface to IEC 60169-23—mate with APC-3.50, GPC-3.50, SMA, K and RPC-2.92 connectors. These test port adaptors operate to 18 or 26.5 GHz, with in-series and inter-series adaptors available, which are RPC-3.50 to RPC-N and RPC-7, respectively.

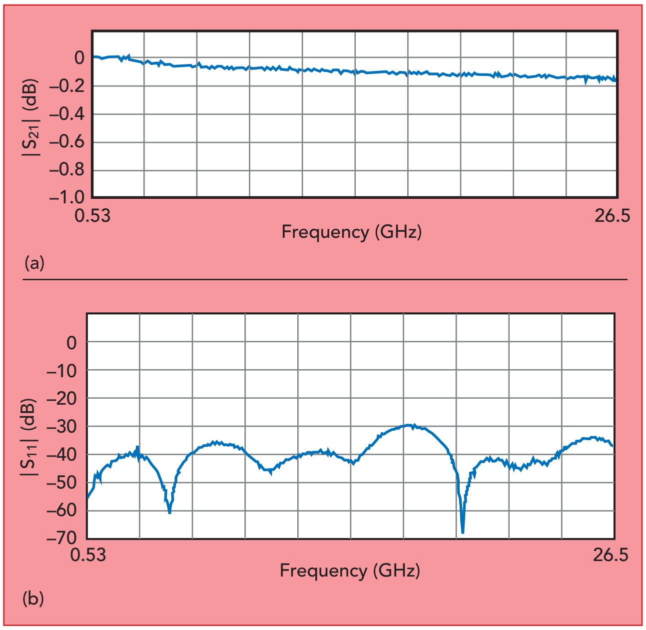


Fig. 1 Typical insertion loss (a) and return loss (b) of a Rosenberger test port adaptor, illustrated by the RPC-3.50 female to male adapter.

The RPC-2.92 test port adaptors—interface to IEC 61169-35—mate with APC-3.50, GPC-3.50, SMA, K and RPC-3.50 connectors and operate in the 18 or 40 GHz range. Again, in-series adaptors—RPC-2.92 to RPC-N—as well as inter-series adaptors—RPC-7—are available.

The RPC-2.40 test port adaptors—interface to IEC 61169-40—mate with APC-2.40, OS 50, HP-2.40 or RPC-1.85 and V connectors. These test port adaptors operate to 18, 40 or 50 GHz. Also available are in-series adaptors—RPC-2.40 to RPC-N and RPC-7—along with inter-series adaptors—RPC-2.92.

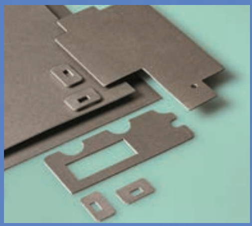
Fig. 2 RPC-3.50 test port adaptor, which operates to 18 or 26.5 GHz.

Fig. 3 RPC-1.85 test port adaptor extends the frequency range to 70 GHz.

Extending the range to 70 GHz is the RPC-1.85 test port adaptor (shown in ***Figure 3***)—interface to IEC 61169-32—that mate with V or RPC-2.40, APC-2.40, OS 50 and HP-2.40 connectors. They are available as in-series adaptors, female and male.

Rosenberger is certified to IATF 16949:2016, ISO 9001 and DIN EN 9100 and runs an accredited calibration laboratory in accordance with DIN EN ISO 17025 (DAkkS). Like all of the company's products, the test port adapters are made to the highest standards.

Rosenberger
Fridolfing, Germany
www.rosenberger.com



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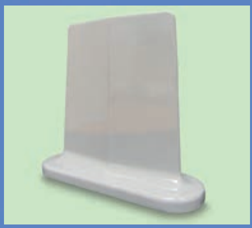

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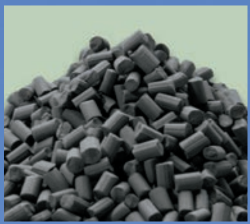

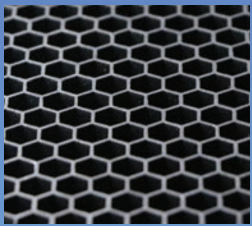

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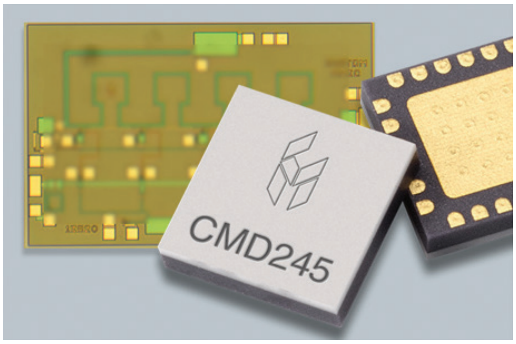


Low Phase Noise Amplifiers Improve Receiver and Radar Performance

Custom MMIC
Chelmsford, Mass.

A microwave system's phase noise impacts everything from target acquisition in radars to spectral integrity in communications systems, with direct down-conversion receivers and radar transceivers especially sensitive to phase noise. A new line of low phase noise amplifier (LPNA) MMICs from Custom MMIC was developed to address this problem.

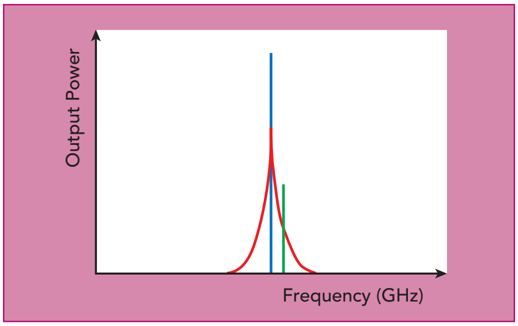
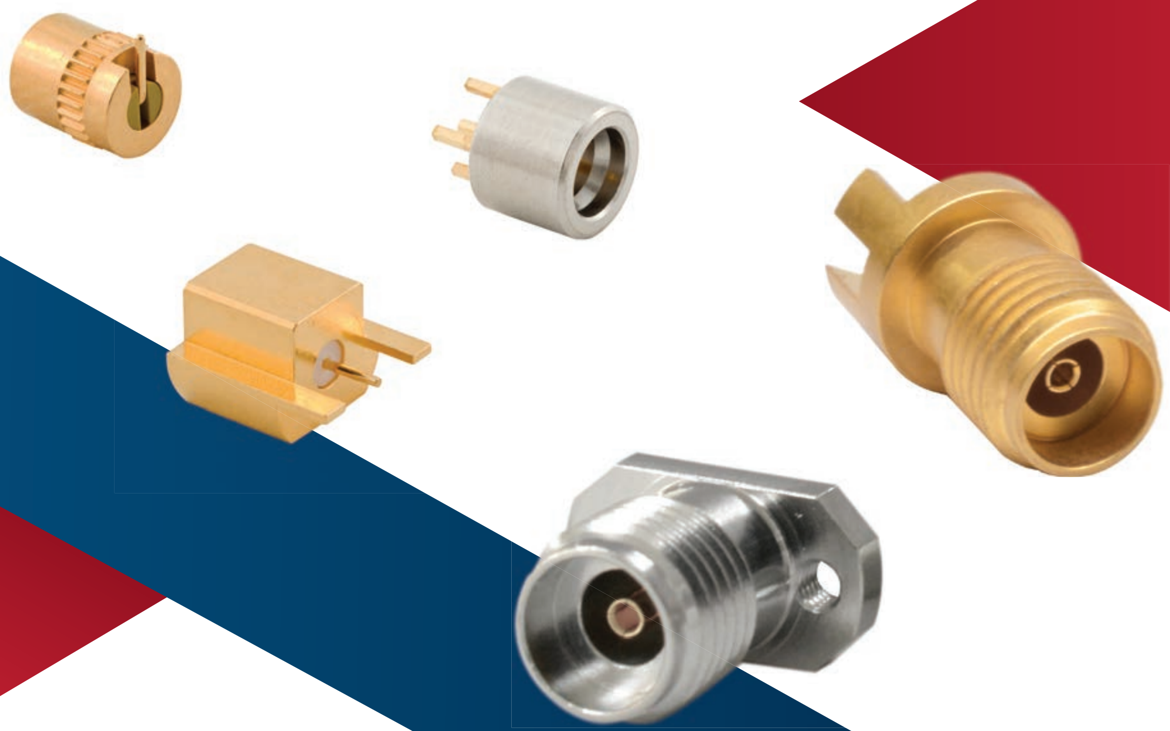


Fig. 1 Ideal LO signal (blue), LO signal with phase noise (red) and a close-in RF signal to be converted to baseband.

The direct down-conversion receiver is popular in microwave communications systems due to its circuit simplicity. The receiver comprises a single mixer driven by a local oscillator (LO), which converts the input RF signal to a very low baseband frequency. The baseband signal is applied to an analog-to-digital converter for digital processing. A common term for this architecture is "RF in, bits out." One problem with direct down-conversion is the input RF frequency being very close to the LO frequency, making the down-conversion susceptible to phase noise, especially if the RF signal strength is low.

In radar systems, the problem is similar. Doppler radar operates by transmitting a pulse at one frequency, then measuring the frequency shift of the return pulse, which is proportional to the velocity of the object being imaged. Objects moving slowly will generate a return pulse close in frequency to the transmitted pulse, and if the cross section of the object is very small—such as from a UAV—the power level of the received



signal will be very low. As the return pulse is converted to baseband to recover the velocity information, phase noise can obscure this data.

The dilemma faced by direct conversion receivers and radar systems is seen in ***Figure 1***, which shows if the power of the RF signal being converted falls below the phase noise spectrum of the LO signal, no baseband information can be recovered, since the signal is obscured by the noise. Reducing the phase noise will increase receiver sensitivity.

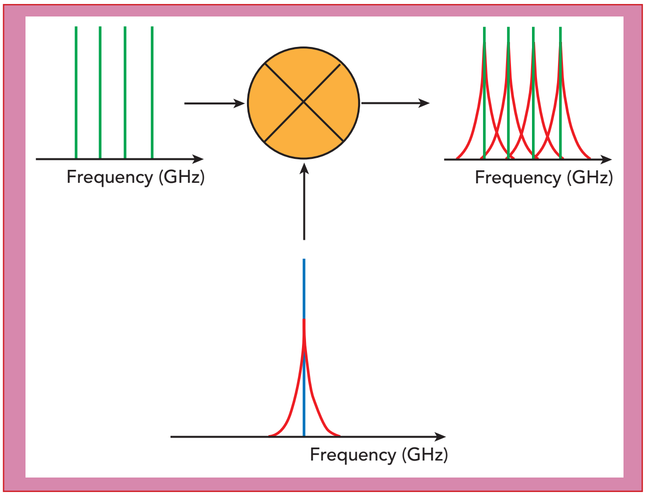


Fig. 2 **Phase noise issues in OFDM systems: ideal LO signal (blue), LO signal with phase noise (red) and RF signal (green).**

The impact of phase noise when down-converting a multi-carrier orthogonal frequency-division multiplexed (OFDM) signal is shown in ***Figure 2***. If the phase noise of the LO is too high, the noise will be converted into adjacent channels of the baseband data, ruining the integrity of the information.

WHERE TO START?

One obvious place to limit phase noise is the oscillator, i.e., spending considerable time and money to design or procure a low noise oscillator. However, most oscillators do not generate sufficient output power to drive the LO input of a mixer and need a post amplifier. If an oscillator output of +5 dBm needs to be amplified to +15 to +17 dBm to drive the LO port of the mixer, will the amplifier affect the phase noise of the LO signal? Ideally, the answer is "no," as the amplifier simply raises the desired LO signal and its skirts by the same level.

However, the reality is microwave amplifiers add noise, generated by a phenomenon called 1/f or flicker noise, noise power added to the input signal with a spectrum that falls off proportionally to the inverse of the offset frequency. If this noise is greater than the phase noise of the input signal, then amplifier noise will dominate the output noise spectrum—and the low phase noise of the oscillator will be replaced by the higher phase noise of the amplifier—defeating the purpose of a low phase noise oscillator (see ***Figure 3***).

Understanding this, the amplifier becomes another component to address in the chain. Why has this not been addressed before? The answer lies in device physics: 1/f noise is caused by random and thermal charge movement in the

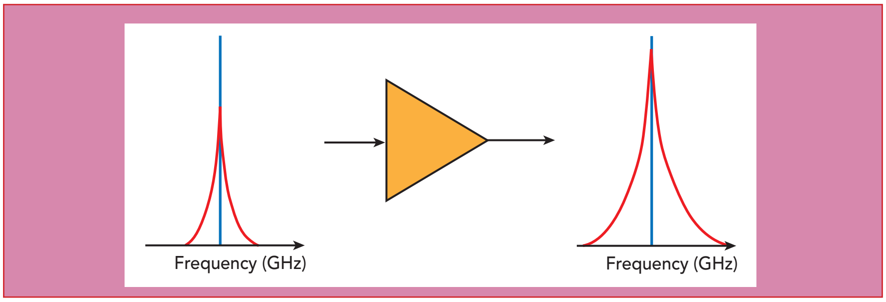


Fig. 3 **Phase noise degradation due to an amplifier: the skirts of the input signal on the left are increased after passing through the amplifier, yielding the output spectrum on the right.**

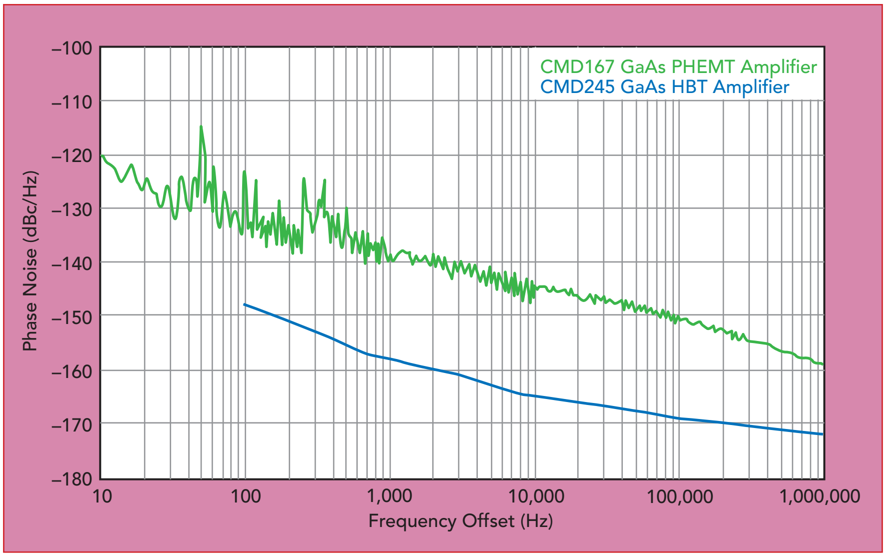


Fig. 4 The phase noise of a GaAs PHEMT amplifier (CMD167) is typically greater than that of a GaAs HBT amplifier (CMD245)

channel of an active device. FETs fabricated using a GaAs PHEMT process typically have a higher frequency 1/f corner because of high electron mobility. On the other hand, GaAs bipolar devices (e.g., HBT) tend to have lower electron mobilities, which results in a much lower 1/f noise, and they have considerably better phase noise than their FET counterparts (see ***Figure 4***). Therefore, one solution for lowering the additive phase noise is to use a GaAs HBT process.

After exploring this option for some time, Custom MMIC recently released a family of off-the-shelf, LPNA MMICs fabricated with a GaAs HBT process. Models offering wideband coverage are available from DC to 40 GHz and are matched to 50 Ω. The five products in the family achieve phase noise performance as low as -165 dBc/Hz at 10 kHz offset. They also feature low noise figures down to 3 dB, high linearity with OIP3 as high as 29 dBm and 18 dB gain to 18 GHz, 17 dB to 22 GHz and 13 dB to 40 GHz. The MMIC family includes three die and two packaged MMICs in a 4 mm x 4 mm QFN. These amplifiers are being used in a variety of LO and high sensitivity receiver circuits for military and instrumentation applications. An additional benefit of these designs is self-biasing; they require only a single positive power supply of 3 to 5 V, reducing the need for the extensive biasing circuitry required by devices using a negative supply.

These amplifiers are being used in a variety of LO and high sensitivity receiver circuits for military and instrumentation applications.

OTHER WAYS TO ADDRESS PHASE NOISE

Other components besides oscillators and amplifiers contribute to phase noise, including frequency multipliers. Some microwave systems use a lower frequency oscillator multiplied to produce a higher frequency. One common approach to multiplication is using a harmonically terminated amplifier to generate the required output frequency. Unfortunately, this adds the amplifier's phase noise to the multiplied signal, which degrades the phase noise of the original oscillator. A second approach is passive multiplication, which adds minimal phase noise to the multiplied signal. Custom MMIC has also developed a family of passive HBT frequency multipliers which do not add to the phase noise of the input signal.

Extensive datasheets, S-parameters and evaluation boards for all Custom MMIC's products are available on the website.

VENDORVIEW

Custom MMIC
Chelmsford, Mass.
www.CustomMMIC.com

Interactive Debugging in Multi-Domain Environments

RIGOL
Beaverton, Ore.

The continued expansion of the IoT and the accompanying RF integration challenges mean that designers benefit from versatility across disciplines. A single product routinely combines RF, digital and analog design elements, meaning engineers need to interactively debug systems that include both RF and embedded subsystems. To address complex debugging issues with flexibility and value, RIGOL combines the latest real-time spectrum analysis with embedded debugging in multi-domain systems.

RIGOL's multi-domain analysis combines the power of our new real-time spectrum analyzers (RTSA) with our high performance oscilloscopes to make investigating, correlating and analyzing signals easier than with traditional instruments. Unlike many of the basic RTSAs on the market, RIGOL's RSA series all have a combination of hardware triggering and IF outputs designed to work with an oscilloscope for advanced multi-domain analysis.

INVESTIGATE

Identifying issues starts with capturing and verifying signals either in the time domain or RF domain. One of the advantages of this multiple instrument approach is how easy it is to view signals, by either time or spectrum. When symptoms appear in the RF transmissions, use real-time to monitor frequency, using seamless capture capabilities to analyze the characteristics of the signal. Extend this analysis into the time domain with the power versus time view or by monitoring the IF signal on an oscilloscope. Deep memory and waveform recording verify signals as they change on longer time scales. Use the real-time analyzer to investigate transient, high speed events. One of the most important views of a real-time signal is the density view. Density view highlights transient signals that are difficult to capture using other techniques by showing the probability of occurrence in color (see ***Figure 1***). Density view makes it possible to differentiate signals, even when

Fig. 1 Density view of a hidden signal artifact.

Fig. 2 Visualization of both time and spectrum using the spectrogram mode.

one is obscured by the spectrum of the other.

The real-time visualization modes can capture any RF errors and investigate how they change over time. As a debugging tool, RIGOL's RSA enables viewing time in three distinct modes: Density shows time as probability of occurrence. Power versus time shows time domain signals, and the spectrogram shows a history of power across the spectrum (see ***Figure 2***). The figure shows a signal with hopping FSK modulation. The image in the top center shows the 1 ms repetition rate of the transmission, the spectrogram on the left shows the hopping sequence and the spectrum in the bottom panel shows the latest capture of the FSK pulse, to determine power and frequency characteristics. Each of these RF pulse widths are less than 2 µs. To zoom in on their time domain activity, connect the scope to the IF output, which enables viewing the precise timing of the RF pulse to see it in context of other signals.

CORRELATE

There are three ways the RSA and an oscilloscope, such as the RIGOL 4000 series, can be used to correlate signals. For all three methods, first connect the RSA and the oscilloscope. The RSA trigger out is connected to either the external input or a standard channel. The oscilloscope's trigger output is connected to the RSA trigger input. Finally, the IF output is connected to a scope channel in 50 Ω mode.

The first method involves triggering on the oscilloscope itself. With the RSA in real-time mode, select a view and trigger on the scope channel connected to the RSA IF output. The scope can be set to trigger on RF power changes and correlate RF with other signals on the scope display. The IF output down-converts the real-time center frequency to 430 MHz. In the second method, the RSA triggers with the scope, making correlated visualization of the spectrum possible whenever the scope identifies a trigger event. In this mode, basic visualization of the spectrum can also be done with the FFT math function on the oscilloscope. For more complex RF signals, use the third triggering method. This takes advantage of the real-time capabilities to trigger on the power level or specific values

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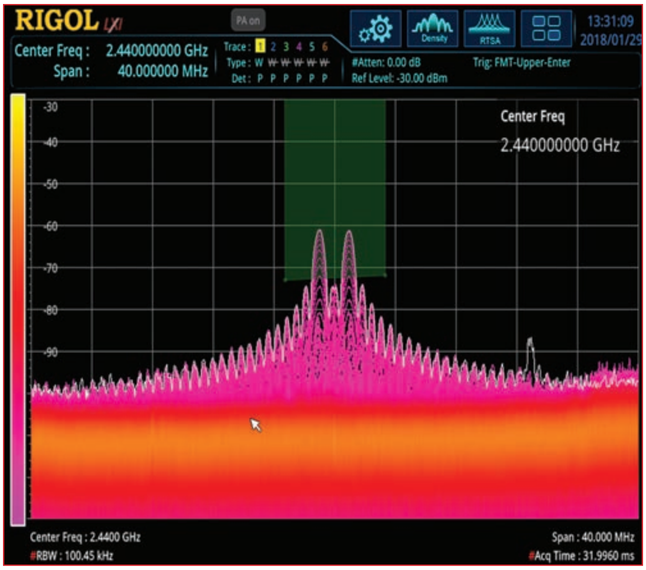

Fig. 3 Display using frequency mask trigger mode.

Fig. 4 Using 4000 series scope capture reveals a glitch in the center of the mask, captured in a recording of frames.

within the spectrum. Set the RSA trigger mode to power or frequency mask trigger, enable the RSA's trigger out and use this signal to trigger the scope. This allows viewing the status of embedded, power and serial signals at the time of an RF event or EMI emission. The frequency mask trigger used to capture a FSK pulse is shown in ***Figure 3***.

ANALYZE

With a deep memory scope like the 4000, the long record length enables viewing the time before and after an RF event to find the root cause. This time-based analysis is critical, since many causes are not instantaneous, rather a result of a previous event. Programmable components like FPGAs hide many of these errors. One way to debug and verify their performance is to monitor changes over time in a continuous dataset, to locate the logic or state error. RIGOL's waveform record mode is another powerful tool for multi-domain analysis. Record mode makes it possible to capture a sequence of thousands of trigger events, followed by playing back and analyzing these frames using pass/fail masks or a point-by-point RMS difference analysis. Comparing occurrences of errors and establishing a common cause is critical to ultimately fixing the underlying cause. ***Figure 4*** shows capturing the IF pulse (in purple), with the RSA trigger channel 1, shown near the bottom of the display.

CONCLUSION

The RSA series RTSAs from RIGOL are configured to make it easy to bring real-time visualization to multi-domain debugging. Used with a RIGOL MSO4054 oscilloscope or a 500 MHz mixed-signal oscilloscope already on the bench, the RSA bridges the gap between RF and embedded signals, making true multi-domain analysis possible. Multi-domain analysis includes time-correlated RF and embedded signals, configurable triggering across signal types and real-time visualization of the RF signals, saving engineers both time and money.

RIGOL
Beaverton, Ore.
www.rigolna.com

S-Band Rotary Joints for Space Applications

Many of the rotary joints available for use in space operate in X-, K- or Ka-Bands. Now, SPINNER has expanded its range of rotary joints for space, primarily for antenna pointing mechanisms, by developing S-Band units.

Based on its proven contactless RF transmission technology, the company has surmounted the challenges involved in designing and producing S-Band rotary joints that are comparable in size to those for higher frequencies, despite the longer wavelength. Thanks to their small dimensions, as well as the use of special aluminum alloys and other materials specifically designed for use in space, each entire rotary joint weighs less than 100 g.

These S-Band rotary joints handle average power to 10 W, with a maximum VSWR of 1.15 and a maximum VSWR variation with rotation of 0.05. Insertion loss is very low—less than 0.25 dB—while the insertion loss variation over rotation does not exceed 0.05 dB. These values are guaranteed across a very wide temperature range from −100°C to +120°C.

Thanks to their small size and excellent transmission properties, SPINNER's rotary joints enable flexible design of antenna pointing mechanisms, and the frequency range can be adapted as required. This opens up possibilities for direct communication between satellites and base stations and expands the scope for designing satellites.

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Compact, Accurate, Digital In-Line Power Meters

Werlatone's digital in-line power meters combine the company's heritage in directional couplers with an RMS power meter, integrated in a compact package for cost-effective monitoring of forward and reverse power. The three models in the family cover 2 to 32 MHz, 20 to 200 MHz and 80 to 1000 MHz, eliminating the need for dedicated and costly test equipment to monitor high-power transmitters.

Welatone's digital power measurement and interface enables instantaneous and simultaneous local and remote monitoring. Alarms for VSWR and temperature extremes can be set by the user, triggering notifications and relays when exceeded. Two temperature sensors are provided, one within the power meter, the second an external sensor placed by the user. Multiple in-line power meters can be networked and monitored via the TCP/IP SNMP, RS232 or RS485 interfaces and using the digital dashboard spreadsheet and Windows graphical interface software. An Android app is available to monitor and remotely control system operation.

The WPM11199 model measures up to 10 kW CW from 2 to 32 MHz and is integrated with a 6 in. line section and 1 5/8 in. EIA connectors. The WPM10800 measures up to 10 kW from 20 to 200 MHz and is packaged in a 6 in. x 3 in. x 2.24 in. housing with LC high voltage connectors. The WPM11235 measures up to 1 kW and is packaged in a 3 in. x 3 in. x 1.59 in. housing with 7/16 connectors. The power meter has 40 dB dynamic range and will indicate the forward power in either W or dBm and reverse power in W. The reflected power measurement can be provided as W, return loss or reflection coefficient. After the initial calibration by Werlatone, which is traceable to the National Institute of Standards and Technology (NIST), subsequent calibration is not required.

The in-line power meters can be powered with an AC power adapter, power over Ethernet (PoE) or through the RS485 serial interface. An optional rack-mounted, 8-channel monitor with graphical interface is available.

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Ultra-Low PIM and 1 kW Cavity Filters

MCV Microwave has developed three new filter families for wireless infrastructure. The first is a line of ultra-low passive intermodulation (PIM) cavity filters and multiplexers covering the TETRA and all LTE frequency bands from 300 to 3600 MHz. The typical production PIM performance is −163 dBc, measured with two CW tones, each at 43 dBm. An even lower PIM filter line with a guaranteed −173 dBc is available for PIM test bench and more demanding testing applications.

Typically, the filters have approximately 1 dB passband insertion loss, 20 dB minimum return loss, 95 to 120 dB rejection or isolation between the transmit (Tx) and receive (Rx) bands, 200 W CW power handling and −173 dBc PIM with quick-latch, blind-mate or torque-matched connectors.

These high-power, low PIM filters are suitable for small cell, tower-mounted amplifiers, Tx or Rx combiners, multiplexers, distributed antenna systems and PIM test benches. Rather than using a hybrid coupler for a duplexer, a triplexer can be used to provide power at two separate Tx frequencies with low insertion loss, saving the 3 dB loss of the hybrid.

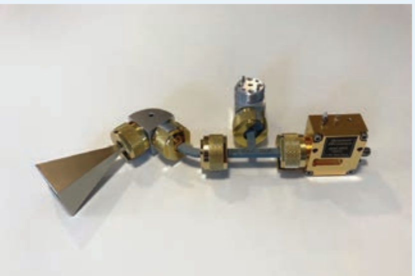
A second new product family from MCV: cavity filters and duplexers with 1 kW CW, 8 kW peak power handling and −173 dBc PIM. Filters in this high-power line cover the 850, 900, 1800, 2100 and 2600 MHz cellular bands.

The third new product from MCV is a constant 118 dB ±3 dB PIM duplexer. For example, used in the 1800 MHz uplink band, two CW tones of 45 dBm at 1810 and 1870 MHz injected into the antenna port will generate a constant PIM at 1750 MHz. Similarly, in the 2600 MHz uplink band, two 45 dBm CW tones at 2625 and 2690 MHz injected into the antenna port yield a constant PIM at 2560 MHz.

MCV's low PIM series bandpass filters (BCCM), duplexers (DCCM), dual duplexers (DDCCM), multiplexers (MCCMx), band reject filters (RCCM) and combiners (CCCMx) can be ordered in standard and miniature sizes, and custom requirements are welcome.

VENDORVIEW

MCV Microwave
San Diego, Calif.
www.mcv-microwave.com



Speed Waveguide Plumbing, Reduce Leakage

One of the frustrations working with waveguide is the tedious process of interconnecting sections: straight pieces, bends, transitions, antennas, passive and active components. Each connection typically requires mating four waveguide screws and precise alignment of the two waveguide sections to minimize leakage. With any volume—the final test of waveguide components, for example—the cumbersome process adds time and possible errors to R&D or the manufacturing flow.

Quantum Microwave's Guide-Lock™ Millimeter Wave Waveguide Flange Quick Connect Coupling System eliminates the tedium and potential errors. To use, the two pieces of the Quick Connect Coupling System are unscrewed, slipped over the waveguide on each side of the interconnection, then screwed back together, which connects and aligns the two waveguide sections. No tools are needed.

The patent-pending Quick Connect system fits any standard waveguide band, from 50 to 325 GHz (WR15, WR12, WR10 through WR03) and is available in flange connector, adapter and bend formats. The standard flange connector has anti-rotation pins but can be ordered without them.

Adding the Quick Connect system reduces RF leakage and eliminates misalignments for repeatable performance. With a maximum outside diameter under 1 in., it is usable in tight spaces where ball drivers will not fit.

Quantum Microwave
Cohasset, Mass.
quantummicrowave.com

200 MHz to 6 GHz, 4-Channel Digital Attenuator with 120 dB Range

The latest and most advanced Lab Brick digital attenuator from Vaunix, the LDA-602Q, covers 200 MHz to 6 GHz and features bi-directional fixed attenuation and swept attenuation ramps and fading profiles. The LDA-602Q provides up to 120 dB control range, 0.1 dB step size and an input IP3 of over 55 dBm. Maximum input power handling is +28 dBm. Each RF port of this 4-port attenuator is matched to 50 Ω, with a typical VSWR of 1.3:1. Fast switching within 15 µs is typical, and the attenuator is designed to operate reliably from –10°C to +50°C.

The LDA-602Q is compact, fitting into a single standard rack unit with well-spaced 50 Ω SMA female connectors for each RF port. Power and control are provided through a standard USB type-B female interface. Two counter-bore holes streamline mounting and placement.

This digital attenuator can be used in numerous applications, including UHF to C-Band wireless automated test equipment; MMIO testing; and LTE, Bluetooth and SATCOM fading simulators.

The Lab Brick LDA series of digital attenuators comes with a fully programmable graphical user interface application that can operate multiple attenuators from a PC or self-powered USB hub. Vaunix supplies LabVIEW drivers, Windows API DLL files and a Linux driver, complete with instruction manuals for applications that require deeper customization.

VENDORVIEW

Vaunix
Newburyport, Mass.
www.vaunix.com/digitalattenuators/

Show Some Brotherly Love at IMS2018

Patrick Hindle
Microwave Journal *Editor*

The IEEE MTT-S International Microwave Symposium (IMS) 2018 returns to the east coast after taking place in Phoenix, San Francisco and Honolulu from 2015 through 2017. It makes its return to Philadelphia, taking place June 10-15, after last visiting the city in 2003. IMS is the largest gathering for the RF and microwave industry, consisting of a full week of conference sessions, workshops, short courses, panel sessions, student activities, social events and commercial exhibitions. In addition to the normal inclusion of the RFIC and ARFTG conferences, IMS is once again including the 5G Summit and, new for just this year, the 2018 International Microwave Bio-Conference (IMBioC 2018), following in the theme of this year's event, "Microwaves, Medicine and Mobility."

IMS is a great place to network and there are several nice opportunities to do so, including the Welcome Reception on Monday at 7:00 p.m. at the famous Reading Terminal Market, directly following the Plenary session (IMS will parade the attendees to the terminal area). On Tuesday at 6:30 p.m., there is the Amateur Radio Society event at the convention center and at 7:30 p.m. there is the Young Professionals networking event at Lucky Strike. On Thursday at 7:00 p.m., the Women in Microwaves will host a guest speaker and networking event at the Philadelphia Academy of Fine Arts. Finally, there is the three-day exhibition starting Tuesday, with the opportunity to meet with industry professionals from around the world representing more than 600 companies.

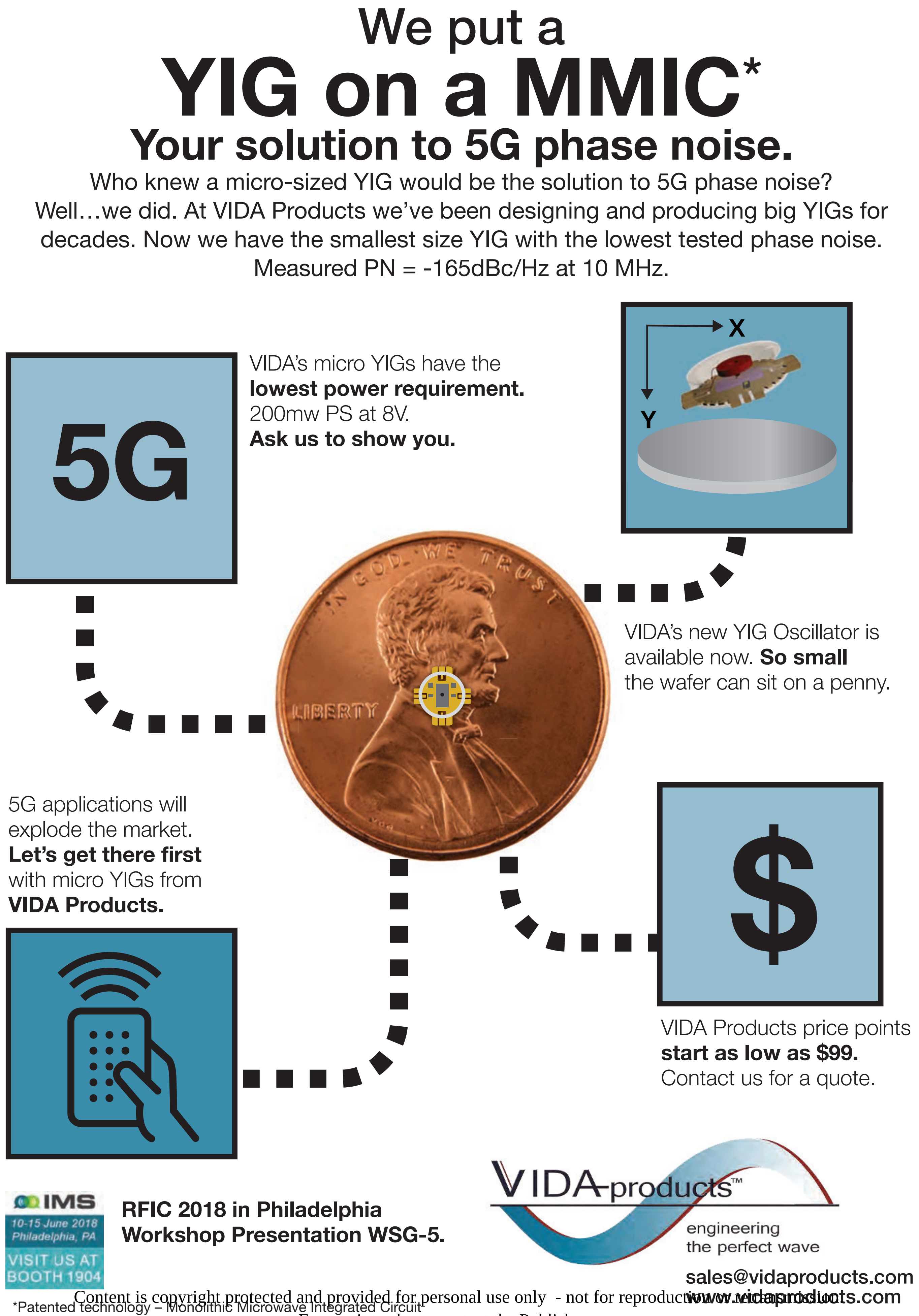
Philadelphia is the economic and cultural center of the Delaware Valley, located along the lower Delaware and Schuylkill Rivers. The city is just coming off a Super Bowl win for the Philadelphia Eagles (over my New England Patriots) and NCAA Basketball Championship for Villanova, so will likely still be celebrating in June. Philadelphia is famous for the Liberty Bell and Amish population, among other attractions, so make some time to get out and see some of the historical sites and area attractions.

Microwave Journal has put together the following summary of the main conferences written by the general and technical chairs organizing each event. After this article is a list of exhibitors by booth number and new products section highlighting many of the products that will be on display in the exhibition.

IMS2018: MICROWAVES, MEDICINE, MOBILITY

Sridhar Kanamaluru
IMS2018 General Chair

Welcome to Philadelphia, the city of brotherly love! IMS2018 will be held June 10-15 as part of the IMS Microwave Week of conferences at the Pennsylvania Convention Center in Philadelphia (see ***Figure 1***). The week's conferences include the customary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▲ Fig. 1 **Pennsylvania Convention Center (Courtesy of Pennsylvania Convention Center).**

Radio Frequency Integrated Circuit (RFIC) Symposium and Automatic Radio Frequency Techniques Group (ARFTG) Conference, and unique to 2018, the 2018 International Microwave Bio-Conference (IMBioC 2018). In addition, the 5G Summit will co-locate at the event through a partnership with Communications Society (ComSoc).

As many long-time IMS attendees know, the IMS and the IEEE Microwave Theory & Techniques Society (MTT-S) that organizes the IMS have been successful for a very long time. For IMS, 2018 is the 61st year of technical sessions and the 46th year of exhibits. For MTT-S, 2018 is the 66th year of its formation. The MTT-S has maintained IMS' leading status as the only show in the world where exceptional talents that produce cutting edge technology meet to collaborate with a mature industry that produces solutions, services and products. There is no other event with the size and breadth of subjects as the IMS for anyone associated with RF, microwave and mmWave technology and industry.

The IMS success is achieved by focusing on the fundamentals, something that I call "listen, learn, earn and enjoy." IMS addresses the needs of all its attendees—from students trying to "listen and learn" the latest developments in theory and techniques; to researchers and practitioners who publish their latest peer-reviewed work to collaborate and "earn" acclaim from their peers; to industry partners who provide the products and services, and must "earn" a good ROI for the time and treasure that they invest in the exhibition. Finally, and as importantly, every attendee must "enjoy" the IMS Microwave Week that is a large annual family get-together—a worldwide family with a shared interest to create technologies that improve our everyday lives.

As MTT-S and IMS mature, the early discoveries of field theory, device physics and circuit design have blossomed to the current age of "systems, services and products." IMS2018 focuses, through its theme "Microwaves, Medicine Mobility," on two such areas. The first area is "Mobility," exemplified by the approaching deployment of 5G services and applications. This topic is highlighted throughout the week by a series of workshops, technical sessions and the one-day 5G Summit co-sponsored by MTT-S and ComSoc. It is further complemented by the 5G Pavilion in our exhibition, where industry partners demonstrate 5G hardware and services, as well as educate us at the 5G theater "fire-side" chats.

The second area is "Medicine," where our community has provided practical solutions and products whether they are for diagnostics, therapy or tele-medicine. This topic is highlighted by the Plenary Session talk by Dr. Stephen Klasko, president and CEO of the $5 billon Jefferson Health System. Technical, focus and special sessions; workshops and short courses; and Thursday's "Panel with Practicing Physicians" is culminated by the IMS Closing and IMBioC Opening Session talk by Dr. Nicholas J. Ruggiero II, M.D.

Other areas where significant development is seen in past years include 3D technology and products, radar sensors, large MIMO systems and my favorite, "Direct Digital RF Transceivers." In each of these areas, hitherto insurmountable limitations are overcome by a new generation of technologists equally adept at microwaves, photonics and signal processing. MTT-S and IMS have taken note of these trends, providing ample opportunities for our attendees to listen, learn and participate in what I am sure will be an exciting conference. Our industry partners (in the exhibition) have opportunities to interface with the attendees during the Wednesday noon through 4 p.m. "Exhibition Only" time. The Micro-Apps Theater and Industry Workshops provide additional opportunities for IMS partners to highlight their products and services. Unique to IMS2018, our industry can guide the future of talented students, most of who specialize on topics that were previously mentioned as the amalgam for the future, at the Thursday "Career Counseling Fair."

MTT-S and IMS are a global community and you are a major part of it. Your key to this community is the IMS Mobile App, available in the App Store and Google Play. Starting in 2018, the IMS Mobile App will be a portal to everything related to IMS—information, registration, content downloads and, yes, a social networking feature that lets you opt-in to maintain contact with your peers throughout the year. MTT-S and IMS will also be reaching out to you with announcements and updates via the Mobile App.


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2018 RFIC SYMPOSIUM WELCOME

Walid Ali-Ahmad
RFIC 2018 General Chair

Stefano Pellerano and Waleed Khalil
RFIC 2018 Technical Program Co-Chairs



The 2018 IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2018) will be held in Philadelphia from June 10-12. The RFIC Symposium is the premier integrated circuit (IC) design conference focused exclusively on the latest advances in RF, microwave and mmWave IC technologies and designs, as well as innovations in high frequency analog/mixed-signal ICs and ultra-low power radios. With a wide range of papers from industry and academia, all attendees will find plenty of relevant and technically interesting topics to choose from.

The RFIC Symposium is an annual IEEE conference that is co-located with IMS, ARFTG and the Industry Exhibition to form Microwave Week, the largest worldwide RF/microwave technical meeting of the year. In addition to the vast array of technical content, attendees will have the opportunity to interact with world experts, expand their networks and leave invigorated with new ideas and a drive to innovate.

RFIC 2018 will begin on Sunday, June 10 with 12 RFIC-focused workshops—eight full day and four half-day. In addition, there will be several joint RFIC/IMS workshops on Sunday and Monday. These workshops cover a wide range of advanced topics in RFIC technology and IC design, including 5G systems and beyond.

Sunday's RFIC-focused workshops include the following topics:

- RFIC Design in CMOS FinFET and FD-SOI
- ICs for Quantum Computing and Quantum Technologies
- 5G mmWave Power Amplifiers, Transmitters and Beamforming Techniques with Massive MIMO
- eXtreme-Bandwidth Architecture for RF and mmWave Transceivers in Nanoscale CMOS
- Integrated mmWave and THz Sensing Technology for Automotive, Industrial and Healthcare
- Advanced Integrated RF Filtering Circuits and Techniques
- Synthesizer Design and Frequency Generation/Synchronization Schemes for High Performance Wireless Systems
- High Performance WLAN Transceiver Design and Calibration Techniques
- High Efficiency Power Amplification for Emerging Wireless Communication Solutions from Devices to Circuits and Systems
- mmWave Systems, Manufacturing, Packaging and Built-In Self-Test
- Towards Direct Digital RF Transceivers
- Ultra-Low Power Transceiver SoC Designs for IoT Applications

Following the full day of workshops, the RFIC Plenary Session will be held on Sunday evening beginning with conference highlights, the presentation of the Student Paper Awards and the Industry Paper Awards. The plenary session talks begin with Zachary J. Lemnios, vice president of science, technology and government programs at IBM Research, who will talk about "Compact Silicon Integrated mmWave Circuits: From Skepticism to 5G and Beyond." The second talk will be given by NXP's Automotive CTO, Lars Reger, who will share his vision on "The Road Ahead for Autonomous Cars—What's In for RFIC." Immediately following the Plenary Session will be the RFIC Reception that will highlight our industry showcase and student paper finalists in an engaging social and interactive technical evening event supported by the RFIC Symposium corporate sponsors. You will not want to miss the RFIC Reception this year.

On Monday and Tuesday, RFIC will have multiple tracks of oral technical paper sessions as well as the popular Interactive Forum poster session (see ***Figure***


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2). Beginning in 2017, the theme of the RFIC Symposium has been on emerging 5G technology. There are several 5G-focused sessions presenting full microwave and mmWave transceivers with integrated antennas, various beam-steering techniques, building blocks for 5G and sub-6 GHz circuit techniques related to transceiver linearization, harmonic rejection and efficiency enhancement. In addition to 5G, the industry push for autonomous driving highlights the need for better sensing. We also see a trend going forward with sessions focused on automotive radar, IoT and THz imaging.

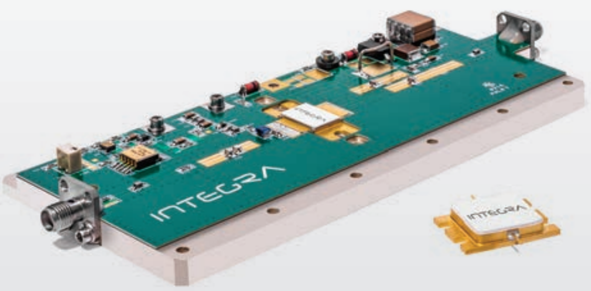
RFIC 2018 has 17 Technical Paper Sessions on Monday and Tuesday with the following topics:

- Building Blocks for 5G Transceivers
- Advances in Packaging, Modeling and Optical Phased Arrays
- Techniques for High Performance Frequency Synthesis
- 28 GHz Phased Arrays, Beamformers and Sub-Components for 5G Applications
- Technology Optimization for RF Applications
- ADC-Based RF/Mixed-Signal Systems and Wireline Transceiver Techniques
- RF Front-Ends for Emerging Wireless Paradigms
- Mixed Signal Transmitters and Power Amplifiers
- cm/mmWave CMOS Integrated Phased Array Building Blocks
- Ultra-Low Power Radios for Security, Ranging and Connectivity
- Silicon Integrated mmWave Transmitters
- Highly Efficient mmWave Oscillators with Wide Tuning Range
- mmWave Power Amplifiers
- Submillimeter Wave and Terahertz ICs
- mmWave Radar and Beamforming Transceivers
- mmWave LNAs and RF Receiver Front-Ends
- Wireless Transceivers and Transmitters for Connectivity and Cellular

Enlightening lunchtime panels focusing on the Microwave Week key themes will be featured on both days. The Monday panel session, titled "How Will the Future Self-Driving Cars See? LIDAR versus Radar," will cover the state of the art in radar and LIDAR technologies and attempt to draw contrasts between the two approaches in the con-

Fig. 2 Interactive Forum poster session (Courtesy of RFIC Symposium).


FIND YOUR POWER


INTEGRA

text of self-driving cars. The Tuesday panel session, titled "Can A Residential Wireless Gbps Internet Connection Compete with Wired Alternatives?," will convene expert panelists to discuss some of the technology advancements that are enabling Gbps internet connections and will debate the merits of both the wired and wireless technology alternatives. Please make sure to bring your engaging opinions and questions to both panel sessions as they will be highly interactive.

On behalf of the RFIC Steering and Executive Committees, we welcome you to join us at the 2018 RFIC Symposium in Philadelphia. Please visit the RFIC 2018 website at http://rfic-ieee.org/ for more details and updates.

SPRING ARFTG 2018

Dominique Schreurs
President and 2018 Spring ARFTG Conference Chair

Andrej Rumiantsev and Jean-Pierre Teyssier
2018 Spring ARFTG Technical Program Committee Co-Chairs



The Automatic Radio Frequency Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. ARFTG was created in 1972 to help end users get the most from the latest generation of test and measurement equipment. In the early years, the primary focus was on instrumentation automation and calibration. In the meantime, measurement techniques have evolved greatly, and now include such diverse topics as: nonlinear measurements, production testing, temporal measurements, high frequency fixturing and probing, multiport network analysis, mixed-signal measurements, mmWave and THz measurements. The broad range of ARFTG interests is reflected in the nature of the conferences.

ARFTG sponsors two conferences each year. The Spring Conference this year will be a single-day conference on Friday, June 15, and is co-sponsored by MTT-S and colocated with IMS. The theme for this 91st ARFTG Microwave Measurement Conference is "Wideband Modulated Test Signals for Network Analysis of Wireless Infrastructure Building Blocks."

The topical themes of the conference are:

- 5G Communications and Beyond
- IoT
- MIMO Measurements
- SATCOM
- RF/Digital Mixed-Signal Measurement and Calibration

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Economy & High Accuracy
T40/T50 Series
40/50GHz
High Reliability
& Accuracy
VNA Series
Up to 50GHz
Super Precision & Stability
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- Nonlinear/Large-Signal Measurement and Modeling Techniques
- THz Measurement Techniques
- Adaptive Communications, such as Cognitive Radio
- Other topical areas of RF, Microwave, mmWave Measurements

The arrival of 5G is a huge move in the electronic communication industry. 5G technologies need more than state-of-the-art specs in all directions. ARFTG is focused on RF measurements, the carrier frequencies and the modulation bandwidth for 5G require advanced or breakthrough RF measurement approaches to meet the needs. This Spring ARFTG Conference will focus on these techniques.

Oral technical sessions are single track (see ***Figure 3***) and extended breakout sessions, combining exhibition and interactive forum, aid networking with vendors and among colleagues, whether researcher or practitioner (see ***Figure 4***). The conference is preceded by the "NVNA Users' Forum" and the "On-Wafer Users' Forum," held on Thursday afternoon, June 14.

If you have interest in measurements from 1 kHz to 1 THz and beyond, be sure to add ARFTG 2018 to your conference plans in Philadelphia in June. You will find the conference atmosphere informal and friendly, which enhances interactions and opportunities for you to learn new ideas and to discuss with colleagues. Details about the 2018 Spring ARFTG Conference program can be found at www.arftg.org. Also check out www.twitter.com/arftgconference for regular updates.

Fig. 3 ARFTG single track technical sessions (Courtesy of Lyle Photos, Atlanta, Ga.).

Fig. 4 ARFTG Interactive Forum sessions (Courtesy of Lyle Photos, Atlanta, Ga.).

5G SUMMIT PHILADELPHIA

The IEEE MTT-S and ComSoc are partnering to hold a special joint 5G Summit at IMS2018 on Tuesday, June 12. The Summit will provide a platform for leaders, innovators and researchers from both industrial and academic communities to collaborate and exchange ideas regarding this emerging technology that may help drive the standards and enable rapid deployment.

After the successful 5G Summit at IMS2017 in Honolulu, both MTT-S and ComSoc decided to work together again to collaborate and organize another 5G Summit during IMS2018. The 5G Summit at IMS2018 is part of a collaboration that puts together the MTT-S "hardware and systems" focus with the ComSoc "networking and services" focus to address a full system view on the topic.

Attendees will be able to register for the 5G Summit using the IMS2018 registration site. The 5G Summit will be complemented by a 5G Demo Forum on the exhibition floor. The 5G Summit program will feature top experts who will share knowledge and discuss strategies and solutions with summit attendees.

SESSIONS

The morning session of the Summit will start with Professor Theodore Rappaport of NYU WIRELESS as the opening keynote speaker. Rappaport will provide a vision and overview on 5G and beyond. Speakers following the keynote address will cover topics including standards, spectrum use, operator and service-provider perspectives, infrastructure issues, systems and circuits as well as emerging applications.

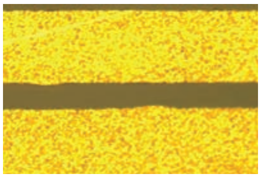
The day-long Summit will include a lunchtime panel on the "mmWave ICs in Smartphones: What They Will Look Like in 2, 5 and 10 Years." The afternoon session will feature Jin Bains from Facebook with a presentation titled "Bringing the World Closer Together." AT&T Vice President David Lu will also speak on "AT&T Perspectives on 5G Services."

Other featured presentations from Huawei, GM, Keysight, NI, GLOBALFOUNDRIES and MACOM as well as academia will include: Spectrum/Regulatory Issues; Infrastructure/Trials and Applications; RFIC/CMOS Transceivers for 5G; Technologies, Circuits and Systems; Design, Test & Measurement Challenges Test-Bed Services for 5G.

5G SPECIAL DEMOS

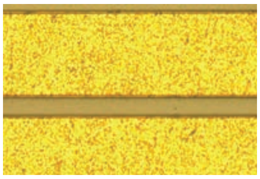
There will also be a 5G Demo Forum on the exhibition floor. Participating companies will have a 5G demo kiosk to display their demo and will also presenting in the 5G Pavilion's theater area. With 5G being the hottest area in our industry, it makes perfect sense to have a dedicated summit covering this area of technology.■

See the Precision You Have Been Missing In Your Thin Film Circuits



Chemical Etching

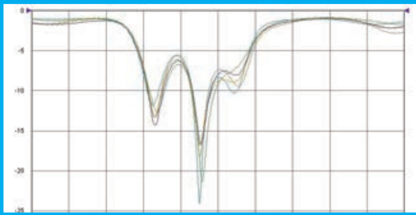
Ion Beam Etching



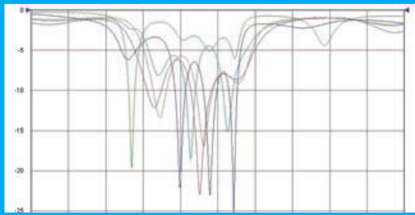
Are you tired of having to re-design your thin film circuits and tune the final assemblies to compensate for the imprecision of chemical etching? There is an alternative: Ion Beam Etching. The ion beam etching process is proven to produce circuits that more faithfully match simulator models and offer near perfect circuit-to-circuit performance repeatability.

Circuit-to-Circuit consistency for five filter samples as measured by Anritsu VNA

Ion Beam Etch



Chemical Etch



For over 35 years, Ion Beam Milling has been providing ion beam etch services to the microwave, microelectronics and photonics communities. Our experience in process development has enabled us to offer ion beam etch quality at prices competitive with chemical etching.

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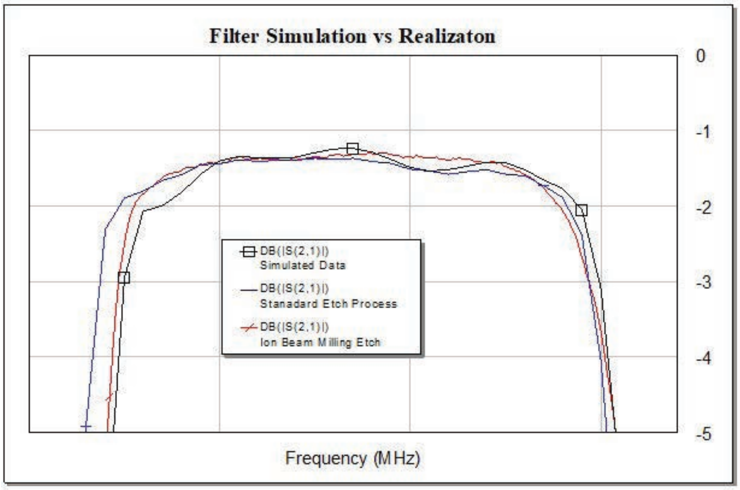

"Etch accuracy allows first time success in terms of Filter Bandwidth. Standard process (chemical etching) may result in re-spinning circuit to correct for errors caused by over or under etching of metallization.

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-Feedback from a customer who switched to Ion Beam Etching

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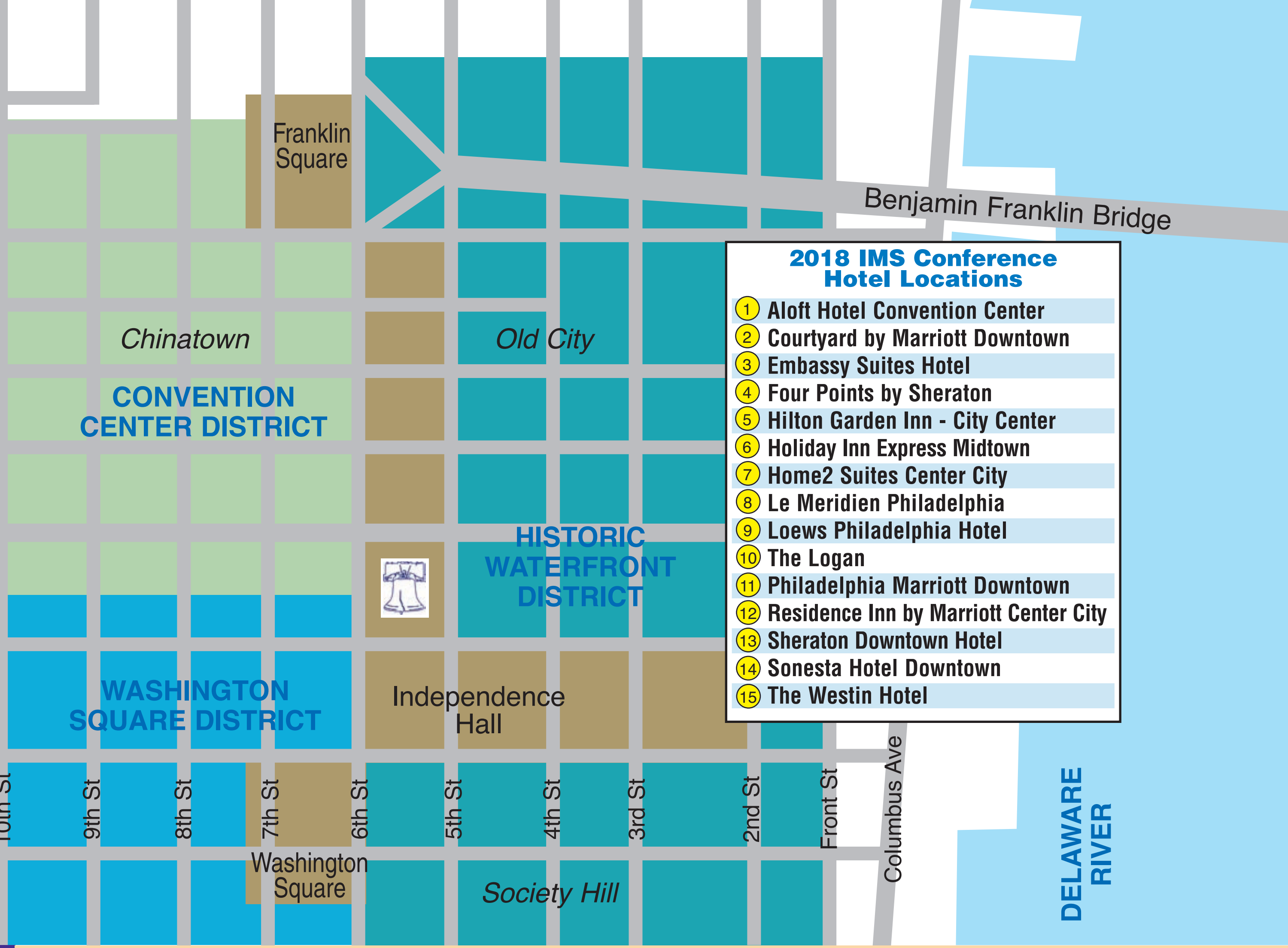
Map of Philadelphia area provided courtesy of CTT, Inc.



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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See us at IMS Booth 1213

The following list is complete as of April 3, 2018.
Exhibitors in **ORANGE** have an ad in this issue.

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3G Shielding Specialties	1640
3RWAVE	2110
41st Institute of CETC, The	**1561**
A.J. Tuck Co.	1803
A.T. Wall Co.	909
A-Alpha Waveguide Co.	1309
ABF Elettronica Srl	2319
Accurate Circuit Engineering	1237
ACEWAVETECH	2119
ADMOTECH Co. Ltd	1934
AdTech Ceramics	1937
Advance Reproductions Corp.	959
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Advanced Circuits	2625
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Agile Microwave Technology Inc.	**1263**
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AKON Inc.	761
Aldetec Inc.	1009
Alfred Tronser GmbH	1358
Aliner Industries Inc.	2049
ALPHA-RLH (Lasers and Microwaves French Cluster)	2051
Altair Engineering	**1609**
AMCAD Engineering	1231
Amcom Communications Inc.	**1356**
American Beryllia Inc.	2724
American Microwave Corp.	**2317**
American Standard Circuits Inc.	1055
Ametek CTS US - Instruments For Industry	1507
Amosense Co. Ltd.	2059
Ampleon	1449
Amplical Corp.	553
AmpliTech Inc.	1102
Amwav Technology Ltd.	1956
Analog Devices Inc.	**1725**
Anapico Ltd.	1709
Anaren Microwave Inc.	**2304**
Anatech Electronics Inc.	2054
Ancortek Inc.	2316
Anokiwave	**538**
Anritsu Co.	**925**
ANSYS Inc.	1025
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API Technologies	**503**
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ASB Inc.	1210
Aselsan	**2305**
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Association of Old Crows	2502
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Astronics Test Systems	1440
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Atlanta Micro Inc.	2128
Avalon Test Equipment	1360
AVX Corp.	707, 713
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B&Z Technologies	**1202**
Barry Industries Inc.	949
Beijing Xibao Electronic Technology Co. Ltd.	2012
Besser Associates Inc.	**1833**
BJG Electronics	1652
Bliley Technologies Inc.	2218
Boeing	1814
Boonton	932, 938
Bowei Integrated Circuits Co. Ltd.	1239
BSC Filters Ltd.	**515**
Butler Winding (GCG)	**1735**
C.W. Swift	802
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Caiqin Technology Co. Ltd.	441
Cambridge University Press	1608
Carlisle Interconnect Technologies	956
CDM Electronics	1259
CEL	317
Centerline Technologies	**305**
Century Seals Inc.	2337
Cernex Inc.	**1406**
Charter Engineering Inc.	**2207**
Chen Precision Co. Ltd.	2424
Chengdu Filter Technology Co. Ltd.	2406
Chengdu Heguang Industry Co. Ltd.	2248
Chengdu Keylink Microwave Technology Co. Ltd.	308
Chengdu Ninecharm Technology Co. Ltd.	662
Chin Nan Precision Electronics Co. Ltd.	1060
Chinese Microwave Society	1512
Chi-Shuai Enterprise Co. Ltd.	1905
Chongqing Acoustic-Optic-Electric Co. Ltd.	1109
Ciao Wireless Inc.	**902**
Cicor Group	2006
Cinch Connectivity Solutions	1031
Cirexx International Inc.	1338
ClioSoft Inc.	1656
CML Microcircuits (USA) Inc.	**551**
Cobham	**1039**
Coilcraft Inc.	**1215**
Colorado Engineering Inc.	2232
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Connectronics Inc.	1241
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Corning Inc.	**1616**
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CTT Inc.	**1213**
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Custom Microwave Components Inc.	**915**
Custom MMIC	**851**
Custom-Cal Global Tech Solutions	**1661**
Daa-Sheen Technology Co. Ltd.	1936
Dalian Dongshin Microwave Absorbers Co. Ltd.	1063
Danyang Teruilai Electronics Co. Ltd.	2431
DAPU Telecom Tech. Co. Ltd.	1902
dB Control	452
dBm	**1739**
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Design Workshop Technologies Inc.	2029
DeWeyl Tool Co. Inc.	917
Diamond Antenna & Microwave Corp.	1302
Dino-Lite Scopes	1708
DITF Interconnect Technology	1903
DiTom Microwave Inc.	1726
Donggan Yuhoo Electronic Technology Co. Ltd.	1062
Dow-Key Microwave	**515**
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Ducommun Inc.	**1312**
Duet Investment LLC	2434
DYCO Electronics (GCG)	**1735**
Dynamic Engineers Inc.	1807
Dynawave Inc.	**1817**
Eastern Optx Inc.	1553
EB Industries	315
ECHO Microwave Co. Ltd.	858
Eclipse Microwave Inc.	**1806**
EGIDE	2108
Elbit Systems	1113
Element Six (UK) Ltd.	1908
Elite RF LLC	**307**
Eljay Microwave LLC	1432
EM Research Inc.	2230
EMCO Elektronik GmbH	2012
Empower RF Systems Inc.	**1048**
EMSCAN	1442
EMWorks	1002
ENGIN-IC Inc.	437
Epoxy Technology Inc.	2132
Erzia Technologies S.L.	**2318**
ETL Systems	1809
European Microwave Association	1512
European Microwave Week	**1842**
Evaluation Engineering	2117
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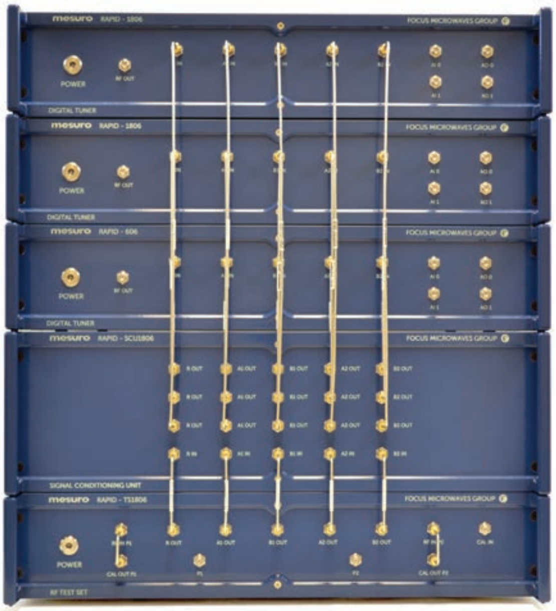

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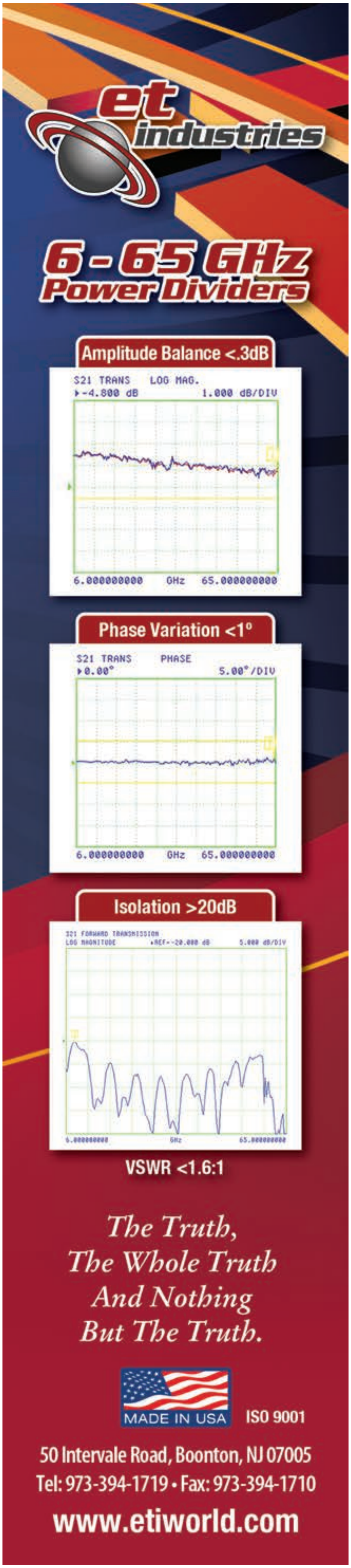


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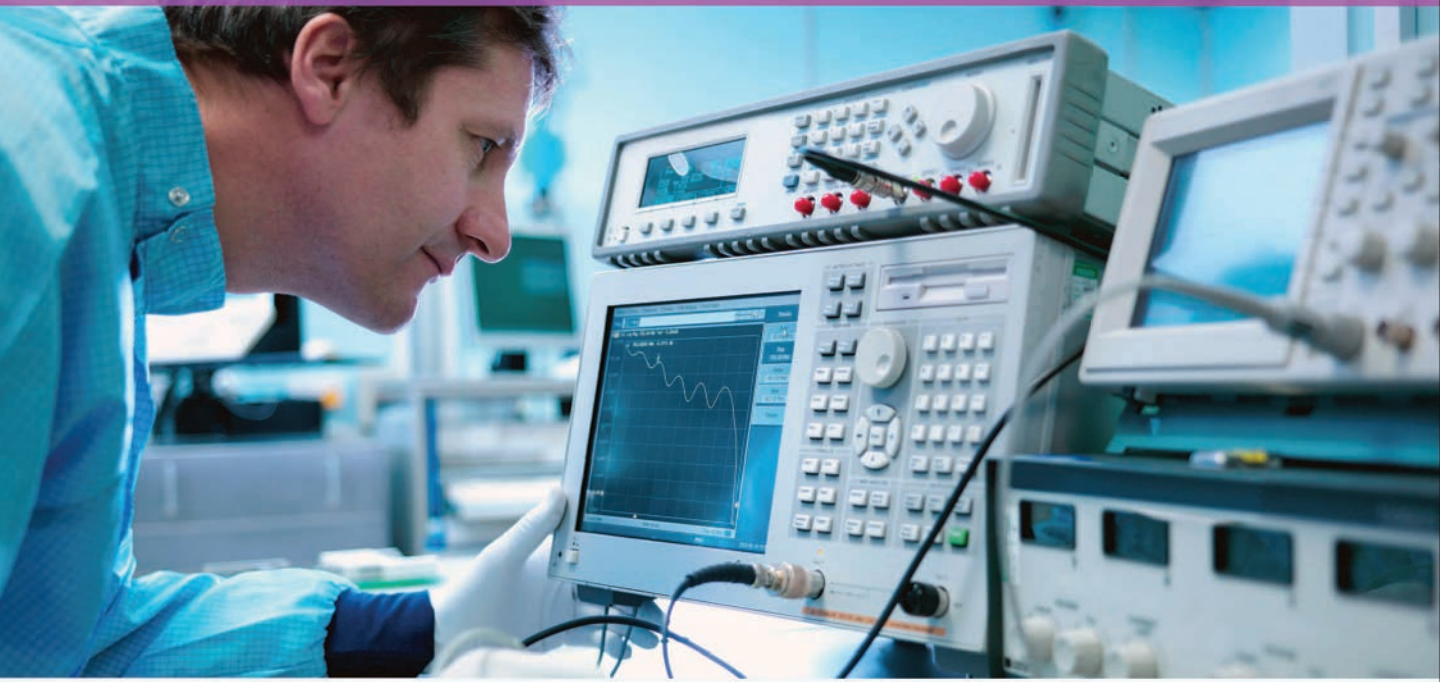

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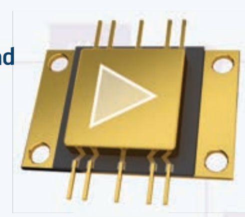

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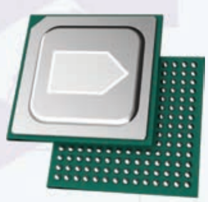

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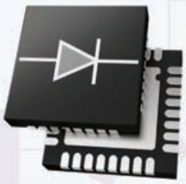

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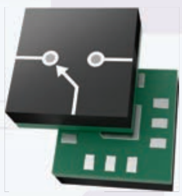

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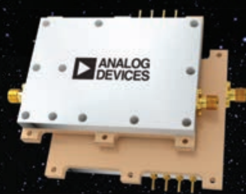

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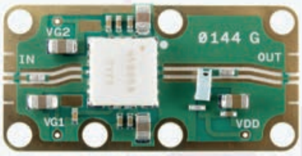

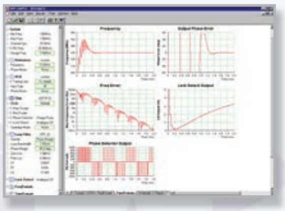

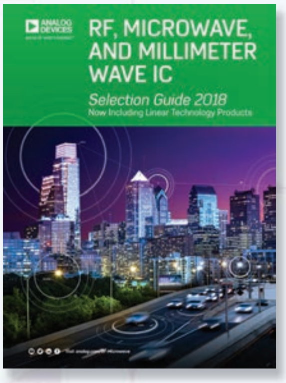

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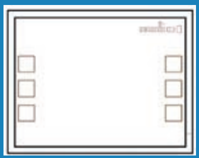
The following booth numbers are complete as of April 3, 2018.

Mini-Circuits Booth 203

USB/Ethernet Programmable Attenuator

Mini-Circuits' RCDAT-30G-30 is a precision programmable attenuator covering an extremely wide bandwidth from 0.1 to 30 GHz with attenuation range from 0 to 30 dB in 0.5 dB steps. The device is controlled via either USB or Ethernet allowing easy control directly from the user's PC or remotely over a network. It also allows daisy chaining of up to 25 attenuators through one USB or Ethernet connection to a single master unit.

Ultra-Wideband MMIC Frequency Doubler Die



Mini-Circuits' CY2-44-D+ ultra-wideband MMIC frequency doubler die converts input signals from 7 to 20 GHz into output signals from 14 to 40 GHz. This new model's extremely wide output frequency range makes it suitable for applications such as 5G, Ka-Band SATCOM, instrumentation and more. It has an input power range from +12 to +18 dBm and provides low conversion loss of 13 dB (typ.). The multiplier achieves excellent suppression of fundamental signal and unwanted harmonics (F1, 20 dBc or better; F3; 24 dBc or better).

Ultra-Reliable Electromechanical SPDT Switch

Mini-Circuits' MSP2T-26-12+ is an ultra-reliable, rugged-duty, reflective fail-safe SPDT switch, designed in break-before-make configuration. The switch operates from DC to 26.5 GHz and offers extremely long switch life up to 10 million cycles, which can be extended up to 100 million cycles with routine factory cleaning. Powered by +12 VDC, this model has a typical switching speed of 20 ms, insertion loss of 0.25 dB and high isolation of 85 dB.

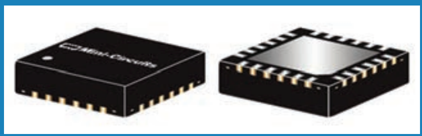
Tiny MMIC SPDT Switch

Mini-Circuits' MSW2-50+ is a reflective SPDT MMIC switch supporting a wide range of applications from DC to 5000 MHz. This model provides extremely fast switching with just 5 ns rise/fall time, 0.7 dB insertion loss at mid-band, 53 dB isolation and +54 dBm IP3. Produced using MESFET process on GaAs, the switch provides excellent repeatability and comes housed in a tiny 3 x 3 mm QFN package, saving space in dense board layouts and minimizing parasitic effects.

Ultra-Wideband Hand-Flex Interconnect Cables

Mini-Circuits' 086-KM+ series of HandFlex™ interconnect cables is ideal for interconnection of a wide variety of cable assemblies from DC to 40 GHz. 2.92 mm male connectors at both ends are ideal for making secure connections in assemblies using 2.92 mm, 3.5 mm and SMA connector types. Tight minimum bend radius of 6 mm makes these cables perfect for installations in tight spots, and hand formable cable construction allows easy bending to almost any shape without special bending tools often needed in semi-rigid cable assemblies.

MMIC Directional Coupler



Mini-Circuits' EDC21-24+ is a MMIC directional coupler with a 21 dB coupling ratio and a wide operating frequency range from 4 to 20 GHz. This model provides ±2 dB coupling flatness across its full frequency range, 0.7 dB mainline loss, 18 dB typical return loss and 19 dB directivity. The coupler can handle up to +15 dBm RF input power (5 minute max.) and comes housed in a tiny 4 x 4 mm QFN package.

Ultra-Wideband MMIC Frequency Doubler

Mini-Circuits' CY2-44+ ultra-wideband MMIC frequency doubler converts input signals from 6.2 to 20 GHz into output signals from 12.4 to 40 GHz. This new model's extremely wide output frequency range makes it suitable for applications such as 5G, Ka-Band SATCOM, instrumentation and more. It has an input power range from +12 to +18 dBm and provides low conversion loss of 14 dB for input signals from 6.2 to 16 GHz, and 17 dB for input signals from 16 to 20 GHz.

150 W Surface-Mount 2-Way 90° Hybrid

Mini-Circuits QCH-382+ is a high-power, surface-mount 2-way 90 degree hybrid capable of handling up to 150 W RF input power for applications over a wide bandwidth from 800 to 3800 MHz. This model provides low insertion loss of 0.25 dB, and 28 dB port-to-port isolation. With 0.35 dB amplitude unbalance and 1.6 degree phase unbalance (relative to 90 degrees), the hybrid produces nearly equal output signals with 90 degree phase shift, ideal for I/Q modulators, balanced amplifiers, antenna feeds and many more applications.

Ultra-High Dynamic Range MMIC Amplifier

Mini-Circuits' PHA-23HLN+ ultra-high dynamic range MMIC amplifier sets the new industry standard for noise figure and IP3 in VHF/UHF communications. This model is well matched to 50 Ω from 30 MHz to 2 GHz and provides 1.4 dB noise figure, +44.4 dBm IP3, making it ideal for maximizing sensitivity and dynamic range in high performance receiver applications. It delivers 21 dB typical gain with ±1.8 dB flatness, +28.4 dBm output power at 1 dB compression. The amplifier is fabricated using E-PHEMT technology with excellent repeatability.

Wideband Double Balanced MMIC Mixer

Mini-Circuits' MDB-44H+ is a wideband, double-balanced, level 15 MMIC mixer with an IF bandwidth from DC to 15 GHz and LO/RF bandwidth from 10 to 40 GHz, supporting a wide range of applications including up- and down-conversion for 5G, defense radar and communications, satellite and more. This model provides 8.4 dB conversion loss, 37 dB L-I isolation, 37 dB L-R isolation and good input/output return loss over its full frequency range without the need for external matching components.

www.minicircuits.com

VENDOR**VIEW**

UP TO **100 Watt**

AMPLIFIERS

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from $995 ea. qty. (1-9)

High-powered performance across wide frequency ranges. Mini-Circuits' class A/AB linear amplifiers have set a standard for wideband high-power performance throughout the RF and microwave industry. Rugged and reliable, they feature over-voltage and over-temperature protections and can withstand opens and shorts at the output! Available with or without heat sinks, they're perfect for demanding test lab environments and for integrating directly into customer assemblies. With standard models covering frequencies from 100 kHz up to 26.5 GHz, chances are we have a solution for your needs in stock. Place your order on minicircuits.com today for delivery as soon as tomorrow! Need a custom model? Give us a call and talk to our engineers about your special requirements!

Model	Frequency (MHz)	Gain (dB)	Pout @ Comp. 1 dB (W)	Pout @ Comp. 3 dB (W)	$ Price* (Qty. 1-9)
ZVM-273HP+	13000-26500	14.5	0.5	0.5	2195
ZVE-3W-83+	2000-8000	35	2	3	1424.95
ZVE-3W-183+	5900-18000	35	2	3	1424.95
ZHL-5W-2G+	800-2000	45	5	5	995
ZHL-10W-2G+	800-2000	43	10	12	1395
ZHL-15W-422+	700-4200	46	8	15	2295
•ZHL-16W-43+	1800-4000	45	12	16	1595
•ZHL-20W-13+	20-1000	50	13	20	1470
•ZHL-20W-13SW+	20-1000	50	13	20	1595
LZY-22+	0.1-200	43	16	30	1595
ZHL-30W-262+	2300-2550	50	20	32	1995
ZHL-25W-63+	700-6000	53	25	-	8595
ZHL-30W-252+	700-2500	50	25	40	2995
LZY-2+	500-1000	47	32	38	2195
LZY-1+	20-512	42	50	50	1995
•ZHL-50W-52+	50-500	50	63	63	1395
NEW! ZHL-50W-63+	700-6000	59	16	50	16995
ZHL-100W-251+	50-250	46	63	100	1695
•ZHL-100W-GAN+	20-500	42	79	100	2845
ZHL-100W-272+	700-2700	48	79	100	7995
ZHL-100W-13+	800-1000	50	79	100	2395
ZHL-100W-382+	3250-3850	47	100	100	3595
ZHL-100W-43+	3500-4000	50	100	100	3595
NEW! ZHL-100W-63+	2500-6000	58	20	100	17995

Listed performance data typical, see minicircuits.com for more details

• Protected under U.S. Patent 7,348,854

** Price Includes Heatsink*

Mini-Circuits®

www.minicircuits.com • P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com 416 Rev AQ

See us at IMS Booth 203

Elite RF **Booth 307**

S-Series Multi-Purpose RF Test System

Elite RF's S-Series multi-purpose RF test system is a flexible alternative to expensive and bulky RF test equipment. Independent control of each RF system allows for maximum test flexibility and the system can be connected to a larger monitor for viewing multiple windows at the same time. Models are priced for every budget: SA441 ($19,995), SPA441 ($29,995), SA1241 ($24,995), SPA1241 ($39,995). Each RF system comes with a two year warranty and is made in the U.S.

www.eliterfllc.com

Passive Plus Inc. **Booth 309**

Capacitors

Passive Plus Inc. (PPI) is now offering the 0708N (0.065 × 0.080 in.) series capacitor. With vertical electrodes which increase bandwidth, these capacitors have low ESR/ESL, and high self-resonance. Uniquely designed for excellent heat transfer in high RF applications, the 0708N offers ultra-stable performance over temperature. These capacitors are 100 percent RoHS compliant and also available in tin/lead termination. Typically used in wireless broadcasting equipment, mobile base stations, GPS, MRI and radar applications.

www.passiveplus.com

LadyBug Technologies **Booth 402**

Thermally Stable Wide Dynamic Range Power Sensor

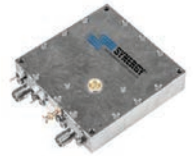
VENDORVIEW

LadyBug's thermally stable LB5918A True-RMS, a 1 MHz to 18 GHz, wide dynamic range power sensor delivers fast accurate measurements on any signal with any modulation including wideband digital signals. Its unique two path design delivers better dynamic range than many three path sensors. SCPI commands and use either USBTMC, USBHID or connect directly with I2C or SPI.

www.ladybug-tech.com

Synergy Microwave **Booth 409**

Phase-Locked Oscillator



Synergy Microwave has developed a phase-locked oscillator (PLO) product line of low-noise, fundamental-frequency signal sources from 100 MHz to 15 GHz—and extendable to 30 GHz, when using an external Synergy doubler. Even more remarkable, these quiet signal sources fit within compact industry-standard 2.25 × 2.25 in. module housings or on a 1.00 × 1.25 in. surface-mount technology (SMT) footprint.

www.synergymwave.com

AR RF/Microwave Instrumentation **Booth 425**

U Series Power Amplifier

VENDORVIEW

AR's new family of "U" (Universal) Series RF solid state Class A power amplifiers now includes a 100 W amplifier that covers the 100 kHz to 1000 MHz frequency range and is ideal for EMC, laboratory use, antenna and component testing, watt meter calibration, medical/physics research and more. This compact, high performance and affordable amplifier joins a family of products available in 1, 2.5, 10, 25 and 50 W output levels that covers 10 kHz to 1000 MHz.

www.arworld.us/html/18200.asp?id=1409

API Technologies Corp. **Booth 503**

OPTO-FIRE™ Optical Core Product Platform

API Technologies will be showcasing the OPTO-FIRE™ optical core product platform, a high speed micro-optical transceiver designed for critical data communication systems in military, aerospace and oil and gas applications. The U.K. designed, qualified and manufactured optical core platform addresses the need for system engineers looking to improve performance and reliability while also achieving reduction in SWaP consumption in harsh environments. The optical core offers a replacement for traditional copper cabling while delivering improved data transfer performance.

www.apitech.com

Teledyne Relays **Booth 525**

Indium Phosphide HEMT RF Switch

Teledyne Relays introduces the InP1012-40, a new indium phosphide HEMT RF switch. This SPDT reflective switch has a 10 kHz to 40 GHz bandwidth, low insertion loss, high linearity and a switching time under 100 ns. The InP1012-40 can operate from -65°C to 125°C and tolerate up to 100 krads of radiation and its 9 mm^3 sized flip-chip packaging provides shock and vibration resistance. These features make this RF switch perfect for military and space applications, ATE systems and RF and microwave communication.

www.teledynerelays.com

Teledyne Storm Microwave **Booth 525**

E- and W-Band Test Assembly

Teledyne Storm's new SF047EW cable assembly offers the proven durability and robustness of their Storm Flex® 047 cable, optimized for broadband operation to 110 GHz with 1 mm male and female connectors. This miniature, solid core cable has the flexibility to accommodate a variety of test setups and offers consistent, repeatable electrical performance with flexure. Insertion loss stability exceeds the VDI/VDE 2622 Part 19 Standard, and the cable exhibits 1.30:1 VSWR, typ., to 110 GHz.

www.teledynestorm.com

Dow-Key Microwave Corp. **Booth 515**

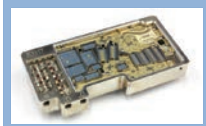
Commercial (COTS) Switch Matrix

Designed for RF, microwave and audio test applications in the DC to 18 GHz frequency range, Dow-Key's matrix product line includes standard configurations ranging from 1 × 100 to 12 × 12. Packaged in a 19-in. rack-mountable enclosure and provided with remote interfaces such as ethernet, GPIB, USB and RS-232 along with a touch screen LCD front panel display or keypad for manual override. Dow-Key uses its own line of coaxial switches for these matrices, providing low loss and excellent isolation.

www.dowkey.com

BSC Filters **Booth 515**

Filtering Modules



BSC has the 2 to 18 spectrum covered and segmented with its agile filtering modules. BSC's miniature thin film filter banks combine high performance miniature filters with high performance switching to provide SWaP advantage. BSCs reconfigurable filter bank provides high speed (sub 100 ns) adaptive pre-selector functionality in a compact outline.

www.dovermpg.com/bscfilters

K&L Microwave **Booth 515**

Pre-Filtered Low Noise Amplifiers

K&L Microwave offers pre-filtered low noise amplifiers for GPS and other frequency bands. The GPS offering can cover L1, L2, L5 or combinations of those frequency bands. Gains available are 16 to 40 dB with noise figures typically 1.8 dB or less. These LNAs are designed for harsh military environments with product supplied to many missile applications. Options are available with or without limiters. DC inputs can be supplied through independent pins or through the RF connector by use of a bias T.

www.klmicrowave.com

Pole/Zero **Booth 515**

Tunable Bandpass Filter

Pole/Zero's HF-ERF™ tunable bandpass filter covers the entire HF tactical radio band of 1.5 to 30 MHz while fitting in a low-profile package measuring 2.00 x 2.78 x 0.60 in. (50.8 x 70.61 x 15.24 mm). It has SMT capability with tune time and has remarkable selectivity for a compact device. These bandpass filters are commonly used in applications where small size, low power and high performance are needed for military handheld radios, radar systems, SATCOM and commercial applications.

www.polezero.com

L3 Electron Devices — Booth 535

MPMs

L3 Electron Devices' MPMs are super components that combine a solid state driver amplifier with a micro-TWT and a power supply in one package that is much smaller, lighter and more efficient than a comparable TWTA or SSPA. L3 MPMs are available in bands from 2 to 95 GHz with output powers from 40 to 200 W. All L3 MPMs are optimized for demanding defense applications that require small, lightweight and environmentally rugged, high-power microwave amplifiers.

www2.l3t.com/edd

L3 Narda-MITEQ — Booth 535

Low Noise Amplifier

L3 Narda-MITEQ's new low noise amplifier Model JDM1-38004200-40-10P covers a frequency range of 38 to 42 GHz with broadband performances across the entire Q-Band. It features ultra-low noise with gain choice, variable I/O interface options, a dual DC power supply and a compact, lightweight package. Lower power models are also available with single supply. This model offers superior performance and is excellent for use in SATCOM, telecommunications, test instrumentation, transceiver subassembly applications and more.

www.nardamiteq.com

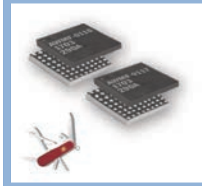
IMS2018 Show Coverage

Catch our exclusive conference information, news, social networking, photos, videos and more at: **mwjournal.com/IMS2018**

Anokiwave — Booth 538

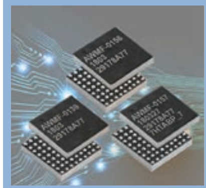
mmWave Intelligent Gain Blocks

VENDORVIEW



Anokiwave is redefining traditional single function gain blocks with multi-function silicon ICs offering complete T/R functionality and active gain and phase control. The ICs offer versatile RF blocks that can be used in wide range of designs across SATCOM, radar, 5G communications and mmWave sensing in Ku- and Ka-Bands. The AWMF-0117 operates at 10.5 to 16 GHz and AWMF-0116 operates at 26 to 30 GHz. Both ICs feature 6-bit phase/gain control and are packaged in a 2.5 x 2.5 mm WLCSP.

3GPP Compliant Quad Core ICs



Ready for 3GPP compliance? Anokiwave's new 2nd generation 5G silicon active antenna IC family at 26, 28 and 39 GHz enable 3GPP compliant 5G basestations. The ICs each support four radiating elements, include gain and phase control for analog RF beam steering and enable low-cost hybrid beamforming with high energy efficiency and fast beam steering™. The 2nd generation IC family is part of Anokiwave's on-going strategy to commercialize 5G mmWave systems with silicon ICs.

Silicon ICs

From IC to array, Anokiwave enables your 5G system. Anokiwave offers highly integrated silicon ICs with embedded functions for remote telemetry fast beam steering™ at all major mmWave 5G bands—24/26, 28 and 39 GHz. The company also offers active antenna innovator kits, based on their ICs to demonstrate the performance achievable using low power silicon integration and efficient antenna layout and design.

www.anokiwave.com

TechPlus Microwave — Booth 550

1U High VHF Duplexer

The TM1003 is a VHF duplexer operating between 135 to 172 MHz which will fit in a 1U 19-in. rack mount. Space is a premium so the company designed this duplexer with the lowest profile possible. T/R spacing, 5 MHz min., passband, 500 KHz min., insertion loss, 3.6 dB max. Return loss 20 dB min., rejection at Fc ± 20 MHz 60 dB min. Max power 40 W. They also make a bandpass version.

www.techplusmicrowave.com

Rohde & Schwarz **Booth 649**

Inline Calibration Units

VENDORVIEW

Rohde & Schwarz presents the R&S ZN-Z32 and R&S ZN-Z33 inline calibration units for its R&S ZNB(T), R&S ZVA and R&S ZVT vector network analyzers. The calibration units are ideal for satellite component testing in thermal vacuum chambers (TVAC) and for multiport component testing on production lines. The R&S ZN-Z32 covers the frequency range from 10 MHz to 8.5 GHz, the R&S Z33 from 10 MHz to 40 GHz. They are controlled by an R&S ZN-Z30 CAN bus controller, which supports up to 48 units.

www.rohde-schwarz.com/press/analyzers

American Technical Ceramics **Booths 707, 713**

Thin Film Low Pass Filter

ATC's new 1206 HP LPF Series high performance thin film SMT low pass filters offer superb high frequency performance in a low profile EIA style package. This series offers sharp cut-off response, excellent stopband rejection, low passband insertion loss with 50 Ohm input and output impedance characteristics. Their superb performance makes them well suited for the most demanding wireless frequency applications. The LPF 1206 filter series is supplied in tape and reel making them fully compatible with high speed automated pick-and-place manufacturing.

www.atceramics.com

Qorvo **Booth 725**

GaN on SiC RF Transistor

Introducing Qorvo's QPD1025 for IFF avionics applications. It is the highest powered GaN transistor on the market. The QPD1025 is a dual-channel 1.8 kW, 1 to 1.1 GHz GaN on SiC transistor in the 41 x 10 mm Ni-1230 package. The transistor comes in eared and earless package configurations. At 65 V, each side delivers a max of 900 W at 1 GHz, for a combined 1.8 kW. Peak efficiency at loadpull is 77 percent. Linear gain in the application board is 21 dB.

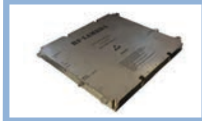
www.qorvo.com

RF-Lambda USA LLC **Booth 749**

300 W 6 to 18 GHz Solid State Amplifiers

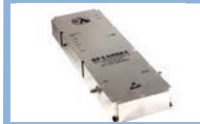
RFLUPA06G18GG RF-Lambda announces a new high-power wideband solid state power amplifier that is currently in production and will be ready in the third quarter of 2018. This amplifier is first of its class with 300 W of power and a frequency band that covers 6 to 18 GHz. The unit comes equipped with multiple protection features such as input over drive, over current and over temperature shutdown making it ideal for EMC, Vsat, test and radar applications.

2 to 6 GHz Wideband Power Amplifier



RFLUPA02G06GC is an ultra-wide band solid state power amplifier covering 2 to 6 GHz with a saturated output power of 100 W. The nominal gain is 47 dB, with a typical Psat of 50 dBm.

18 to 47 GHz Wideband Power Amplifier



RFLUPA18G47GE is a wideband solid state power amplifier covering 18 to 47 GHz with a saturated output power of 3 W. The nominal gain is 47 dB, with a typical Psat of +35 dBm.

www.rflambda.com

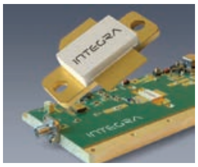
Herotek **Booth 812**

Limiter

Herotek offers a wide range of high-power limiters. Model LS0812PP100A is a 100 W CW limiter operating from 8 to 12 GHz with 1 kW peak, 1 µs pulse width limiting protection. It has a low insertion loss of 2 dB and 2:1 VSWR with typical leakage of +13 dBm at 100 W CW input. This limiter comes in a hermetically sealed package with removable connectors for drop in assemble and designed for both military and commercial applications.
www.herotek.com

Integra Technologies Inc. **Booth 815**

GaN/SiC Power Transistors, Power Amplifier Components and Integrated PAMs



Integra Technologies Inc. is dedicated to helping radar system engineers meet their goals for the highest resolution and most dependable signal transmissions. Among Integra's latest products released are a number of L-, S-, C- and X-Band high-power, highly efficient, GaN/SiC power transistors, power amplifier components and integrated power amplifier modules (PAMs, aka "pallets"). Integra offers expertise in solving long range pulsed RF and microwave challenges and will customize any of their 100+ standard devices to suit your unique application requirements.
www.integratech.com

CST of America **Booth 825**

CST STUDIO SUITE® 2018

VENDORVIEW

From initial concept to final prototype, every stage of product development means balancing multiple requirements; performance, reliability and cost on the one hand, and specifications, legal regulations and deadlines on the other. New features in the 2018 version of CST STUDIO SUITE® focus on system and hybrid simulation, enabling new workflows for system-level analysis such as electromagnetic compatibility (EMC), installed performance and biological exposure. Connect the dots of your design, see the full picture and develop the potential of your ideas with CST STUDIO SUITE® 2018.
www.cst.com

Custom MMIC **Booth 851**

MMIC SP5T Switches

VENDORVIEW

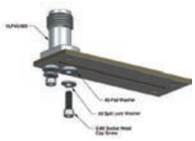
The CMD235C4 and CMD236C4 are DC to 18 GHz broadband MMIC SP5T switches. They are ideally suited for high performance military and instrumentation applications, both switches provide a switching speed of around 60 ns and an input P1dB of 21 dBm. They feature binary decoder circuitry that reduces the number of logic control lines, from three to two for the SP3T and from five to three for the SP5T.

GaN MMIC LNAs

The CMD276C4, CMD277C4 and CMD278C4 GaN MMIC LNAs deliver high linearity performance with output IP3 of +32 dBm while offering high input power handling of 5 W. The high input power handling feature enables system designers to avoid limiters and other protection networks, while still achieving extremely low noise figure over the operating bandwidth. These new MMIC LNAs are housed in a leadless 4 x 4 mm QFN package.
www.custommmic.com

Signal Microwave **Booth 863**

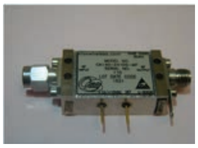
Solderless Connectors



Signal Microwave's VLF40-002 is a 2.92 mm connector system mounted on RF boards using screws, no soldering required. The rear of the connector makes contact to vias in the board using a raised grounding ring and center pin. The vias are used to carry the signal into the board to a stripline circuit inside the board or microstrip/GCPW on the back side of the board.
www.signalmicrowave.com

Ciao Wireless Inc. **Booth 902**

1 to 40 GHz Amplifier with Detected Output



Ciao Wireless Inc. has introduced an ultra-broadband amplifier which features an integrated wideband detector for communication applications. This amplifier comes with two min. gain options of 30 dB min. (35 dB typ.) and 15 dB min. (20 dB typ.). The gain flatness is ±3.25 max. The typical output power is +13 dBm across 1 to 28 GHz. The input and output VSWR is 2.3 or better. The typical noise figure is 6 across the full band (1 to 40 GHz).
www.ciaowireless.com

SV Microwave **Booth 903**

PCB Coaxial Interconnects

SV Microwave just launched their unique line of 3 mm between board spacing PCB coaxial interconnects. This line allows for the lowest stacked height (3 mm) of any board-to-board high frequency RF connection system. SV's 3 mm product line is ideal for high density stacked and multiport applications and is available in an optional solderless design that reduces yield and assembly time. Additionally, COTS versions are readily available through distribution.
www.svmicrowave.com/new-product/3mm-board-board-interconnects

Wenzel Associates Inc. **Booth 907**

Multiplied Crystal Oscillators to 16 GHz

Ultra-low phase noise and excellent spectral purity are the main characteristics provided in Wenzel Associates' Multiplied Crystal Oscillator (MXO) series of products at fixed frequencies between 200 MHz and 16 GHz. This versatile product line allows the customer to specify the exact frequency needed and select specific options such as phase locking with an external or internal reference, high output level, base oscillator output and multiple outputs along the multiplier string. Basically, a customized low noise frequency source without the cost of NRE.
www.wenzel.com

Custom Microwave Components **Booth 915**

12-Channel Attenuator/Monitor

Each of the 12-channels contains an attenuator in series with a solid-state sampler/amp switch (SAS) module. The attenuator modules provide independent control of their respective channel's loss by 70 dB in 0.5 dB steps. The SAS modules resistively samples the respective channel's output and selects/deselects the sample's routing to the monitor port for signal analysis.
www.customwave.com

Anritsu **Booth 925**

Signal Analyzer

VENDORVIEW

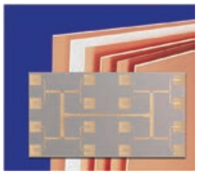
Signal Analyzer MS2850A is a spectrum/signal analyzer with max. analysis bandwidth of 1 GHz and frequency range of 9 kHz to 32 GHz or 44.5 GHz. With a wide dynamic range up to > 140 dB and excellent amplitude/phase flatness, it provides high-end performance at a mid-range price for improved cost-of-test. Software options provide

engineers with a cost-efficient and accurate solution to verify RF Tx characteristics of next-generation 5G base stations and mobile devices, SATCOM equipment and wideband communications systems.
www.anritsu.com/en-US/test-measurement/products/ms2850a

Rogers Corp. **Booth 939**

AD300D and IM Series Laminates

VENDORVIEW



The IM Series high frequency laminates are an outstanding Passive Intermodulation (PIM) performing version of its AD300D™, AD255C™ and DiClad® 880 antenna grade laminates. The laminates now include the newly developed IM system option. This product utilizes an ultra-smooth (Rq = 0.5 µm by non-contact interferometry method) electrodeposited copper foil option which has excellent adhesion to the substrate materials. The PIM performance of all substrates with the IM cladding has typical values of -166 dBc at 0.030" and -165 dBc at -060" using the Rogers internal test method of two 43 dBm swept tones at 1900 MHz. These specialty materials are specifically engineered and manufactured to meet the demands of today's base station antenna markets.
www.rogerscorp.com

Aethercomm **Booth 1012**

GaN RF Amplifier

Aethercomm introduces a high-power, super broadband, GaN RF amplifier that operates from 20 MHz to 6 GHz. This power amplifier is ideal for broadband military platforms as well as commercial applications because it is robust and offers high-power over an extremely large bandwidth with decent power added efficiency. This amplifier is packaged in a modular housing that is approximately 5 x 5 x 2 in. The weight of this unit is ~3.5 lb max.
www.aethercomm.com

Richardson RFPD **Booth 1014**

High-Power SDR/Small Cell Developers Kit

Developing platforms that seamlessly integrate the baseband SoC, RF transceiver IC, and RF front-end in a small cell system is a complex, time-consuming task that requires careful planning to achieve max. system flexibility. Richardson RFPD's development kit offers an alternative to get your solution to market faster. This complete kit includes a high-power RF front-end board combined with existing ADI FPGA and transceiver tools.
www.richardsonrfpd.com

Cobham Advanced Electronic Solutions **Booth 1039**

Miniature Synthesizer Demonstration Kit

VENDORVIEW

Cobham, a provider of high performance frequency and signal generation products, introduces the Model 1018 miniature synthesizer and demonstration kit. The 1018 is great for calibration, testing and simulation of tactical radar and electronic warfare platforms. It is a high performance solution in a small, lightweight package, priced for tactical applications and easy to integrate.

Waveguides

Cobham offers industry-leading custom rigid, rigid-flexible assemblies and extra-long waveguides with complex shaping, while incorporating high electrical performances and specializing in custom bracketry and integrated waveguides from cast to 3D printed to hybrid. Cobham is excited to introduce its new product line of lightweight, high frequency Q-, V- and U-Band waveguide to enable the next evolution of SATCOM payloads for future constellations providing world-wide connectivity.
www.cobham.com

Empower RF Systems **Booth 1048**

Tri-Band Amplifier

VENDORVIEW

Empower RF model 2198 is a solid state tri-band amplifier in a single 3U chassis ideal for general purpose lab and production line test applications. With user selectable modulation and power output modes this amplifier integrates easily into any test system and simplifies test setups with selectable AGC and ALC modes. The amplifier is ready to go out of the box with its built in browser GUI so there is no software to install for PC or Lan control.
www.empowerrf.com

Morion Inc. **Booth 1107**

Ultra Precision OCXO

Morion released the MV336M, ultra precision OCXO with ultra-low short-term stability, phase noise and excellent temperature stability in a 92 x 80 x 50 mm package. Available with a frequency of 10 MHz, the MV336 has phase noise of < -93 dBc/Hz at 0.1 Hz and -120 dBc/Hz at 1 Hz, short-term stability < 1E-13 at 1 sec and < 3E-13 until 100 sec which is accompanied by temperature stability of < 4E-11 vs. -10...+70°C. The MV336M operates at 12 V.
www.morion-us.com

HUBER+SUHNER **Booth 1116**

PSM Connectors

VENDORVIEW

To meet the increasing demand of cost and weight sensitive applications in the aerospace market, HUBER+SUHNER introduces the Power Sub-Miniature (PSM) interface, offering power levels equivalent to a standard TNC interface without exceeding the envelope and mass of 50 percent smaller and lighter SMA connectors. The PSM interface will enable customers to maximize connector density and minimize weight to reduce the overall system footprint without sacrificing on power handling capability.
www.hubersuhner.com

SAGE Millimeter **Booth 1103**

Dual Polarized Scalar Feed Horn Antenna

VENDORVIEW

Model SAF-2434231535-358-S1-280-DP is a dual polarized, WR-28 scalar feed horn antenna assembly that covers several popular 5G bands in the frequency range of 24 to 42 GHz. The antenna features an integrated orthomode transducer (OMT) that provides high port isolation and cross-polarization cancellation and a broad band scalar horn that provides low sidelobe levels. At center frequency, the horn antenna exhibits 15 dBi nominal gain and a typical half power beamwidth of 35 degrees and -25 dB sidelobe levels, respectively.

Full E-Band Power Amplifier

Model SBP-6039032012-1212-E1 is an ultra-broadband power amplifier with a typical small signal gain of 20 dB and P1dB of +12 dBm in the frequency range of 60 to 90 GHz. The saturated output power of the amplifier is +16 dBm. The mechanical configuration offers an inline structure with WR-12 waveguides and UG387/U-M flanges. Other port configurations, such as with 1 mm connectors or the right angle structure with WR-12 waveguides, are also available under different model numbers.
www.sagemillimeter.com

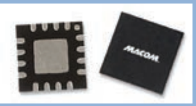
MACOM — **Booth 1125**

Low Phase Noise Amplifiers

MACOM's new family of low phase noise amplifiers includes the MAAL-011151-DIE, an easy-to-use, wideband distributed amplifier ideal for test and measurement, EW, ECM and radar applications where low phase noise and drive power are required. Operating from 2 to 18 GHz, this device provides -154 dBc/Hz of phase noise at 1 KHz, 17 dB of linear gain, 16 dBm of P1dB and 4 dB of noise figure at 8 GHz. The input and output are fully matched to 50 Ohms with typical return less of > 15 dB.

Internally-Matched Power Detector

MACOM's MADT-011000 is a single-ended, internally-matched power detector featuring

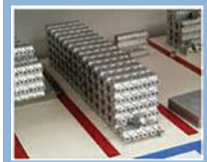


optimal wide input bandwidth and high dynamic range of 30 dB. Operating from 5 to 44 GHz, this device is well suited for power control in microwave radios, test and measurement equipment and radar applications. The circuit consumes 70 µA from a 4.5 V supply, while matched detector and reference diodes provide temperature compensation in differential operation.

www.macom.com

Quest Microwave — **Booth 1130**

Ferrite Devices



Quest Microwave provides a broad range of ferrite devices for the global microwave electronics marketplace. Standard and custom designs are available for both commercial and military applications. With over 60 years of combined experience, the company's engineering staff can design and develop ferrite devices for virtually any application. They are there to provide you with a world class microwave components solution.

www.questmw.com

Spectrum Elektrotechnik GmbH — **Booth 1130**

Hermetically Sealed Adapters

Spectrum Elektrotechnik GmbH offers a wide range of hermetically sealed adapters to the hermeticity of 10^{-8} atm. cm³/s min. The adapters use fused in glass seals between center contact and outer conductor. This ensures complete hermeticity of the units. The adapters are normally used at vacuum chambers testing products that are intended for outer space with the testing equipment and the personnel staying at regular environment. Available connector styles are 1.85 mm, 2.4 mm, 2.92 mm, N and TNC.

www.spectrum-et.org

MiniRF Inc. — **Booth 1135**

CATV Coupler

MiniRF Inc. has reached 40 not in years of business but in dB of isolation in its new 75 Ohm CATV coupler designed for full duplex systems. MRF-CP0016 coupler has achieved what switches only dream of with 40 dB typ. isolation up to 780 MHz between ports with only ~1 dB main line loss and 8 dB ± 0.5 dB nominal coupling. The performance is achieved in its small 0.25 x 0.28 in. surface-mount package.

www.minirf.com

RFMW — **Booth 1135**

RF Power Limiter

pSemi's PE45361 RF power limiter handles 100 W of pulsed input power from 10 MHz to 6 GHz. Its monolithic structure is 8× smaller than discrete, PIN-diode solutions and eliminates thermal hysteresis. The adjustable limiting threshold is set from +7 to +13 dBm via a low current control voltage, eliminating the need for external bias components. Fast response time of < 1 ns ensures instantaneous protection of sensitive components and rapid return to normal operation. Highly flexible and highly linear, it delivers simple, repeatable and reliable receiver protection.

www.rfmw.com

Krytar Inc. — **Booth 1203**

Hybrid Copuler

New 90 degree coupler, Model 3040440, delivers exceptional versatility from 4 to 44 GHz. Specifications include 3 dB coupling; amplitude imbalance: ±1.2 dB; phase imbalance is ±12 degrees; isolation is > 13 dB (4 to 30 GHz) and > 8 dB (30 to 44 GHz); max. VSWR: 1.65 (4 to 30 GHz) and 1.90 (30 to 44 GHz); and insertion loss of < 3.2 dB. The coupler comes with 2.4 mm female connectors and measures just 1.99 x 0.80 x 0.42 in. and weighs only 1.5 oz.

www.krytar.com

Pivotone — **Booth 1212**

RF Filter/Duplexer/Combiner

Pivotone announces the release of series of RF filter/duplexer/combiner products with exceptional low PIM performance. These low PIM products are designed to be used in the PIM measurement equipment and the wireless communication systems. Their products cover all the wireless frequency

bands all over the world. The PIM performance of filter/duplexer/combiners for measurement applications has reached the level of -127 dBm with two 40 W tones, and for the wireless applications the PIM performance has reached -130 dBm with two 20 W tones.
www.pivotone.com

CTT Inc. — Booth 1213
40 W X-Band GaN Power Amplifier

CTT's new solid-state GaN-based power amplifier, model AGX/180-4656, covers 3 to 18 GHz with 40 W of CW power output. The compact size of 5.16 x 4.90 x 0.28 in. offers RF/microwave designers an excellent choice for SWaP solutions for many EW applications, including jammers, and for use as a TWT (traveling wave tube) driver amplifier.
www.cttinc.com

LPKF Laser & Electronics — Booth 1216
LPKF ProtoLaser U4

The ProtoLaser U4 is a versatile and easy-to-use lab system to instantly create intricate RF and microwave circuits with superior accuracy and definition. The system uses a tool-less laser direct ablation method and works straight from CAD data. With its high-power, short-pulse UV laser (355 nm) and 20 µm spot size, it can process a wide range of materials including flex circuits (e.g., DuPont Pyralux TK), Rogers, Taconic, FR4, ceramic (Al2O3) and many others.
www.lpkfusa.com/pls

GLOBALFOUNDRIES — Booth 1225
HP SiGe Technologies

High performance (HP) SiGe solutions are designed to deliver the best performance/power ratio while leveraging cost-effective, silicon-proven 90 and 130 nm technology nodes, at mask costs significantly lower than RF CMOS. With NPN fMAX as high as 370 GHz, 100× lower 1/f noise than CMOS and the higher breakdown voltages associated with bipolar devices—resulting in higher power output-drive capability—HP SiGe technologies are an ideal match for 5G mmWave, optical/wireless/wired and radar/LIDAR applications.
www.globalfoundries.com

RelComm Technologies Inc. — Booth 1257
RRDL-SC-Series 1P2T

RelComm Technologies compliments its product line with a high performance 1P2T coaxial relay configured with "SC" type connectors and excellent RF performance up to 6 GHz. CW power rating is 1500 W at 1 GHz and 600 W at 6 GHz. Operating temperature range is -30°C to +70°C. The relay is available in failsafe, latching and multi-throw configurations and is fully RoHS compliant. Options include position indicators, D-SUB header, splash-proof sealed and TTL controlled input.
www.relcommtech.com

Ducommun — Booth 1312
E-Band Block Down-Converter

Model SNG-12-01 is a full E-Band block down-converter that extends testing capabilities for low cost, low frequency noise figure meters; allows noise figure testing of E-Band devices without noise figure meter, using the Y factor method. It is versatile in low cost designs; Model SNG-12-01 is an affordable expansion to mmWave laboratories that do not have the budget for large scale equipments. Featuring low spurious/harmonics, low LO frequency and power requirement and is compact and lightweight.
www.ducommun.com

Peregrine Semiconductor Corp. (pSemi) — Booth 1349
50 GHz DSA

pSemi (formerly Peregrine Semiconductor) extends its high performance digital step attenuator (DSA) family into higher frequencies with a 50 GHz DSA, the PE43508. This 50 Ohm, 6-bit DSA offers wideband support from 9 kHz to 50 GHz and features flexible attenuation steps of 0.5 and 1 dB up to the 31.5 dB range. Offered as a flip-chip die, the PE43508 is ideal for 5G test and measurement applications.

Value, High Performance DSAs

pSemi (formerly Peregrine Semiconductor) introduces a family of value, high performance DSAs. These four DSAs—the PE43620, PE43650, PE43665 and PE43670—supplement pSemi's top-performance and high frequency DSA products but at an entry-level price point. The value 50 and 75 Ohm DSAs feature pSemi's industry-leading attenuation accuracy and are offered in a 2-, 5-, 6- and 7-bit configuration.
www.psemi.com

Cernex Inc. — Booth 1406
Benchtop Amplifiers

VENDORVIEW

Cernex's benchtop amplifiers are designed for use in a wide range of general purpose applications such as laboratory test equipment, instrumentation and other applications. Reliable operation is achieved using rugged stripline circuit construction with selected GAsFETs, PHEMTs and MIMICs.
www.cernex.com

General Microwave Corp. — Booth 1416
Indirect Synthesizers

Kratos General Microwave enhanced its series of fast switching (1 usec) indirect synthesizers with the addition of the Model SM6220 with frequency modulation capability covering the full band 2 to 20 GHz. It can provide a frequency deviation of 1 GHz at up to a 10 MHz modulation rate and can be modulated with either analog or digital inputs. Of special significance; the synthesizer output frequency remains fully locked even while in the FM mode.
www.kratosmed.com

OML Inc. — Booth 1436
Wireless Communications Test Solutions

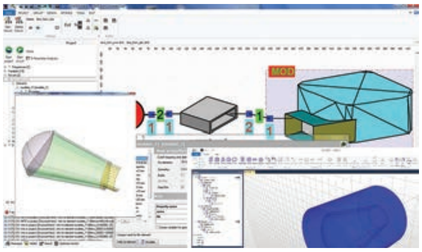
OML, with over 25 years of mmWave innovative designs and application expertise, is delivering industry leading novel designs and application solutions for customers worldwide. OML's display will focus on economical and portable wireless communications test solutions. Showcase products feature the latest USB-powered spectrum analysis solutions with IF bandwidth greater than 4 GHz for 5G, IoT, WLAN, point-to-point communication, radar, EW and satellite, as well as traditional laboratory benchtop and modular mmWave solutions to 500 GHz.
www.omlinc.com

Micro Lambda Wireless — Booth 1503
Low Noise Frequency Synthesizer

Standard frequency models are available covering 6 to 18, 8 to 20 and 10 to 21 GHz. These synthesizers have been designed with superior integrated phase noise over the 20 kHz to 50 MHz offset frequencies and provide exceptional Error Vector Magnitude (EVM) performance. Standard models are specified to operate over the 0°C to +65°C temperature range. Extended temperature ranges are available.
microlambdawireless.com

Mician GmbH Booth 1549

µWave Wizard Hybrid EDA Software Tools



Mician, a developer of EM software tools for the analysis, synthesis and optimization of passive components like feeding networks, couplers, multiplexers and horn antennas, including reflectors, will show their µWave Wizard hybrid EDA software tools. The tools combine the flexibility of fast and powerful numerical methods with an appealing and ergonomic GUI that enables flexibility and openness including CAD export formats interfacing with most mechanical design tools.

www.mician.com

Ceyear Booth 1561

Network Analyzers

The Ceyear AV3672 line of network analyzers are cutting edge and have an extremely competitive value proposition without compromising quality. It is offered in five different frequency ranges up to 67 GHz, both 2- and 4-port configurations, and frequency range extension up to 500 GHz. A number of measurement options such as time domain, frequency offset, gain compression, mixer measurements, embedded LO, pulse and much more are available.

www.topdogtest.com/ceyear
www.cc-globaltech.com

Planar Monolithics Industries Inc. Booth 1603

Extended Dynamic Range DLVA

VENDORVIEW

PMI Model No. ERDLVA-218-DC-LPD is an extended dynamic range DLVA designed to operate over the 2 to 18 GHz frequency range. It employs planar diode detectors and integrated video circuitry for high speed performance and outstanding reliability. It is of superior construction using state of the art MIC/MMIC technology.

www.pmi-rf.com

Smiths Interconnect Booth 1625

Chip Attenuators

VENDORVIEW

Introducing the SpaceNXT™ HC Series high-reliability temperature variable and fixed chip attenuators for NextGen commercial space applications. Operating from DC to 18 GHz, pre-tested for mission assurance (Group A) and qualified for space use, the HC Series provides a high-reliability, readily available solution at competitive pricing without additional charges for flight testing. Utilizing Thermopad® technology, a totally passive, surface-mounted device that offsets gain variation over temperature, HC Series offers significant competitive advantages including zero distortion and a compact PCB footprint.

www.Smithsinterconnect.com

Modelithics Booth 1642

mmWave & 5G Library

VENDORVIEW

Modelithics Inc. has recently introduced a new library product, the Modelithics mmWave & 5G Library. All models in this powerful collection of advanced simulation models have been validated to at least 30 GHz, with some validated up to 125 GHz. The Modelithics mmWave & 5G Library was developed to support the design needs of the next generation of cellular and wireless communication, rapidly expanding into the mmWave frequency range.

www.modelithics.com

Exodus Advanced Communications Booth 1704

53 dB System

VENDORVIEW

Exodus Advanced Communications introduces AMP2065A, a solid-state, 6 to 18 GHz, 200 W CW, 53 dB system. This class AB linear state of the art C and W power amplifier features an instantaneous wideband GaN design with built-in protection circuits for high-reliability and ruggedness. It is available with optional digital control and monitoring and local/remote interfaces. It is suitable for all single channel modulation standards. Other typical applications including TWT replacements, EMI/RFI, EW, SATCOM and lab use.

www.exoduscomm.com

Signal Hound — **Booth 1714**

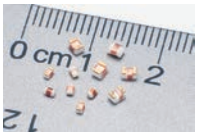
RF Spectrum Analyzer

The new SM200A is an affordable, compact and capable spectrum analyzer for a range of applications. Tuning from 100 kHz to 20 GHz, the analyzer has an instantaneous bandwidth of 160 MHz and a high dynamic range of 110 dB. A sustained sweep speed of 1 THz/s and ultra-low phase noise means the SM200A introduces only 0.1 percent error to EVM measurements. Ready to ship.

www.signalhound.com

Gowanda Components Group — **Booth 1735**

High Performance Inductors



Gowanda introduces high performance inductors developed to address market needs. Advancements in the company's design technology and manufacturing capability deliver significant improvement—nearly 2× or more—in SRF and current ratings for these new inductors as compared to traditional molded designs with equivalent inductance. The first six series—CC4H1008, CF4H1008, CC4H1210, CF4H1210, CC4H1812 and CF4H1812—will be on display at IMS2018. Gowanda Electronics, DYCO Electronics, Communication Coil, Butler Winding, TTE Filters, Microwave Circuits and Instec Filters are affiliates of Gowanda Components Group.

www.GowandaComponentsGroup.com

RLC Electronics — **Booth 1748**

65 GHz SPDT Switches

RLC Electronics is offering DC to 65 GHz SPDT switches, made available with customization options including your choice of control voltage, operating mode, indicators and TTL or BCD drivers, as well as special mating/power connectors. These switches exhibit low loss (< 1 dB) and maintain high isolation (> 50 dB) over the full passband. Manually controlled options are available as well which are hand-driven utilizing a toggle on the top of the switch. Some typical applications for the 65 GHz switches include collision avoidance test systems and 5G products.

www.rlcelectronics.com

Ion Beam Milling — **Booth 1752**

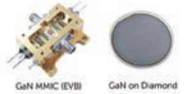
Thin Film Filters

Ion Beam Etching produces superior thin film filters at all frequencies over chemical etch methods. Straight side walls, elimination of undercut, and circuit to circuit consistency are hallmarks of the Ion Beam Etching process. Ion Beam Etched filters have real world performance that closely matches performance specifications developed by modeling software. Because of the close performance match, you do not waste time or money tweaking your design and Ion Beam Milling Inc. filters are cost competitive with chemically etched products.

www.ionbeammilling.com

RFHIC — **Booth 1755**

RF and Microwave Components



RFHIC is a company that specializes in design and manufacturing of RF and microwave components for telecommunication, military/commercial radar and ISM applications utilizing GaN solution. All currently listed GaN products will soon be available with RFHIC's next generation GaN on Diamond. RFHIC will showcase GaN MMIC at X-, Ku-, K-, Ka-Band, 5G small cell, 15 kW CW microwave generator at ISM band, microwave electrodeless lighting, 5 kW X-Band SSPA transmitter and GaN on Diamond transistor.

www.rfhic.com

MIcable — **Booth 1802**

Test Cable

T40 is high performance and reliable test cable, which is up to 40 GHz. It is ideal for high precision mmWave and frequent test in production line and labs. The cable construction is very rugged, which still works well on electrical performance after 20,000 harsh flex cycles. A wide range of stainless steel connectors are available, such as SMA, N type, 2.92 mm, 3.5 mm.

Microwave Cable Assemblies

MIcable C29F(.086Flex) microwave cable assemblies offer superior electrical performance up to 50 GHz in low VSWR, low loss and phase stability. The typical VSWR is 1.25 at 50 GHz and phase stability over temperature is < 500 ppm at -40~+70°C. It is ideal for use in 5G MIMO connecting and testing, and regular use in lab and production line.

www.micable.cn

Eclipse Microwave — **Booth 1806**

Planar Back Diodes

The MBD series of planar back (tunnel) diodes are fabricated on germanium substrates using passivated, planar construction and gold metallization for reliable operation up to +100°C. Unlike the standard tunnel diode, Ip is minimized for detector operation and offered in five nominal values with varying degrees of sensitivity and video impedance. The diodes have zero bias operation, excellent temperature stability and low video impedance.

www.eclipsemicrowave.com

Norden Millimeter — **Booth 1812**

Power Amplifiers

Norden Millimeter announced that their power amplifiers (N16-5631) and low noise amplifiers (N16-5619) have been chosen to be included on Keysight's 5G Application Note 5992-1326EN. The N16-5631 and N16-5619 provide wideband frequency operation from 18 to 44 GHz. Pictured is the N16-5631 amplifier which is available in single channel or 4-channel configurations. Norden continues to expand its line of amplifier, multipliers and converters covering 5G mmWave frequency bands. Norden can also provide custom designs to meet specific test module requirements.

www.nordengroup.com

West·Bond Inc. — **Booth 1816**

Wire Bonders

Introducing the most flexible, complete wire bonders system available today. 7KE and 4KE series wire bonders: bonding at 45 degree feed for tail control, 90 degree for ribbon and deep access and ball bonding without changing heads. Wedge bonding Au, Al, Cu; ball bonding Au, Cu. automatic, semiautomatic and manual all ESD protected. Ultrasonic, thermosonic and thermocompression wire/ribbon bonders; eutectic and epoxy die bonders, insulated wire bonders and pull testers.

www.westbond.com


New Babies
arrived
Miniature
Phase Adjusters
DC to 40.0 GHz , 2.92mm
DC to 50.0 GHz , 2.40mm
DC to 65.0 GHz , 1.85mm
When Quality is needed:
Spectrum
Elektrotechnik GmbH
80905 Munich, Germany
P.O. Box 450533
Telephone: +49-89-3548-040
Facsimile: +49-89-3548-0490
www.spectrum-et.com
Email: sales@spectrum-et.com
See us at IMS Booth 1130

IMS PRODUCT SHOWCASE

AISLES 1800-1900

Dynawave **Booth 1817**

Cable Assemblies

The ArcTite® series of cable assemblies is now available from DC to 40 GHz. ArcTite® provides ultra-low profile bends without the need for supplemental strain relief boots. Dynawave's innovative connector designs conform to the MIL-STD-348 interface specification and utilize a 360 degree internal solder termination for high-reliability and enhanced shielding effectiveness. They are ideal for high density, internal module connections and provide a cost effective, higher performance alternative to SMA right angle connectors.

www.dynawave.com

NI AWR **Booth 1825**

NI AWR Design Environment V14

VENDORVIEW

AWR

This new release introduces network synthesis technology for power amplifier design, distributed computing for EM analysis, MIMO antenna solutions and enhanced module/PCB design flows. NI AWR Design Environment includes Visual System Simulator™ for system design, Microwave Office/Analog Office for circuit design, and AXIEM and Analyst™ for EM. The broader NI AWR software portfolio also includes AntSyn™ for antenna synthesis and AWR Connected™ for third-party solutions.

www.awrcorp.com

NI Microwave Components **Booth 1825**

Frequency Synthesizers

The QuickSyn series of frequency synthesizers delivers instrument-grade performance, increased functionality, and efficient power consumption at a reduced size and low cost. The synthesizers employ a phase-refining technology that provides a unique combination of fast-switching speed and low phase noise characteristics. Models include frequencies of 10 and 20 GHz, and three popular mmWave bands—27 to 40, 50 to 70 and 76 to 82 GHz.

www.ni-microwavecomponents.com

Besser Associates Inc. **Booth 1833**

RF and Wireless Training

BESSER ASSOCIATES The Worldwide Leader in RF and Wireless Training

Besser Associates is a worldwide leader in RF and wireless training. Their instruction combines theory with hands-on practice, the latest tools and technology and the most appropriate training media (online and traditional classroom) for individualized, meaningful participant experiences. The company choose their instructors from the best and brightest in their fields around the world; they carry an average of 20 years of field and applied teaching experience. Courses can be presented on-site and customized to meet the specific needs of the client.

www.besserassociates.com

Rosenberger **Booth 1841**

Test & Measurement Equipment and Products

Rosenberger of North America highlights its latest developments at IMS2018. The company has available test and measurement equipment and products for microwave and VNA measurements, such as calibration kits (full and industrial versions), with a wide range of coaxial interfaces, as well as compact calibrations kits such as MSO (open, short, load) and MSOT (open, short, load, thru) versions. They also supply microwave and test cable assemblies and an expanded range of test ports for VNAs.

www.rosenberger.com/us_en

Copper Mountain Technologies **Booth 1849**

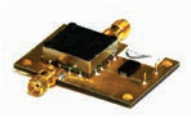
Frequency Extenders

Copper Mountain Technologies released new FET1854 frequency extenders with frequency range from 18 to 54 GHz. With the launch of the new FET1854 extenders, the CobaltFx series allows engineers to build a scalable and affordable 5G testing solution. Anchored by a 2- or 4-port 9 or 20 GHz USB vector network analyzer, CobaltFx includes extenders in multiple frequency bands: 18 to 54, 50 to 75, 60 to 90 and 75 to 110 GHz. Frequency extension is a standard software feature.

www.coppermountaintech.com

VIDA Products **Booth 1904**

Low Cost X-Band VCO



Featuring extremely low open loop phase noise specified at a 1 MHz offset of -145 dBc/Hz. VCO input is designed for easy integration with phase lock MMICs. Evaluation board allows for speedy verification of performance and system testing. Standard unit is operational from -10°C to 60°C. Power dissipation is less that 1 W. The performance is delivered by VIDA's New YIG MMIC, their upgraded DRO replacement, YOMICA. Ask about volume discounts.

www.vidaproducts.com

Remcom Inc. **Booth 1917**

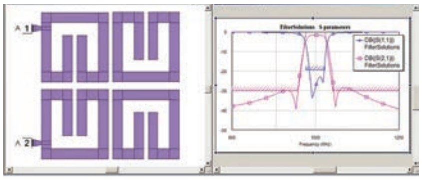
Wireless InSite® for 5G mmWave and MIMO Simulations

Wireless InSite MIMO is a unique ray tracing tool that simulates the detailed multipath of large numbers of MIMO channels while overcoming the limitations of traditional methods including 3D ray tracing valid up to 100 GHz, simulate massive MIMO arrays, spatial multiplexing and beamforming, diffuse scattering and high performance computing. With optimizations that minimize runtime and memory constraints, wireless InSite efficiently simulates even the large arrays in Massive MIMO systems. Visit Remcom's booth for a demonstration.

www.remcom.com

Nuhertz Technologies **Booth 1935**

Microstrip Port Tuning Optimization Process



FilterSolutions® (Nuhertz Technologies) has improved its already fast and accurate Microwave Office® microstrip port tuning optimization process to be faster, more accurate and more flexible than ever. Accurate optimized planar designs are normally produced in just a few minutes for a wide variety of design requirements, including cross coupled microstrips. In addition to microstrips, supported technologies include suspended and inverted microstrips, and balanced and unbalanced striplines. Trial licenses, demos and training are available from Nuhertz.

www.nuhertz.com

Holzworth Instrumentation Inc. **Booth 1949**

Real-Time Phase Noise Analyzer

VENDORVIEW

The HA7000 Series real-time phase noise analyzer products resolve the historical speed and accuracy issues in both R&D and high throughput (ATE) manufacturing test environments. The HA7000 Series currently includes the HA7062C, HA7402C and the new HA7701A delay line analyzer. These versatile phase noise analyzers offer ease of test setup and high speed acquisition times without compromising on data accuracy or limitations in the measurement floor. Extended frequency ranges and measurement offset capabilities will be demonstrated at IMS2018.

www.holzworth.com

The 2018 IMS Microwave Week is held, 10 - 15 June 2018, at the Pennsylvania Convention Center in Philadelphia. Register today for the IMS Microwave Week of conferences, including the Radio Frequency Integrated Circuits (RFIC) Symposium, International Microwave Symposium (IMS), and the Automatic Radio Frequency Techniques Group (ARFTG) Conference. Unique to the 2018 IMS Microwave Week, the International Microwave Bio-Conference (IMBioC) will be a co-located conference.

IMS Microwave Week – At a Glance	
Sunday, 10 June 2018	Workshops, Short Courses RFIC Plenary, Joint Industry Show Case & Interactive Forum, RFIC Reception
Monday, 11 June 2018	Workshops, Short Courses, RF Bootcamp; Three Minute Thesis (3MT®) Competition RFIC Technical Sessions, Panel Session, IMS Historical Exhibit IMS Plenary, Welcome Reception
Tuesday, 12 June 2018	IMS, RFIC Technical Sessions and Interactive Forum; Student Design Competitions, Student Paper Competition, IMS Exhibition, Historical Exhibit, Industry Workshops & MicroApps 5G Summit and Lunch Panel; Joint IMS/RFIC Panel Session Young Professionals (YoPros) Panel, Networking Event Amateur Radio (HAM) Talk and Networking Reception
Wednesday, 13 June 2018	IMS Technical Sessions, Panel, and Interactive Forums IMS Exhibition, Historical Exhibit, Industry Workshops & MicroApps Industry Hosted Reception; MTT-S Awards Banquet
Thursday, 14 June 2018	IMS Technical Sessions and Interactive Forums; Physicians Lunch Panel Session MTT-S Student Awards Luncheon; (Student) Career Counseling Fair IMS Exhibition, Historical Exhibit, Industry Workshops & MicroApps IMS Closing Ceremony; Also, IMBioC Opening Ceremony Women in Microwaves Panel Session and Networking Reception
Friday, 15 June 2018	Workshops, Short Courses ARFTG Conference and Exhibition; IMBioC Technical Sessions and Exhibition

WWW.IMS2018.ORG

PENNSYLVANIA CONVENTION CENTER • PHILADELPHIA, PENNSYLVANIA, USA

Exhibition Dates: 12–14 June 2018 • Symposium Dates: 10–15 June 2018

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MTT-S

IMS2018 Keynote Speakers

Plenary Session Talk
Monday, 11 June 2018
Stephen K. Klasko, MD, MBA

President and CEO, Thomas Jefferson University and Jefferson Health

"The Hitchhiker's Guide to the Healthcare Galaxy: The Actions That Changed the Healthcare Landscape in America from 2017-2027"

The author of the books, We CAN Fix Healthcare and The Phantom Stethoscope, President Klasko uses science fiction to challenge audiences to imagine an ideal future and identify what it takes to design that future today. He reviews twelve "disruptors" for the demise of the old healthcare system and shows how each is an opportunity to take the trends and incremental steps we see today and create the transformations and disruptions tomorrow.

Closing Session Talk
Thursday, 14 June 2018
Nader Engheta, PhD

H. Nedwill Ramsey Professor
University of Pennsylvania

"Extreme Platforms for Extreme Functionality"

Platforms with unprecedented "extreme" electromagnetic features can now be constructed, providing ample opportunities for manipulating, tailoring, and sculpting waves and fields at various scale lengths. We have been exploring a series of phenomena related to the wave-matter interaction in platforms with extreme scenarios, such as near-zero-index materials and specially engineered materials that solve equations as waves go through them. These "extreme platforms" offer new opportunities for functional devices in the future.

Closing Session Talk
Thursday, 14 June 2018
Dr. Nicholas J. Ruggiero II, MD

Thomas Jefferson University

"Renal Denervation for Uncontrolled Hypertension: Complexity After Symplicity".

Renal denervation for uncontrolled hypertension was demonstrated to be extremely successful in many early trials. The large, randomized, pivotal US trial, Symplicity HTN 3, unfortunately showed no benefit in comparison to optimal medical therapy. These results bridled enthusiasm for this technology and accounted for many companies to desert the premise altogether. Fortunately, those who believe in the procedure are pressing forward and multiple new trials which are currently enrolling will ultimately determine the future of renal denervation.

The IMS Welcome Reception will be held on Monday, 11 June 2018 at the historic Reading Terminal Market Building in Philadelphia. The reception immediately follows the conclusion of the IMS Plenary Session. The plenary session attendees will be led, as a parade, to the Reading Terminal Market by the "Mummers".

For the latest on IMS and Microwave Week visit www.ims2018.org

Technical Sessions, Tuesday, 12 June 2018

Time	201A	201B	201C	202AB	203AB	204A	204B	204C	Exhibition Area	
	Room Number, Location									
08:00 – 09:40			**Session Tu1C** Advances in Combiners and Dividers	**Session Tu1D** Novel MW and MMW Materials, Devices, and Radiating Structures			**Session Tu1G** Resonator-based Sensors	**Session Tu1H** Advanced Structures using Additive Manufacturing Process		
09:40 – 10:10	**AM Coffee Break, Grand Hall and Exhibition Hall**									IMS Exhibition, MicroApps Seminars, Student Design Competitions
10:10 – 11:50			**Session Tu2C** Recent Developments in Passive Circuits	**Session Tu2D** Advances in Modeling and Design Optimization	**Session Tu2E** **Focus Session** Radio to Terahertz Waves toward Nanoscale Sensing, Imaging and Characterization of Biological Samples		**Session Tu2G** Advances in Near-Range Radar Sensors	**Session Tu2H** 3D-Printed Waveguide Structures	IMS Student Paper Competition	
11:50 – 13:30	**IMS/RFIC Panel** Can a residential wireless Gbs internet connection compete with wired alternative?									
13:30 – 15:10		**Session Tu3B** Nonlinear Circuit Analysis, Modeling, and Distortion Compensation	**Session Tu3C** Advances in Millimeter-Wave Integrated Waveguide Components and Transitions	**Session Tu3D** Advances in Numerical Modelling for Multi-Scale and Multi-Physics Applications	**Session Tu3E** Advances in Microwave and Terahertz Applications in Nanotechnology	**Session Tu3F** Biomedical Radar	**Session Tu3G** Advances in Backscattering and RFID Circuits	**Session Tu3H** Novel Package-PCB Integration Concepts		
15:10 – 15:55	**PM Coffee Break (15:10 - 15:40), Exhibition Hall**									
15:55 – 17:15		**Session Tu4B** **Focus Session** Non-Doherty Load Modulated Power Amplifiers	**Session Tu4C** Integrated Wave-guide Structures and Techniques	**Session Tu4D** Novel Theoretical Approaches in MW Structure Analysis & Design	**Session Tu4E** Nano-Scale Devices and Antennas		**Session Tu4G** Advances in Chipless and RFID Sensors	**Session Tu4H** Novel Interconnects for W- and D-band	**TUIF1:** Interactive Forum #1	

Technical Track Key: Field, Device and Circuit Tech. | Passive Components | Active Components | Systems & Applications | Emerging Technical Areas | Focus or Special Sessions

Also on Tuesday: 5G Summit; Industry Workshops; YoPros Panel and Networking Event; Amateur Radio Talk and Networking Reception; Prof. Herczfeld Celebration Event

For the latest on IMS and Microwave Week visit www.ims2018.org

Technical Sessions, Wednesday, 13 June 2018

Time	201A	201B	201C	202AB	203AB	204A	204B	204C	Exhibition Area	
08:00 – 09:40	**Session We1A** 5G sub-systems: from predistortion to complete link	**Session We1B** VHF-UHF Components and Analog Signal Processing	**Session We1C** Planar Multiplexers and Multi-Band Filters	**Session We1D** Advanced Behavioral Models of Devices and Systems	**Session We1E** Advanced MEMS Filters, Resonators, and Waveguides	**Session We1F** Si-based MMW-THz Circuits	**Session We1G** Enabling Array Components and Beam Forming Architectures	**Session We1H** High Performance Power Amplifiers		
09:40 – 10:10	AM Coffee Break, Grand Hall and Exhibition Hall									IMS Exhibition, MicroApps Seminars
10:10 – 11:50	**Session We2A** Multi GHz all Digital and Mixed Signal Circuit and Systems	**Session We2B** Advances in Mixers and Frequency Multipliers	**Session We2C** Filter Tuning, Synthesis, and Innovative Coupling Realizations	**Session We2D** Trapping Phenomena in GaN HEMTs	**Session We2E** Ferrite, Ferroelectric, and Phase-Change Components	**Session We2F** THz and mm-Wave Amplification Multiplication and Control Innovations	**Session We2G** Phased Array Systems and Applications	**Session We2H** High Power Doherty Power Amplifiers	**WEIF1:** Interactive Forum #2	
11:50 – 13:30	**IMS Panel** Body Wearable Technology; is it still relevant and what's its future?									
13:30 – 15:10	**Exhibit Hall Only Time; No Technical Sessions**									
15:10 – 15:55	PM Coffee Break (15:10 - 15:40), Exhibition Hall									
15:55 – 17:15	**Session We3A** Novel Microwave Circuits and Systems Applications	**Session We3B** Focus Session Emerging RF switch technologies for 5G and defense applications			**Session We3E** Microwave Accoustic Components for Wireless Applications	**Session We3F** Terahertz and mm-wave Technologies and Applications	**Session We3G** Broadband Radar Systems and Technologies	**Session We3H** Special Session Women in Microwaves: Research on Biomedical Applications	**WEIF2:** Interactive Forum #3	

Technical Track Key: Field, Device and Circuit Tech. | Passive Components | Active Components | Systems & Applications | Emerging Technical Areas | Focus or Special Sessions

Also on Wednesday: Industry Workshops; Prof. Haddad Celebration Event Industry Hosted Reception; MTT-S Awards Banquet

For the latest on IMS and Microwave Week visit www.ims2018.org

Technical Sessions, Thursday, 14 June 2018

Time	201A	201B	201C	202AB	203AB	204A	204B	204C	Exhibition Area	
	Room Number Location									
08:00 – 09:40	**Session Th1A** Advanced Technologies for Non-Planar Filters and Diplexers	**Session Th1B** Advanced Rectifiers and Energy Harvesters for Wireless Power Transfer	**Session Th1C** Electromagnetic Biosensing	**Session Th1D** IMS/ARFTG Advanced High Frequency Large Signal Measurement Techniques	**Session Th1E** Recent Advances in Terahertz and Photonics	**Session Th1F** RF Transceiver Architecture for MIMO and Beam Steering		**Session Th1H** Doherty and Load-Modulated Power Amplifiers		
09:40 – 10:10	**AM Coffee Break, Grand Hall and Exhibition Hall**									
10:10 – 11:50	**Session Th2A** Synthesis and Design of Non-Planar Filters and Multiplexers	**Session Th2B** Recent Developments in Wireless Power Transfer Techniques	**Session Th2C** Hyperthermia Treatment and Implants Wireless Powering	**Session Th2D** IMS/ARFTG Session Innovative mm-wave calibration and measurement techniques	**Session Th2E** Focus Session Integrated Microwave Photonics for Millimeter-wave and 5G Applications	**Session Th2F** Focus Session 5G Millimeter-Wave Beamformers and Phased-Arrays		**Session Th2H** Millimeter Wave Broadband Power Amplifiers	**THIF1:** Interactive Forum #4	IMS Exhibition, MicroApps Seminars
11:50 – 13:30	**IMS Panel** 5G mmW PA/FEM: Si or III-V who will win the race?						**IMS Physicians Panel** (12:00 - 14:00) Utilization of RF/ Microwave in Medicine			
13:30 – 15:10	**Session Th3A** New Tuning Concepts for 3-D, Planar, and Integrated Filters and Duplexers	**Session Th3B** Focus Session Techniques and Components for High-PowerMicrowave Technology	**Session Th3C** Biomedical Devices	**Session Th3D** Advances in CMOS Microwave and Millimeter Wave Signal Sources	**Session Th3E** Advances in Semiconductor Monolithic Integrated Circuit Technology	**Session Th3F** THz and mm-Wave Sensing and Communication Systems		**Session We3H** Advances in Low Noise Technology	IMS Student Career Fair	
15:10 – 15:55										

Technical Track Key: Field, Device and Circuit Tech. | Passive Components | Active Components | Systems & Applications | Emerging Technical Areas | Focus or Special Sessions

Also on Thursday: Industry Workshops; IMS Closing and IMBioC Opening Ceremony and Reception, Women in Microwaves Panel

For the latest on IMS and Microwave Week visit www.ims2018.org

Workshops, Short Courses

Day	Morning (08:00 – 11:50)	Afternoon (13:30 – 17:15)
Sunday, 10 June 2018	WSA: RFIC Design in CMOS FinFET and FD-SOI	
	WSB: ICs for Quantum Computing and Quantum Technologies	
	WSC: 5G mm-Wave Power Amplifiers, Transmitters, Beamforming Techniques and Massive MIMO	
	WSD: eXtreme-bandwidth: architectures for RF and mmW transceivers in nanoscale CMOS	
	WSE: Integrated mm-wave & THz sensing technology for automotive, industrial and healthcare	
	WSF: Advanced integrated RF filtering circuits and techniques	
	WSG: Synthesizer Design and Frequency Generation/Synchronization Schemes for High-Performance Wireless Systems	
	WSH: High-performance WLAN transceiver Design and Calibration Techniques	
	WSI: High Efficiency Power Amplification for Emerging Wireless Communications Solutions from Devices to Circuits and Systems	
	WSJ: Millimeter-wave Systems; Manufacturing, Packaging and Built-in Self Test	
		WSK: Towards Direct Digital RF Transceivers
		WSL: Ultra Low-Power Transceiver SoC Designs for IoT Applications
Monday, 11 June 2018	SMA: Practical computer modeling for electromagnetic medical device design	
	WMH: Microwave and Millimeter-wave Radiometers: Component Technologies, System Architectures, and Emerging Applications	
	WMA: Wireless Technologies for Implantable and Wearable Systems	
	WMB: Microwave to THz imaging technologies for biomedical applications	
	WMC: 3D-/4D-/Inkjet-Printed RF Components and Modules for IoT, 5G and Smart Skin Applications	
	WMD: Power Amplifier Technologies for 5G Communications Systems	
	WME: Digital Pre-Distortion and Post-Correction from DC to mmWave for Wireline and Optical Communications	
	WMF: Microwaving cells: from biological effects to innovative techniques for cell analysis	
	WMG: Recent Advances in Efficiency and Linearity Enhancement Techniques for RF Power Amplification	
	WMJ: Advanced Applications of Nonlinear Vector Network Measurements for broadband RF Power Amplifiers Design and Linearization	
	WMK: Affordable Phased-Arrays for SATCOM and Point-to-Point Systems Using Silicon Technologies	
		SMB: Fundamentals of Magnetic-Resonance Imaging
		WMI: Automotive Radar and Vehicular Network Security
Friday, 15 June 2018	SFA: Multi-Beam Antennas and Beam-Forming Networks	
	WFD: Advanced Synthesis techniques for reduced size filtering networks	
	WFA: Ultra-Low-Power Nanowatt to Microwatt Receivers for the Internet of Things	
	WFB: RF Front-Ends for Enhanced Mobile Communications towards 5G	
	WFF: Tunable Passive Devices for Multi-band Systems	
	WFG: Advances in Linearization Techniques for 5G and Beyond	
	WFH: Module Integration and Packaging/IC Co-Integration for Millimeter-wave Communications and 5G	
	WFI: Innovative Technologies for RF and millimeter-wave Tuning and Switching	
	WFJ: Design of Matching Networks for Optimal Performance of Power Amplifiers and Transmitters	
	WFK: The New GaN: Advancements in novel-materials based GaN Microwave and mm-Wave Technologies	
	WFE: Recent advances in non-linear and non-reciprocal RF microwave devices (08:00 – 11:15)	
		SFB: Using active fiber optic for distributed antenna system (DAS) system in 5G MIMO system and automobile radar system

5G Summit, Panel Sessions, RF Boot Camp

5G Summit, Tuesday, 12 June 2018; Room 103

The 5G Summit, at the Pennsylvania Convention Center in Philadelphia, is an IEEE event that is organized by two of IEEE's largest societies – MTT-S and ComSoc. This special collaboration, for the second year running, complements MTT-S' "hardware and systems" focus with ComSoc's "networking and services" focus. The one-day Summit features talks from experts from government, academia, and industry experts on various aspects of 5G services and applications. It's further complemented by the 5G Pavilion at the IMS2018 exhibition where table top demonstrations and "fire-side" chats are presented at the 5G theater.

5G Summit Speakers:

"Bringing the World Closer Together"

Jin Bains
Head of Connectivity, SCL, Facebook

"AT&T Perspectives on 5G Services"

David Lu
Vice President, AT&T

Other featured presentations from Huawei, GM, Keysight, NI, Global Foundries, MACOM as well as academia will include following topics:

- Spectrum/Regulatory
- Infrastructure/Trials, Applications
- Technologies, Circuits, Systems
- Design, Test & Measurement Challenges
- Test-bed Services for 5G

Lunchtime Panel session: "mmWave Radios in Smartphones: What they will look like in 2, 5, and 10 years"

For complete agenda visit: www.ims2018.org/5g-summit

Panel Sessions

Can a residential wireless Gbps internet connection compete with wired alternatives?
Tuesday, 12 June 2018, 12:00-13:00,
Room 201A

Body Wearable Technology: is it still relevant and what is its future?
Wednesday, 13 June 2018, 12:00-13:00,
Room 201A

5G PA/FEM: Si or III-V - who will win the race?
Thursday, 14 June 2018, 12:00-13:00,
Room 201A

Physicians Panel: Utilization of RF/Microwaves in Medicine
Thursday, 14 June 2018, 12:00-14:00,
Room 204B

RF Boot Camp, Monday, 11 June 2018; Room 109B

This one-day course is ideal for newcomers to the microwave world, such as technicians, new engineers, college students, engineers changing their career path, as well as marketing and sales professionals looking to become more comfortable in customer interactions involving RF & Microwave circuit, and system concepts and terminology. The format of the RF Boot Camp is like that of a workshop or short course, with multiple presenters from industry and academia presenting on a variety of topics including:

- The RF/Microwave Signal Chain
- Network Characteristics, Analysis and Measurement
- Fundamentals of RF Simulation
- Impedance Matching & Device Modeling Basics
- Introduction to RF and Microwave Filters
- Spectral Analysis and Receiver Technology
- Signal Generation
- Modulation and Vector Signal Analysis
- Microwave Antenna Basics
- Introduction to Radar and Radar Measurements

Exhibition, Mobile App, Key Deadlines

Exhibition Overview:

The Exhibition consists of over 600 exhibiting companies who represent the state of the art when it comes to materials, devices, components, and subsystems, as well as design and simulation software and test/measurement equipment. Whatever you are looking to acquire, you will find the industry leaders ready and willing to answer your purchasing and technical questions.

Exhibition Dates and Hours

Tuesday, 12 June 2018	09:30 to 17:00
Wednesday, 13 June 2018	09:30 to 17:00
Exhibit-Only Time:	13:30 to 15:10
Industry Hosted Reception:	17:00 to 18:00
Thursday, 14 June	09:30 to 15:00

MicroApps

The Microwave Application seminars (MicroApps) offered Tuesday, 12 June through Thursday, 14 June, 2018, provide a unique forum for the exchange of ideas and practical knowledge related to the design, development, production, and test of products and services. MicroApps seminars are presented by technical experts from IMS2018 exhibitors with a focus on providing practical information, design, and test techniques that practicing engineers and technicians can apply to solve the current issues in their projects and products.

Industry Workshops

The Industry Workshops are 2-hour industry-led presentations featuring hands-on, practical solutions often including live demonstrations and attendee participation. These Workshops are open to all registered Microwave Week attendees at a nominal charge.

Visit https://ims2018.org/exhibition for more information.

IMS Microwave Week Mobile App:

The IMS Microwave Week app is now available in the Apple App store and Google Play store. Install the app on your Android or iOS device to view the full schedule of Workshops, Short Courses, IMS and RFIC Technical Sessions, IMBioC, ARFTG, Panel Sessions, Social Events and Exhibition information. On-site during Microwave Week you will be able to download IMS and RFIC papers, locate exhibitors, upload photos and explore all that Philadelphia, PA has to offer! Download today!

Apple App Store

Google Play Store

Key Deadlines:

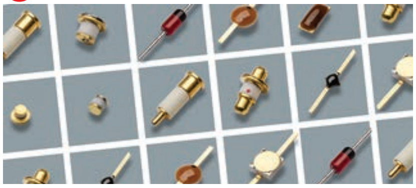
Early Bird Registration Deadline: 14 May 2018
Advance Registration Deadline: 8 June 2018
Housing Burea Deadline: 18 May 2018

For the latest on IMS and Microwave Week visit www.ims2018.org

SemiGen **Booth 2009**

Schottky Barrier Diodes

VENDORVIEW



SemiGen's Schottky barrier diodes offer small junction capacitances, low resistances and low I/F noise, along with 0.6 V forward voltage drop and enhanced TSS. They are ideal for detector, mixer, modulator, power limiter and high speed switch applications. SemiGen's zero-bias Schottky detector diodes exhibit low junction capacitances, high voltage sensitivity, high sensitivity and do not require external biasing. These diodes feature 0.3 V forward voltage drop and exceptional TSS.

www.semigen.net

Pickering Interfaces **Booth 2015**

PXI Microwave Multiplexer Modules

VENDORVIEW

These multiplexers have a characteristic impedance of 50 Ω and are capable of switching signals up to 50 GHz. Available in single or dual 6-channel format occupying three PXI slots with relays mounted on the front panel. These multiplexers are compatible with any PXI chassis and can be used in Pickering's LXI modular chassis for users preferring control via an Ethernet port. Connection is by a high performance SMA, SMA-2.9 and SMA-2.4 Connectors for 50 Ω versions.

www.pickeringtest.com

SignalCore Inc. **Booth 2113**

Single-Stage Down-Converter

The SC5318A is a C- to K-Band single-stage down-converter, converting frequencies from 6 to 26.5 GHz down to DC to 3 GHz. This module also features an internal 26.5 GHz synthesized LO, RF preamplifier and variable gain control. It can be configured for SISO or MIMO applications such as ground-based SATCOM, point-to-point radio and test instruments. Compact, rugged and built for large system integration, the SC5318A can be combined with their SC5308A to form a broadband 100 kHz to 26.5 GHz down-converter.

www.signalcore.com

Pasternack Enterprises Inc. **Booth 2133**

Relay Controlled Programmable Attenuators

VENDORVIEW

Pasternack's relay controlled programmable attenuators cover broad frequency bands from DC to 2000 MHz with attenuation levels ranging from 0 to 127 dB. Attenuator designs have 6 to 8 relay bits with attenuation steps ranging from 0.25 to 64 dB. Typical performance includes low insertion loss ranging from 0.8 to 3.5 dB, attenuation accuracy of ± 0.5 dB and input power up to 1 W CW. Models are offered in 50 and 75 Ohm configurations and feature bidirectional performance capability.

Compact Waveguide Gunn Diode Oscillators

Pasternack's waveguide Gunn diode oscillators incorporate high performance devices and machined aluminum cavities. Due to the extremely high external Q and temperature compensation mechanism, these oscillators exhibit excellent frequency and power stability, lower phase noise and higher anti-load pulling characteristics. The PEWGN1001 is a K-Band waveguide Gunn oscillator module that generates a center frequency of 24.125 GHz with a tuning range of ±1 GHz. The PEWGN1000 generates a Ka-Band center frequency of 35 GHz with a tuning range of ±3 GHz.

www.pasternack.com

Networks International Corp. **Booth 2212**

Pin-Diode Switches

NIC's engineering expertise in high-reliability RF products and integrated assemblies includes a specialty in pin-diode switches that span from 1 to 20 GHz. These high performance switches offer broad bandwidth, low insertion loss, fast switching speeds and TTL compatibility. These switches can be customized to meet passband requirements from 1 to 100 percent and meet a wide range of environmental requirements as well. Whether your challenge is a small form factor, high-power, tough electrical specifications or cost, NIC's unique products showcase a variety of creative solutions for all of your radar and communications needs.

www.nickc.com

MCV Microwave **Booth 2213**

Ultra-Low PIM 1 kW Cavity Filters

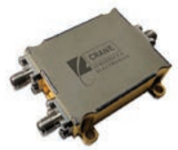
VENDORVIEW

Ultra-low passive intermodulation (PIM) cavity filters and multiplexers covering TETRA and the entire LTE frequency bands from 300 to 3600 MHz. The typical PIM performance in production is -163 or -170 dBc for low-PIM or ultra-low PIM series, respectively measured with two CW tones, each at 43 dBm. These high-power, low PIM filters are suitable for use in small cell, tower-mounted amplifiers, Tx or Rx combiners, multiplexers, distributed antenna system (DAS) and PIM test benches.

www.mcv-microwave.com

Crane Aerospace & Electronics **Booth 2215**

RF, IF and mmWave Components



Crane Aerospace & Electronics designs and manufactures high-performance RF, IF and mmWave components, subsystems and systems for commercial aviation, defense and space. With over 60 years of experience, the company has proven capabilities in major military, communications, EW, radar and satellite systems. Product capabilities: Component and single function devices, integrated microwave assemblies, space qualified products, switch matrices.

www.craneae.com

Anaren Microwave Inc. **Booth 2304**

Form Factor Coupler

VENDORVIEW

Introducing Anaren's all new high-power 0805 form factor coupler product family. Constructed from ceramic filled PTFE composites, which possess excellent electrical and mechanical stability up to +105°C these footprint-optimized couplers handle increased power and have class leading RF performance. Designed with 5G applications in mind and by benchmarking Anaren's current subminiature 0805 product line, these low cost, low profile couplers are available in 2, 3, 4, 5, 10 and 20 dB coupling. Contact to get on the list for samples.

www.anaren.com/contact

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SYNTHESIZER & PLO MODULES

Features:

Up to 30 GHz*

- Proprietary digital Integer and Fractional PLL technology
- Lowest digital noise floor available -237 dBc/Hz figure of merit
- Output frequencies from 100 MHz locked crystal to 30 GHz
- Available with reference clean up dual loop, or single loop for very low noise reference
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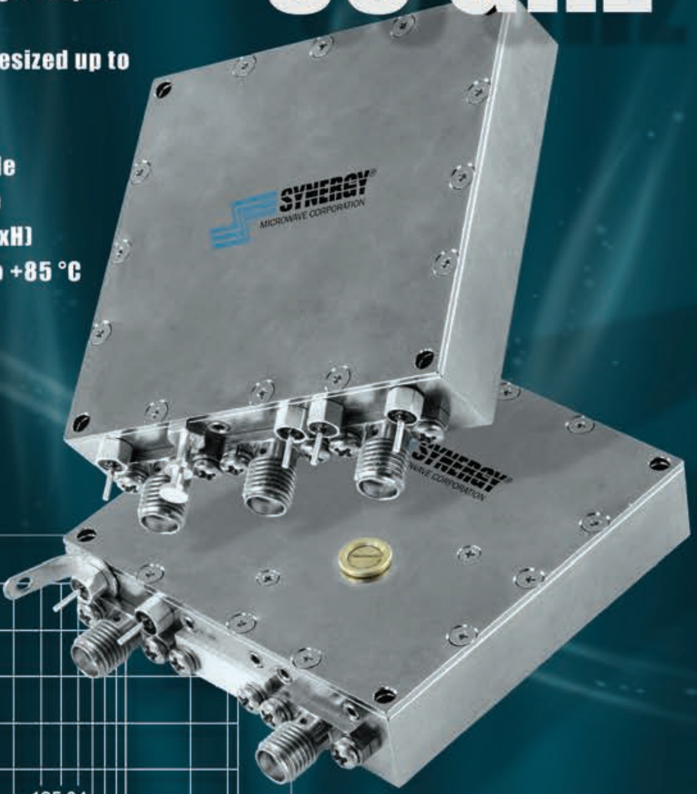
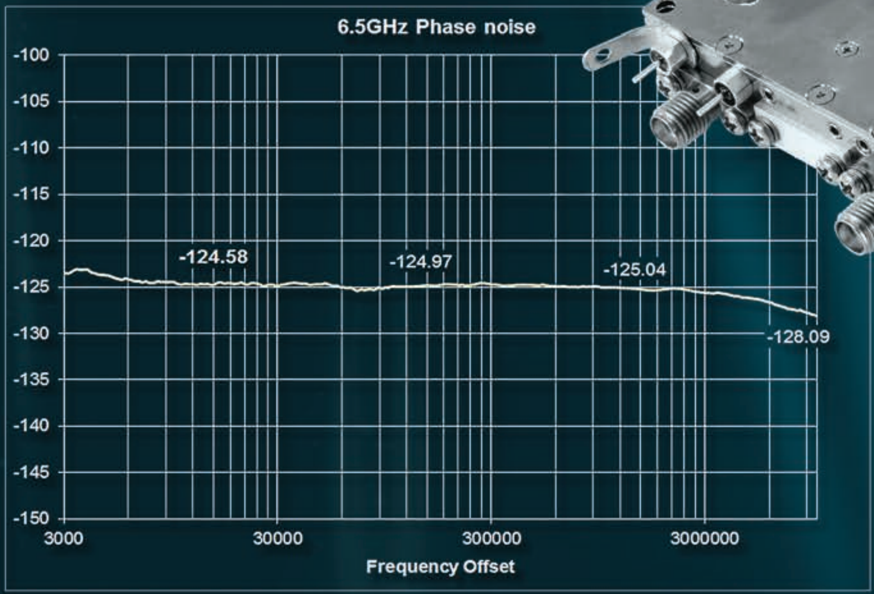
- Standard module size 2.25 X 2.25 X 0.5 Inches (LxWxH)
- Standard operating temperature -10 to 60 °C, -40 to +85 °C available



Applications:

- SATCOM, RADAR, MICROWAVE RADIO

* *16 - 30 GHz with added x2 module < 1" in height.*



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Mail: 201 McLean Boulevard, Paterson, NJ 07504

See us at IMS Booth 409

MegaPhase **Booth 2309**

UltraPhase™ Series

The "E" series product line was designed for optimal performance over a wide temperature range in mind. This very flexible assembly offers a foam FEP dielectric and provides superior phase stability versus flexure and temperature. The temperature performance features linearity across a wide temperature range and does not exhibit the "knee" that traditional PTFE based cables exhibit at ambient temperature. This cable is ideal for applications including both air and ground-based phased array radars, sensors, mobile backhaul and temperature testing.

www.megaphase.com

American Microwave Corp. **Booth 2317**

Improved Sensitivity DLVA Technology

VENDORVIEW

Retrieving signals buried in noise and multiplying the range of modern monostatic pulsed radar receivers is possible using a technique called "Matched Filtering." Matched filtering can improve receiver sensitivity by 6 to 8 dB by retrieving signals buried in noise and improve range by a factor of 2 min. Advances in digital signal processing and digital correlation techniques have made the application of matched filtering sensitivity improvements possible and practical.

www.americanmic.com

Velocity Microwave **Booth 2403**

Galaxy Gage Kit

Continuing their mission of developing sustainable products that reduce your cost of ownership, Velocity Microwave introduces the Galaxy gage kit. This revolutionary kit provides the ability to test the most common RF/microwave connectors with a single gage. A simple swap of the bushing allows the user to test Type N, SMA (P+D), 3.5, 2.92, 2.4 and 1.85 mm connectors, both male and female. In addition, the gage itself can be calibrated by your preferred, qualified vendor for about $50 per year.

www.velocitybygte.com

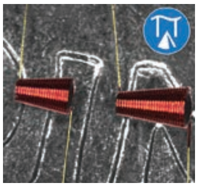
ITEQ Corp. **Booth 2413**

Copper-Clad Laminates

ITEQ's IT-88GMW and IT-88GML are designed for use in automotive radar, millimeter wave, phased array antenna, in-package antenna and emerging 5G applications. The Dk- 2.98 and Df 0.0012 at 10 GHz make them the lowest loss offerings for thermoset resins. IT-88GML offers low flexural and in-plane modulus with very low skew. Both products can be used in hybrid mlb applications for automotive driver-assist systems. Available in core and prepreg materials enabling high layer count boards.

Piconics Inc. **Booth 2418**

50 Awg Broadband Conical Inductors



Piconics Inc. has introduced a new line of broadband conical inductors utilizing ultra-fine 1 mil (50 Awg) diameter wire. This Inductor Series offers increased inductance in a smaller size than traditional conical inductors while maintaining broadband performance past 40 GHz. The ultra-fine wire reduces capacitance build up at the terminations and along the coil to minimize loss across the frequency band. Typical applications: bias tees, broadband amplifiers, high speed switches, optical linear drivers and isolation circuits on semiconductor test boards.

www.piconics.com

NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE
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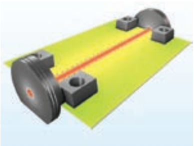
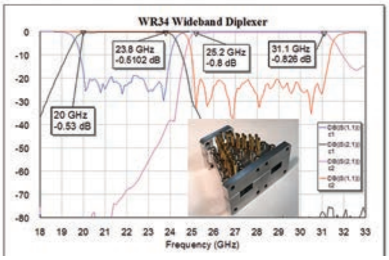
COMSOL Inc.
RF Module



The latest version of the RF module, an add-on product available in the COMSOL Multiphysics® software, features an extended part library with edge launch connectors and a new adaptive frequency sweep study type. This study type enables users to compute the frequency response of a linear model more efficiently while using a very fine frequency resolution with the asymptotic waveform evaluation (AWE)—a reduced-order modeling technique.
www.comsol.com

Exceed Microwave
Waveguide Diplexers
VENDORVIEW



Exceed Microwave's WC-Series waveguide diplexers can provide very wide passbands and also comes in small sizes. DPX-WC-22-28-34 is a WR34 diplexer covering nearly the entire waveguide operating frequency band. Each channel bandwidth of DPX-WC-22-28-34 is roughly 20 percent while maintaining very good return loss at all ports. The size is only 1.5 x 1.8 x 0.9 in. which allows waveguide assemblies to be compact. WC-Series diplexers are available in different waveguide sizes. Exceed Microwave designs and manufactures high performance waveguide and coaxial filters.
www.exceedmicrowave.com

Fairview Microwave Inc.
PIN Diode Waveguide Switches

Fairview Microwave Inc., a provider of on-demand RF and microwave components, has released a new line of E- and W-Band PIN diode waveguide switches. These single-pole single-throw (SPST) and single pole double-throw (SPDT) mmWave waveguide switches offer an ultra-broadband frequency range with fast switching performance. They are ideal for telecommunications, test instrumentation, research and development programs and radar front-ends in applications that involve general switching, receiver protection, pulse modulation and antenna beam switching.
www.fairviewmicrowave.com

Kaelus
Cable and Antenna Analyzers

The iVA Series of cable and antenna analyzers from Kaelus enable users to accurately measure return loss sweeps, distance-to-faults and cable loss in RF infrastructure. Built for purpose, durability and efficiency the iVA series is easy to learn, provides test functions at your fingertips, supports frequency ranges from 560 to 2700 MHz and its lightweight format (1.5 lb) provides rugged and reliable performance for test reports and site certifications.
www.kaelus.com/en

M Wave Design Corp.
High-Power WR90 Junction Isolators

The M Wave Design Corp. 90IJ12xx Junction Isolator is an air cooled 8.5 to 10 GHz device with 20 dB isolation (min.), 1.20:1 (max.) VSWR and 0.20 dB (max.) insertion loss at 500 W CW forward (10 Kw peak). A 400 W dummy load is incorporated to absorb reflections. M Wave Design Corp. offers high-power isolator designs from 80 MHz to 40 GHz.
www.mwavedesign.com

Master Bond
Electrically Conductive Systems
VENDORVIEW

Master Bond MB600S is a silver conductive water based sodium silicate system for shielding applications that withstands temperatures up to 700°F. MB600S will cure at room temperature in 24 to 48 hours or in 1 to 2 hours at 80°C. It features high temperature resistance with a service temperature range of 0°F to 700°F. The compound is available in glass jars, and has a shelf-life of six months in original, unopened containers at room temperature.
www.masterbond.com

PolyPhaser
Coaxial RF Surge Protectors with 4.3-10 Connectors

PolyPhaser's SX series of surge arrestors now includes 4.3-10 connectors. Using PolyPhaser's patented spiral inductor technology, these arrestors respond almost instantaneously to a lightning surge. Available in DC pass and DC block, all models have a typical PIM rating of -130 dBM and support broad frequency ranges from 698 MHz to 2.7 GHz. The compact, weatherized design makes these arrestors ideal for use with small cells and DAS applications that require 4.3-10 connectors.
www.polyphaser.com

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www.rfeng-inc.com

RF Superstore
Reverse Polarity Adapters and Connectors

RF Superstore has expanded their product offering to include a large selection of in-stock reverse polarity adapters and connectors. The newly added products are coaxial adapter designs made of brass with nickel or gold plating and 50 Ohms impedance. The product lines span in-series and between-series BNC, N, MMCX, SMA and TNC.
www.RFsuperstore.com

NewProducts

Spacek Labs
Frequency Quadrupler

Spacek Labs' active frequency quadrupler, Model A487-4XW-19, is a frequency multiplier designed for output operation from 44 to 51 GHz. Requiring only 5 dBm input power, it is capable of generating 20 dBm typical output power across the entire frequency range with better than 35 dBc undesired harmonic rejection. This active quadrupler is ideal for use as a driver for subsequent multiplication used in very high frequency communication systems.
www.spaceklabs.com

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The new M2p.59xx series of 16-bit PCIe digitizers from Spectrum deliver an unrivalled combination of features, all packed into one very small half-size PCIe card. Furthermore, you can choose exactly the performance level you need by selecting from 20 different models. Units are available with sampling rates of 20, 40, 80 and 125 MS/s, and with 1, 2, 4 or even 8 channels. Spectrum Instrumentation offers a full five year warranty.
www.spectrum-instrumentation.com

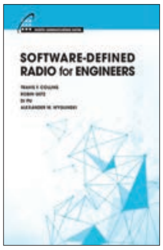
SPINNER
2.2-5 Calibration Kit

VENDORVIEW

New applications such as small cells, MIMO and DAS are driving the development of even more compact network equipment and smaller connectors to support the further miniaturization of antennas and RRUs. The new 2.2-5 connector system is derived from 4.3-10 and delivers the same excellent electrical performance while only being half the size. It is now well on its way to being standardized, and SPINNER has already launched the first high-precision calibration kit for it.
www.spinner-group.com

Wright Technologies
Multiplier

The model ASX40-B217 multiplier product, with the output operating frequency range of 18 to 40 GHz. The output frequency range is further complemented with medium output power levels up to +17 dBm minimum across the entire frequency band. This multiplier features output harmonics better than 20 dBc, and is designed with a cost-effective four year warranty program. The ASX series products are offered in many different broadband frequency ranges listed in their recently updated website.
www.wrighttec.com



Software-Defined Radio for Engineers

Travis F. Collins, Robin Getz, Di Pu and Alexander M. Wyglinski

Based on the popular Artech House classic, *Digital Communication Systems Engineering with Software-Defined Radio*, this book provides a practical approach to quickly learning the software-defined radio (SDR) concepts needed for work in the field of wireless communications. This up-to-date volume guides readers on how to quickly prototype wireless designs using SDR for real-world testing and experimentation. This book explores wireless communication techniques such as single-carrier waveform synchronization, orthogonal division multiplexing (OFDM) and SDR hardware interfacing. Furthermore, readers will gain an understanding of how wireless hardware, such as the RF front-end, analog-to-digital and digital-to-analog converters, and various processing technologies, affect the behavior and performance of real-world communication systems. Lessons are focused on hands-on examples based in the MATLAB® programming language to help accelerate the learning process for students.

Starting with fundamental concepts in digital communications, signal processing and probability, this book will provide practical insights on topics such as timing estimation, carrier recovery, frame synchronization, equalization and OFDM in order to enable the reader to ultimately implement and experiment with real-world communication systems using SDR. All experiments and exercises are built around the ADALM-PLUTO Active Learning Module (PlutoSDR) from Analog Devices Inc., an affordable and versatile SDR platform available to both students and professional engineers, with code written in MATLAB.

Contents: What is SDR; Signal & System Overview; Probability Review; Digital Communications Review; Coarse and Fine Frequency Correction; Timing Estimation and Matched Filtering; Frame Synchronization Message Decoding, and Source Coding; Equalization; Orthogonal Frequency Division Multiplexing; HDL Code Generation and Deployment; WLAN Toolbox: OFDM Beacon Reception; LTE Toolbox: Downlink Reception; Appendix SDR, FFT, SNR and Signal Manipulation.

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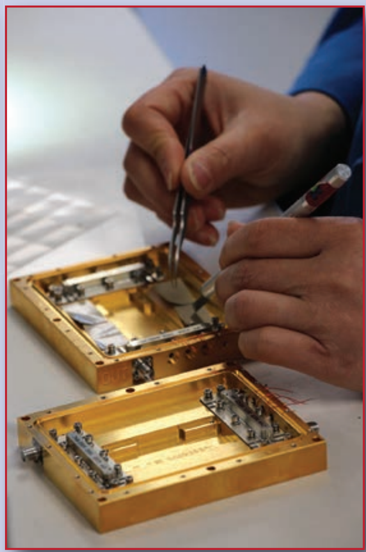

Surrounded by pastoral fields in Souderton, Pennsylvania, the modern building with its distinctive orange is immediately recognizable, mirroring the trim on the high-power amplifiers that built AR. Now four businesses with a staff of more than 200, AR began in founder Donald "Shep" Shepherd's basement in 1969, motivated by his vision to supply the best performing, highest power and highest frequency power amplifiers (PA) in the world. AR's success achieving that vision is reflected in many ways, with power the most impressive metric.

In 1988, AR developed the first 100 W solid-state PA covering 100 MHz to 1 GHz, a record at the time. By 2015, AR had achieved a 50,000 W CW, class A, solid-state amplifier. To develop and manufacture PAs delivering more than 100 kW, AR expanded its Souderton facility with a two-story addition, comprising 10,000 ft^2 and some 2 MW of electric capacity, clearly differentiating AR among high-power amplifier suppliers.

AR's PAs are the industry standard for electromagnetic compatibility (EMC) testing and have been widely adopted for sub-6 GHz wireless test and measurement, growing with the dynamic mobile market. AR is also well-known in the defense community, with PAs covering the electronic warfare (EW) bands from 700 MHz to 18 GHz. In all markets, AR strives to provide the best performance at a reasonable price, performance defined by output power, flatness, linearity and ruggedness to high VSWR loads.

To meet the company's goals for performance, price and quality—amplifiers that are built to last forever—AR builds its own solid-state PA modules internally in the company's Microelectronics (MET) lab. Recently expanded to add capabilities and increase capacity, the MET lab has 2000 ft^2 dedicated to production and 1000 ft^2 for design, both in a class 100,000 clean room that can be converted to class 10,000 if required. The PA design team brings some 200 years of experience to new designs and is complemented with engineers providing system, mechanical, digital hardware and software expertise. Once products are in production, AR's customers are supported by a technical applications team and the most comprehensive warranty in the industry.

To achieve the highest power density, most PAs use GaN semiconductor devices, assembled into modules with chip-and-wire technology. MET lab capabilities include eutectic and epoxy die attach and a full range of wire bonding processes, with two fully-automated wire bonders and five semi-automatic bonders. To verify these processes provide void-free die attach, AR employs X-ray inspection. A nearby test lab handles any special tests that AR doesn't perform internally.

The future for AR is certain: higher power and higher frequency, including products to support the emerging wireless millimeter wave markets. As one example, new solid-state field generating systems combine a solid-state PA and antenna to achieve electric fields up to 50 V/m at 1 m, from 18 to 26.5 GHz and 26.5 to 40 GHz.

Almost 50 years after starting AR, Shep, who now serves as chairman of the board, maintains his founding vision: "As customers require larger, more powerful amplifiers, we'll be ready for their future needs."

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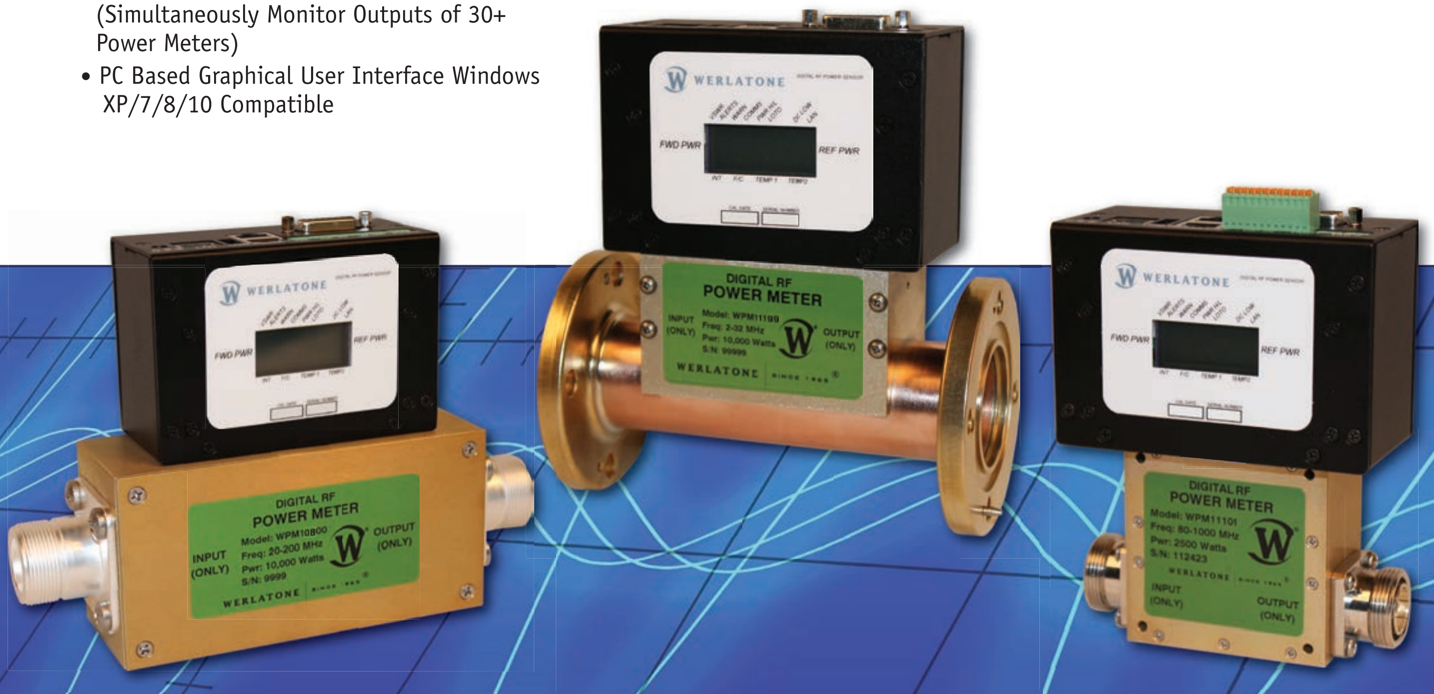

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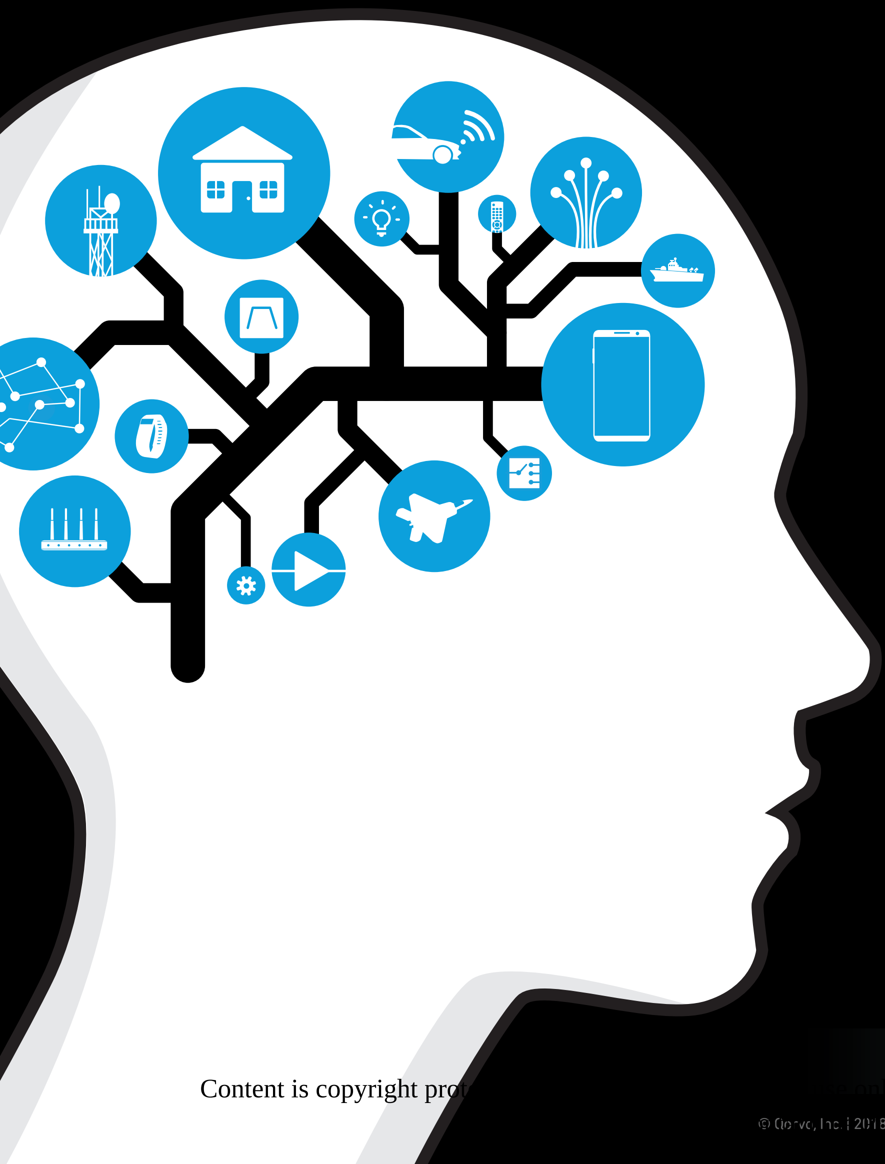

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5G and the Need for Speed

Introduction

Tesla's "Maximum Plaid" speed mode rockets its new Roadster from 0-60 in 1.9 seconds. If you think that's fast, go ahead and Google "5G."

5G is plaid for cellular networking – a next-generation mobile network that promises not only ten-times the available spectrum, for ten-times the download speeds, but across ten-times the devices and with a fraction of the latency.

The move from 1Gbps to 10Gbps speeds will support bandwidth-intensive applications like high-definition video and virtual reality, and near real-time connections will enable ultra-low latency applications like autonomous cars, remote surgery and specialized applications within the Internet of Things (IoT).

5G is impressive, but – spoiler alert – it isn't entirely new. The road to 5G runs through 4G wireless infrastructure, and improvements to 4G technologies like carrier aggregation (CA), small cells, massive multiple-input and multiple-output (MIMO) and beamforming will satisfy our need for 5G speed.

Carrier Aggregation

IDC forecasts that by 2025 the global datasphere will grow to 163 zettabytes. For the folks at home, that's 163 trillion gigabytes. Much of this will be mobile data, transmitted in real-time between phones and IoT devices.

As demand for mobile data increases, mobile carriers and manufacturers face a conundrum. There is a finite amount of radio frequency spectrum at any given time, but they must increase capacity and offer faster data speeds to meet user demand. The key is squeezing the most out of existing RF spectrum – and for that, there's CA.

CA is a technique that combines multiple carrier signals – or "channels" – to increase network performance. As consumers, we love CA, because we hate buffering. CA accelerates downloads and uploads, allowing cellular networks to move more data, faster.

Gamers and Instagram influencers, rejoice!

CA is already used to combine multiple 4G LTE-advanced frequency bands. As we approach 5G, cellular service providers will seek to squeeze even more bandwidth out of existing spectrum by combining as many as five channels.

Small Cell

Cellular base stations connected to cell towers carry signals over the river and through the woods to the dinner table at grandma's house. Because 5G builds on the 4G foundation, carriers can simply upgrade these towers to support higher 5G frequencies, like 28 GHz and 39 GHz.

There's a catch. These millimeter wave (mmWave) frequencies cannot penetrate walls or buildings. Thick walls, frame and cement impede mmWave signals, turning downtown into a dead zone. Plus, being far from a base station is a drag – on your battery life, that is.

This is where small cells come in: mini base stations that act as a relay team to transmit around objects, improve battery life and deliver an extra boost in densely populated areas, like sports stadiums, airports and urban centers. Small cells also help service providers avoid satellite dish syndrome, eliminating expensive rooftop systems while extending coverage.

Massive MIMO

Tiny antennas, massive impact.

I say, "massive," you say, "tiny antennas!"

Maybe not, unless you're an RF engineer familiar with massive MIMO. Massive MIMO is a fancy term for equipping cell towers with more antennas to extend network capacity without requiring more spectrum. Sound familiar?

We're not talking an antenna or two. Massive MIMO systems have ten times more antennas than traditional MIMO systems to connect to multiple devices at once. At Mobile World Congress, Nokia and Sprint demonstrated massive MIMO technology with 64 antennas each for uplink and downlink. According to CIO, this increased capacity by as much as eight times for downloads and as much as five times for uploads.

Massive MIMO has been called the backbone of 5G. Without it, operators could not handle the bandwidth and capacity requirements for the next-generation network. Tiny antennas, massive impact.

Beamforming

Beamforming technology drives signals directly to the point of use.

Tiny antennas also cause massive interference problems.

Enter beamforming, and no that's not a teleporter. Beamforming technology drives signals directly to the point of use. We see this with many new Wi-Fi routers, where beamforming is used to focus the Wi-Fi signal and improve signal strength and range.

Beamforming is used similarly in base stations. With this technology, base station antennas focus data streams as they leave the tower, improving speed and reliability for consumer devices.

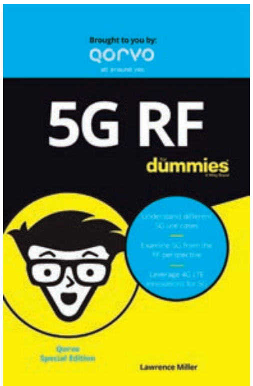
So, whether you're video chatting across the country or sharing cat memes across the table, take a moment to thank these 4G technologies for the speed.

Oh, and buckle your seatbelts. We're going to plaid.

How Carrier Networks Will Enable 5G

Active antenna systems (AAS), beamforming, beam steering, fixed wireless access: the transition to 5G is bringing new terminology and technologies to life in the commercial space. At its heart, 5G begins with the carrier network and how it enables these next-generation technologies. This article explains some of the key RF communication technologies that will enable 5G base stations and networks.

This article is an excerpt from Chapter 4 of our e-book, 5G RF For Dummies®.



5G Begins With The Carrier Network

5G networks must handle many functions that require different active antenna systems to meet the challenges of enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra reliable low-latency communications (uRLLC).

One of the first major applications will be active antenna systems in the mmWave bands, providing FWA. FWA provides an initial stepping stone toward 5G in the mmWave bands. Carriers and infrastructure manufacturers alike have been conducting trials and plan to offer this service as a more scalable and economical way to deliver broadband. Although this service is for nomadic and fixed users, it is being designed with true mobility in mind. This allows carriers to get their feet wet in new mmWave technologies – such as phased array antennas and hybrid beamforming – that will be the basis of mobile 5G.

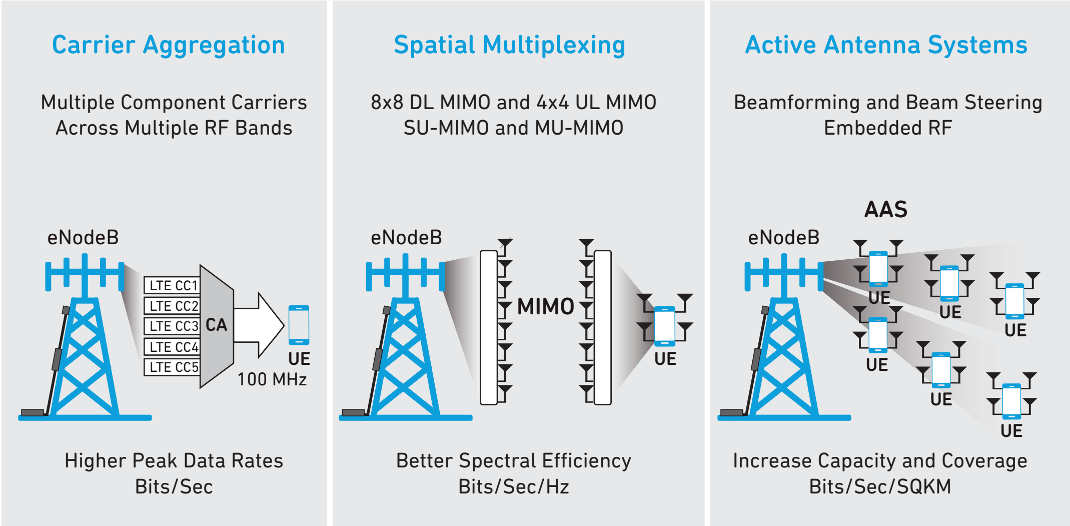
A very recent twist in 3GPP standards definition – the addition of an accelerated path, called non-standalone (NSA) 5G – as a cost-effective way to bring early 5G benefits to market without the expense of building out the 5G network core needed for standalone (SA) 5G. NSA accomplishes this by using an existing 4G 3GPP band as an LTE anchor in the control plane.

AAS/FD-MIMO

The AAS is an advanced base station platform with optimized cost, structure, and performance. 4G release 12 enhancements significantly impacted how enhanced NodeB (eNodeB) radios are designed. Release 12 items included new combinations of carrier aggregation, spatial multiplexing enhancements with downlink MIMO (multiple input/multiple output), and RF requirements needed in AAS. This first figure summarizes portions of the release 12 items with respective features and benefits.

The active antenna system (AAS) is an advanced base station platform.

Evolution of LTE Advanced eNodeB Radio Antennas



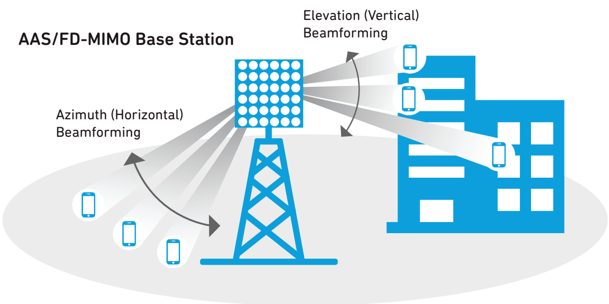
MIMO technology uses multiple antennas installed at both the source (transmitter) and destination (receiver), to improve capacity and efficiency. As shown in the previous figure, more antennas equals more data stream layers. This results in a bigger data pipe to a single user or multiple data pipes to separate users, also known as multi-user (MU) MIMO.

Massive MIMO takes MIMO to the next level. Today's MIMO deployments typically consist of up to eight antennas on the base station and one or two antennas on the receiver. This allows the base station to simultaneously transmit eight streams to eight different users or double down and send two streams to four users. **Massive MIMO scales to dozens or hundreds – theoretically thousands – of antennas, providing capabilities and benefits that include the following:**

- Vastly improved capacity and reliability
- Higher data rates and lower latency
- Better connections (especially with the challenging higher frequencies to be used for 5G)
- Less intercell interference
- Greater efficiency and better signal coverage enabled by beamforming

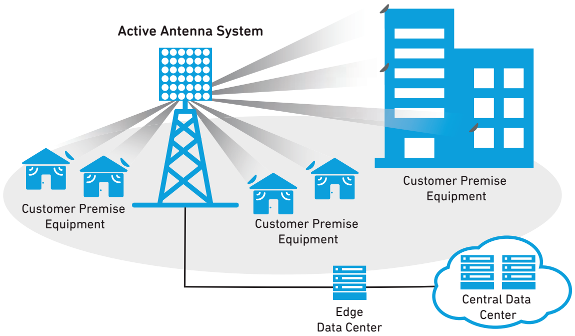
The figure to the right Illustrates how an AAS/full-dimension (FD) MIMO base station can direct beams in both the horizontal and vertical directions.

Antenna Beam Forming



This operation dynamically points the antenna pattern on a per-user basis, providing a better link and higher capacity to that user. In turn, this allows him to offload his traffic and free the radio resources more quickly, which can then be used by others, resulting in a net increase in aggregate capacity for the entire cell.

5G End-to-End Fixed Wireless Access (FWA) Networking Using Beam Steering

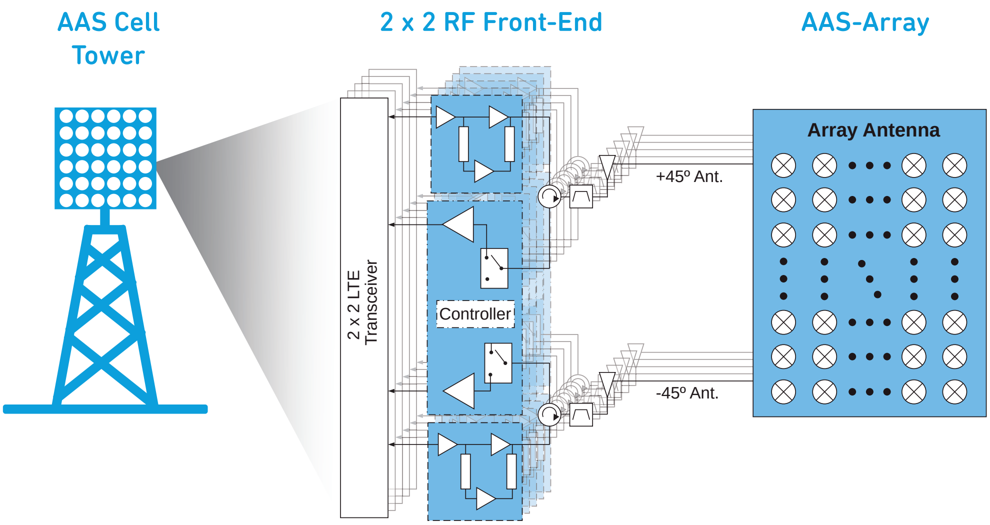


The figure to the left illustrates how AAS uses beam steering to provide end-to-end fixed wireless access (FWA) connectivity to customer premise equipment (CPE) located in commercial buildings and residential homes.

One of the obvious advantages of 5G FWA is its ability to support very high peak data rates without requiring dedicated fixed facilities for each individual user. To enable higher peak data rates and greater system capacity, FWA radios will make use of new higher frequency bands from 24 GHz up to 42 GHz and potentially even higher.

Using larger antenna arrays provides additional beamforming to overcome more severe propagation challenges encountered at mmWave frequency ranges. These arrays can have hundreds of elements but due to the short wavelength are extremely compact. For example, a 64-element antenna array at 30 GHz is only 40 mm x 40 mm. Large arrays provide very focused beams that can be redirected in less than a micro-second. In addition, the large phased array can act as a single array or as multiple independent subarrays with unique beams directed to service multiple user terminals simultaneously on the same frequency resource.

Active Antenna System and Beam Steering RFFE (2x2 LTE RF Front End)



Designing for 802.11ax Wi-Fi: Common Challenges and Tips to Overcome Them

Let's examine some of the challenges that RF engineers will face when designing for 802.11ax and some tips on how to overcome them.

Some Background: 5 OFDMA PPDU Formats For 802.11ax

When developing Wi-Fi access points, designers must consider many wireless technology standards:

But first, let's look at the foundational signal structure for 802.11ax – the physical layer protocol data units that Wi-Fi clients and devices use to communicate.

802.11ax uses five formats for its OFDMA PPDU:

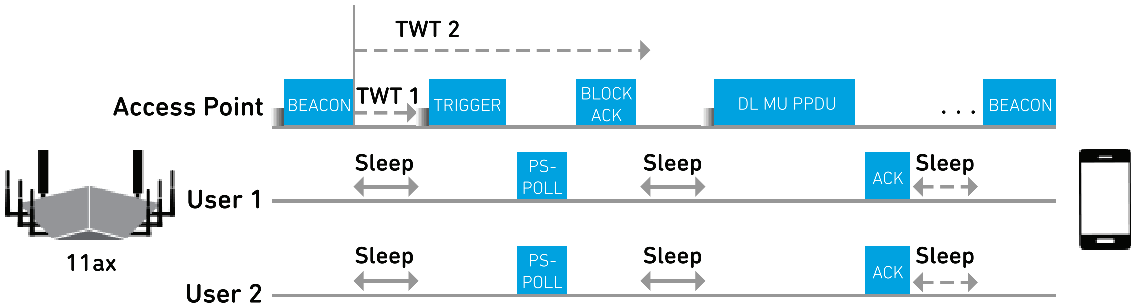
- Single user (HE-SU): for transmitting data from a single user
- Multi user (HE-MU): for transmitting data to one or more users that isn't in response to a trigger frame
- Outdoor (HE-xSU): for outdoor transmission for a single user, this format is new in 802.11ax
- Trigger response (HE-TRIG): for transmitting data in response to a trigger frame, used to coordinate uplink MU-MIMO or uplink OFDMA transmissions with the access point
- Downlink channel sounding (HE-NDP): for beamforming and downlink channel sounding

See the image at the end of this section for details of the frame packets and fields within each PPDU format.

Wait Or Sleep Times: What Are The Challenges For The RF Front End?

One thing 802.11ax adds is target wait time (TWT) – also known as sleep times – which allows a device to stay in a sleep state longer before transmitting data. This resource scheduling improves battery life and means a better experience for a consumer.

TWT in 802.11ax



Credit: NI.com

However, latency in turn-on mode could be an underlying challenge. TWT also brings the following:

- High susceptibility to frequency and clock offsets in OFDMA. Unlike LTE base station technologies, 802.11ax doesn't have a synchronized clock signal. As a result, devices will rely on the access point to keep all the devices on the network synchronized. Additionally, 11ax uses longer OFDM symbols than 11ac, which means more data comes through. In short, the access point will have to work harder – and be more accurate – than in the past.
- Flatness maintained over a longer time period. The specs we've received from some of our chipset partners show that the initial power amplifier (PA) turn-on time has not changed in 802.11ax; it's still 200-400 nanoseconds. However, the gain flatness has been extended, guaranteeing the front-end module (FEM) has no gain expansion or gain droop for the duration of the packet.

Indoor vs. Outdoor Wi-Fi: What Are the Similarities And Differences?

For 802.11ax to work across all environments, both indoor Wi-Fi and outdoor base stations or small cells will be required.

The front-end development is very similar for indoor and outdoor environments. The coexistence strategy – out-of-band rejection, harmonic filtering and frequency range – is similar.

The main differences between indoor and outdoor environments include:

- A new data packet structure for outdoor. As we mentioned earlier, 802.11ax adds an entirely new data packet format for outdoor Wi-Fi, the HE-xSU PPDU format (shown in the PPDU figure at the end of this blog post). The extended range of the outdoor PPDU format allows the Wi-Fi signal to travel longer distances, as is typical for an outdoor Wi-Fi environment.
- Power levels and the resulting thermal considerations. Although some customer premises equipment (CPE) applications have similar power targets as mobile, there is also a high-power category, which means thermal management is even more important.

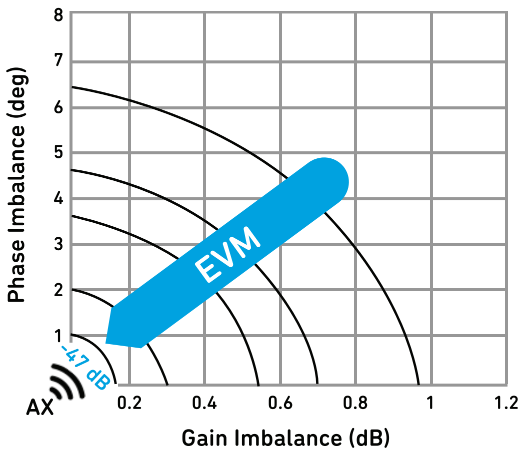
Designing For Tighter System Requirements In 802.11ax

The modulation scheme used in 802.11ax, 1024 QAM, quadruples the wireless speeds. But it also means the system becomes more sensitive to internal and external impairments.

Here are some of the design challenges that engineers should be aware of:

- Tighter linearity specs for the PA. The tighter constellation density in 1024 QAM drives the PA linearity requirement to approximately -47 dB EVM in 802.11ax. (However, there are efforts to relax the system EVM requirement per IEEE doc 11-17-1350.) Also, don't forget to assess the test systems required to measure these EVM levels for FEMs/iFEMs.
- Low noise amplifiers (LNAs) must have a lower NF. Earlier reference designs required LNAs to have a noise figure (NF) target range of 2.5-3 dB. In 802.11ax, system sensitivity targets drive new LNA targets of 1.5-1.8 dB NF.

802.11ax FEM/iFEM vs. System Requirements



- Gain expansion/droop. Ten years ago, the gain imbalance target was 1 dB. Now it has decreased to 0.3-0.5 dB. As shown in the following figure, gain and phase imbalance are being pushed to the lower left to attain -47 dB EVM.
- The overall system margin. From a design perspective, the target PA specification is -47 dB EVM, but the actual system spec is -35 dB EVM. Chipset partners will typically drive for system margin.

To address all these design challenges, engineers and marketing can consider the following:

- **Increase current consumption to meet EVM targets.** A system will typically achieve better EVM if you increase Icc, but it will also lower the power-added efficiency (PAE). To achieve a decent PAE and linearity tradeoff, you need to optimize these major focus areas:
  - Load line
  - Interstage matching
  - Bias circuit design
  - Digital predistortion (DPD)
  - Envelope tracking (ET)
- **Design assumptions:** Ask if the device needs to be best-in-class for the premium tier or serve mass tier. The answer really depends on the market, because requirements vary by customer and application. Early adopters and flagship premium products may push for best-in-class performance (-47 dB EVM). In contrast, if the product is for mass tier or the low-cost market, devices probably won't be required to support 802.11ax for a few years after initial adoption in the premium tier.

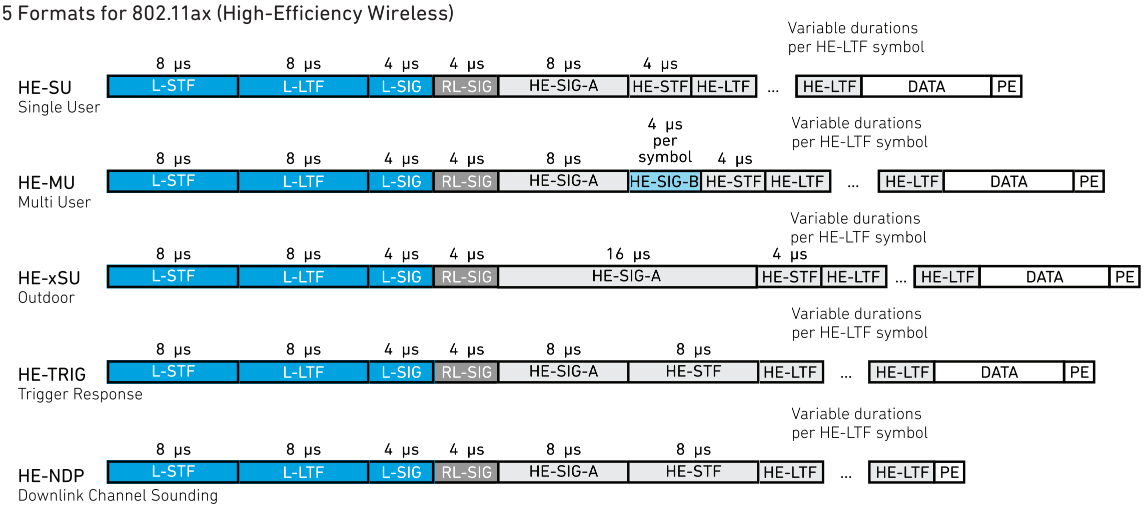
A Final Thought: Designing For A Standard That's Still In Flux

Above all, remember that the 802.11ax spec is still being defined, and you should work with your applications team to maximize your product designs for the emerging standard. Qorvo is committed to helping customers and providing design expertise as this Wi-Fi standard takes shape.

You can also read these resources from some of our hardware partners to dive into technical details of this developing technology.

OFDMA PPDU Formats

5 Formats for 802.11ax (High-Efficiency Wireless)



Field	Description
L-STF	Legacy Short Training Field
L-LTF	Legacy Long Training Field
L-SIG	Legacy Signal Field
RL-SIG	Repeated Legacy Signal Field
HE-SIG-A	HE Signal A Field
HE-SIG-B	HE Signal B Field
HE-STF	HE Short Training Field
HE-LTF	HE Long Training Field
DATA	Data
PE	Packet Extension Field
GI	Guard Interval
LTS	Legacy Training Sequence

Resolving Interference in a Crowded Wi-Fi Environment Using BAW Filters

There are any number of strategies that consumers can try to fix interference problems with Wi-Fi in their homes – moving the router, reconnecting the device to their Wi-Fi network, power cycling the modem... and calling their service provider when nothing works and they don't know what else to try. But as an RF engineer, how can you design a Wi-Fi access point that addresses the biggest interference issues from the outset?

This blog post examines the following factors that can impact Wi-Fi interference:

- The need to support multiple wireless standards
- Different types of interference
- Why band edges matter
- The importance of high-performance bandedge and coexistence BAW filters

One Access Point, Many Standards

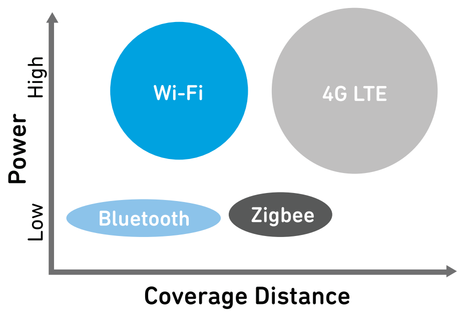
When developing Wi-Fi access points, designers must consider many wireless technology standards:

- Standards that operate at short and mid coverage ranges, such as Bluetooth, Zigbee and Z-Wave
- Standards that operate at higher power levels and short and long ranges, including Wi-Fi, 3G/4G LTE and 5G

Many of these standards can interfere with each other, leading to connectivity problems for users.

And then there's unlicensed spectrum to contend with. Licensed and unlicensed networks are becoming more important factors as constrained wireless communications offload data to continually expand capacity. Also, the new Internet of Things (IoT) realm draws heavily on this unlicensed spectrum.

Characteristics of Wireless Technology

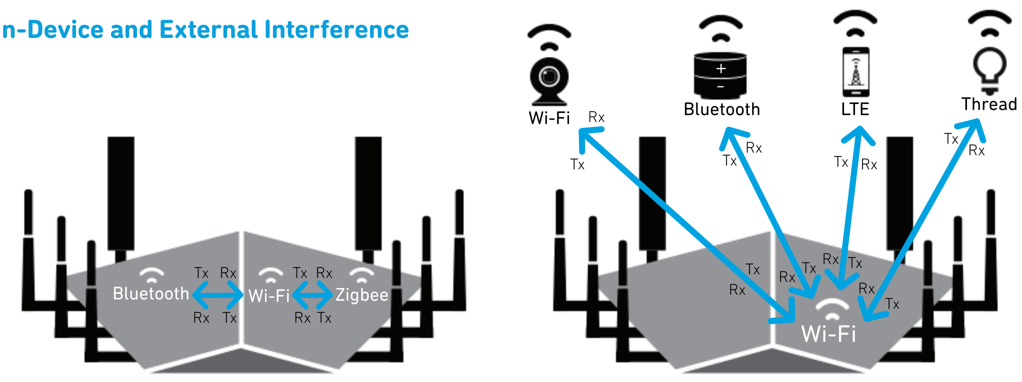


The challenge is to keep all these licensed and unlicensed bands and multiple protocols working in conjunction with each other without interference difficulties.

Different Types Of Interference: From In-Device To LTE And Bluetooth

Interference can occur within a device or between devices, including between wireless carrier signals or between wireless standards. The most common interference scenario is Bluetooth and LTE with Wi-Fi because these technologies are so widespread. Let's look at some of these in more detail.

In-Device and External Interference



In-Device Interference

External Device Interference

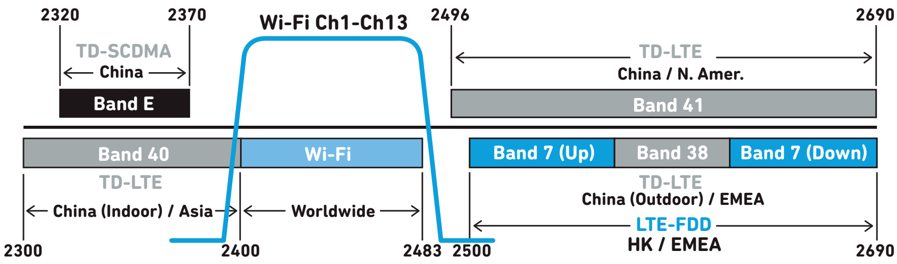
- **In-device coexistence:** For in-device coexistence, the system's multiple antenna architectures can interfere with each other. As a result, the coupling between the affected antennas (antenna isolation) is compromised. The foreign transmit (Tx) signal increases the noise power at the affected receiver, which has a negative impact on the signal-to-noise ratio. The receive (Rx) sensitivity decreases, which causes what engineers call "desensitization."

  Desensitization is a degradation of the sensitivity of the receiver due to external noise sources, and results in dropped or interrupted wireless connections. It isn't a new problem – early radios encountered receiver sensitivity when other components became active – but now it's particularly troublesome for today's wireless technologies, including smartphones, Wi-Fi routers, Bluetooth speakers and other devices.

  The primary "desense" scenarios are:
  - Two radio systems occupy bordering frequencies, and carrier leakage occurs
  - The harmonics of one transmitter fall on the carrier frequencies used by another system
  - Two radio systems share the same frequencies

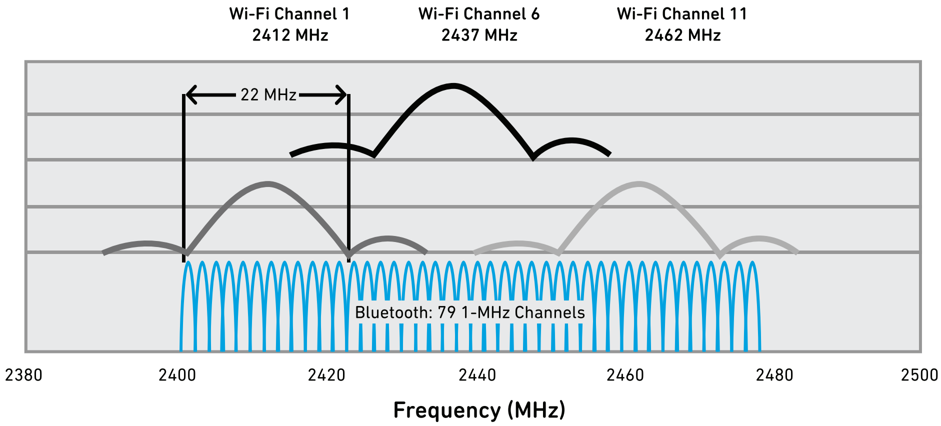
- **LTE and Wi-Fi:** As shown in the below figure, several LTE bands – Bands 40, 7 and 41 – are very close to the Wi-Fi band channels. Leakage into the adjacent Wi-Fi radio band is very probable at both the high and low end of the 2.4 GHz band. Without proper system design, the cellular and Wi-Fi channels 1 and 11 can interfere with each other's transmissions and receive capability.

Spectrum Example of Asia and EMEA



- **Bluetooth and Wi-Fi:** Bluetooth and Wi-Fi transmit in different ways using differing protocols, but they operate in the same frequency ranges, as shown in the following figure. As a result, when Wi-Fi operates in the 2.4 GHz band, Wi-Fi and Bluetooth transmissions can interfere with each other. Because Bluetooth and Wi-Fi radios often operate in the same physical area (such as inside an access point), interference between these two standards can impact the performance and reliability of both wireless interfaces.

ISM, Wi-Fi & Bluetooth Channel Frequencies

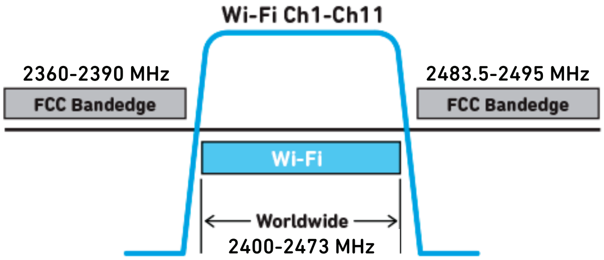


Why Bandedges Matter For Wi-Fi Coexistence

One way federal governments have tried to help consumers is by regulating the emissions and spectrum of many electronic devices and requiring consumer products to undergo compliance testing.

In the United States, the federal communications commission (FCC) requires that most RF devices undergo testing to demonstrate compliance to FCC rules. They enforce strict bandedges by requiring steep skirts on the lower and upper Wi-Fi frequencies, to help with coexistence with neighboring spectrum.

Spectrum Example of Wi-Fi and Bandedge



There are two ways for Wi-Fi access points to meet this FCC requirement:

- Back off the power level on Wi-Fi channel 1 and 11, because they're at the edge of the Wi-Fi spectrum
- Use filters with very steep bandedges

Design Tips To Overcome Interference Challenges: Use High-Q BAW Filters

Our approach is to use high-performance coexistence and bandedge filters, to allow Wi-Fi transmitters to operate close to the upper and lower FCC bandedges.

Customers have had success using high-Q bulk acoustic wave (BAW) bandpass filters, which offer many advantages:

- **Extremely steep skirts** that simultaneously exhibit low loss in the Wi-Fi band and high rejection in the band edge and adjacent LTE/TD-LTE bands
- **Significant size reductions,** which aid designers in creating smaller, more attractive end-user devices for homes and office environments
- **Resolves coexistence of Wi-Fi and LTE signals** within the same device or near one another
- **Unique power handling capabilities,** allowing for implementation into high-performance, high-power access points and small cell base stations

These filters address the stringent thermal challenges of multi-user multiple-input/multiple-output (MU-MIMO) systems, without compromising harmonic compliance and emissions performance. This is critical to achieving reliable coverage across the full allocated spectrum.

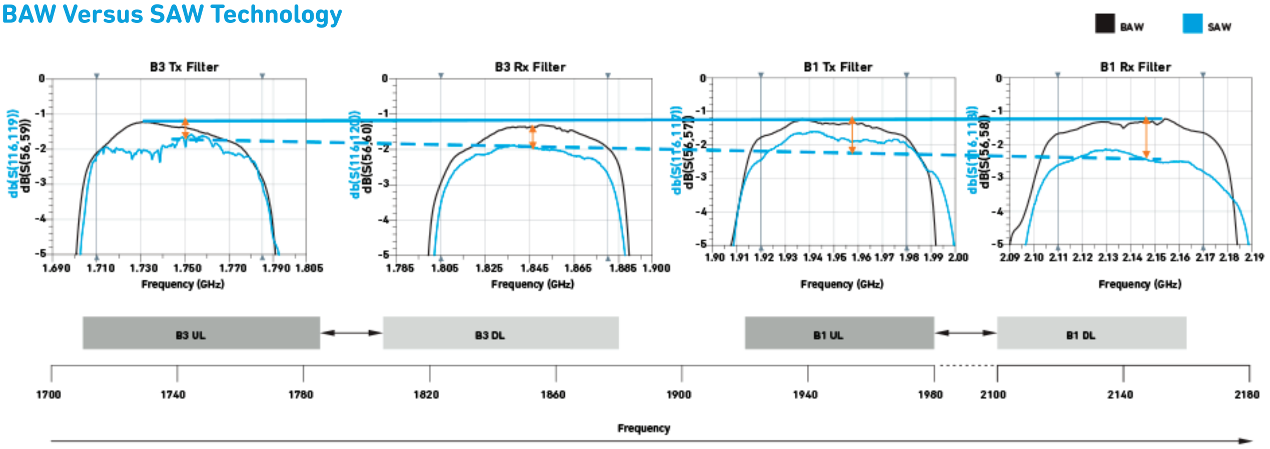
But why do high-Q BAW filters make such a difference for FCC band edges?

#1: BAW devices have lower insertion loss, steeper band edges and better temperature stability than SAW technology at Wi-Fi frequencies
As you move into higher bandwidths like Wi-Fi, surface acoustic wave (SAW) devices can suffer from higher insertion losses than BAW due to radiation of acoustic energy into the bulk of the substrate. As shown in the following figure, as you move up (to the right) in frequency, you can see high-Q BAW is a good option for filter designs due to this bulk radiation loss effect. Also, BAW maintains the steep skirts required for FCC band edges; SAW can't meet the performance requirements at these higher frequencies.

BAW also has better temperature stability than other technologies, which gives it an advantage during FCC certification tests. Most Wi-Fi designs are created at room temperature (20-25°C) on a bench, but the system in its application environment can actually operate around 60-80°C. Insertion loss increases as temperature increases, and failing to estimate for this can cause issues during product certification. Using BAW reduces the shifts in insertion loss and makes certification test results more predictable.

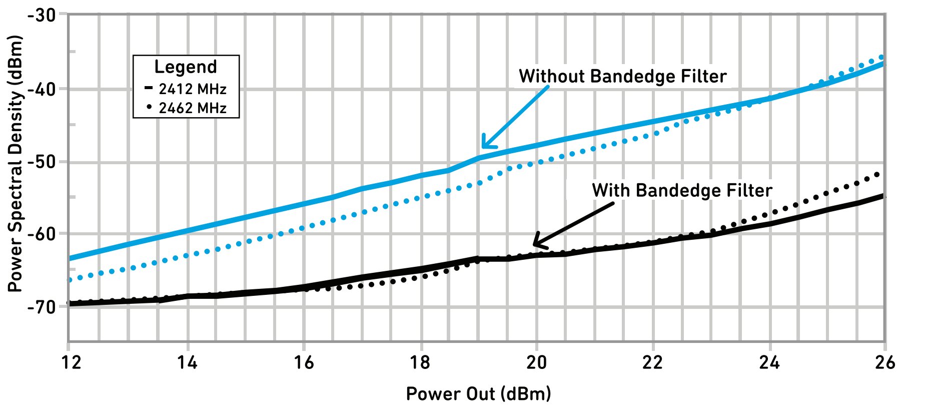
Learn more about BAW versus SAW in our free e-book, RF Filter Technologies For Dummies® (Volume 1).

BAW Versus SAW Technology



#2: BAW filtering can help engineers provide seamless transitioning between interfering bands
As shown in the following figure, the bandedge response is better using a filter than without it, and it allows designers to push the limit on RF front-end output power while meeting the FCC requirement for power spectral density. This means bandedge BAW filtering allows operators and manufacturers to deliver high-speed data and greater bandwidth by using spectrum that might be lost with no filtering.

FCC Restricted Bandedge With and Without BAW Filter



#3: High-Q BAW bandedge filters can extend the range in channel 1 and 11 by 2-3 times

Wi-Fi designers normally must set the entire unit power to whatever the lowest bandedge-compliant power is for all channels. So, if the compliant channel at channel 1 is 15 dBm but channel 6 can achieve 23 dBm, the designer settles the entire power control scheme to 15 dBm. Using bandedge filtering allows designers to set the power scheme to much higher powers, thus making it possible to use fewer RF chains to achieve their goals.

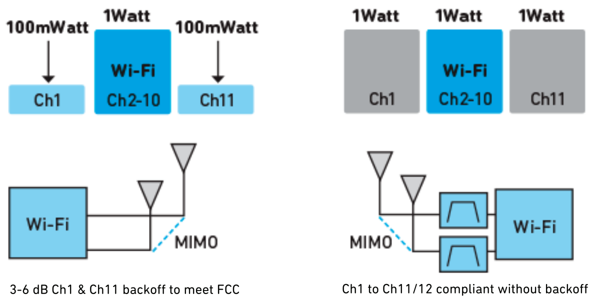
BAW bandedge filters can also exhibit power handling capabilities for transmitting up to 28 dBm. This can improve system performance by greater than 15 percent and enable 5G multi-MIMO with less co-channel interference.

CPE developers who don't use bandedge filtering have difficulty meeting FCC requirements on Wi-Fi band channels 1 and 11. In contrast, when high-Q BAW bandedge filters are used, it allows the CPE designer to keep the power level the same throughout all the channels (1 – 11).

To paint the picture, here's the difference in user experience with and without bandedge filters:

- **Without bandedge filters:** Let's assume you're in a house with several individuals using Wi-Fi and mobile phones. You're on Wi-Fi using channel 5, streaming a football game and experiencing no buffering or interruption. But then new mobile users arrive in the house and begin to take over your channel 5 Wi-Fi space. The CPE unit adjusts and bounces you to channel 1 to free up more space on channel 5. If the Wi-Fi unit doesn't have bandedge filters (as in the block diagram on the left), your Wi-Fi strength and streaming degrade to the point where buffering occurs. Why? Because to meet the FCC requirement, the CPE unit must back off its power in channel 1 so it doesn't interfere with adjacent cellular bands.

Wi-Fi/LTE System Models (With/Without Bandedge Filters)



- **With bandedge filters:** However, if the CPE unit had been designed with bandedge filters (as shown in the block diagram on the right), channel 1 and 11 would not be compromised and the power level would not require backoff. You can watch your streamed football game without any buffering.

Go In Depth: How Qorvo Wi-Fi Solutions Can Help Solve Interference Challenges

In a connected world with more and more devices and wireless standards, coexistence and interference issues will not go away. To make use of every bit of spectrum available, Wi-Fi designs with high-Q BAW filters can improve the performance of Wi-Fi access points.

How Spatial Combining Works New Levels of Power for TWTA Replacements

Replacing legacy systems with next-generation technology isn't always a one-to-one fix. This blog describes spatial combining, why it's important for sensitive equipment like electronic countermeasures (ECMs) and how it helps achieve the highest levels of power available.

Power In The Past


Cathode Ray Tube Television

Historically, vacuum tube amplifiers were used for all amplifiers, from audio frequency to RF and microwave, as well as for lighting and the displays for our television sets. Traveling wave tube amplifiers (TWTAs) have continued to provide high-power amplification at microwave frequencies over broad bandwidths.

But vacuum tubes, typically in the multi-kV range, have lower reliability than solid-state devices, with low-voltage power supplies, and over time, the supply of vacuum tubes and the expertise to manufacture them have decreased. As a result, most vacuum tubes have been replaced with solid-state alternatives, except in applications such as microwave ovens and electronic warfare (EW), which required vacuum tubes to generate the higher power levels necessary for equipment like ECM jamming transmitters.

But power combining techniques now make it possible to achieve these power levels with solid-state devices.

Spatial Combining: What It Is And Why It's Important

ECM systems comprise receivers, processors, displays and jamming transmitters. Only recently have solid-state solutions been able to meet the power and bandwidth requirements of ECM jamming transmitters, due to the advent of gallium nitride (GaN) power amplifier MMICs and low-loss, broadband combining techniques. However, a single GaN MMIC still has insufficient power for most ECM systems, which can have requirements of more than 100 watts from 1.5-7.5 GHz. Solid-state devices must combine multiple power amplifiers to reach the same power levels originally offered by TWTAs.

Spatial combining can create solid-state power amplifiers (SSPAs) in the following ranges of frequency and power – which all provide performance improvements when compared with TWTAs:

- 100 W to 1 kW, 1 GHz to 40 GHz covering up to a decade of bandwidth
- Reduced harmonic content in the output spectrum
- Less noise generated
- Increased linearity

Caution: Heat Dispersed For Best Operation

Thermal management is critical to get the best performance out of solid-state devices. For ECMs, we often work with different thermal environments on different platforms. Some systems could use a cooling fluid or air cooling with a fan.

Spatial combining provides the most efficient means of combining GaN MMICs, lowering the amount of heat dispersed. When we measure thermal performance, the efficiency of the total amplifier is the most important factor.

The efficiency of GaN MMICs combined with the efficiency of spatial combining yields the most efficient solid-state amplifier available. The more efficient the solid-state device, the lower the amount of heat that must be dissipated.

Also, when solid-state components operate cooler, their reliability is better so we want them to operate as cool as possible. Using good thermal conductors, like copper, and maximizing the available cross section are key for improving the thermals. However, there are trade-offs between the types of metals used and the weight of the equipment – it can't be too heavy for airborne platforms, for instance. So, there are other metals that can be used when making size, weight and power (SWaP) considerations.

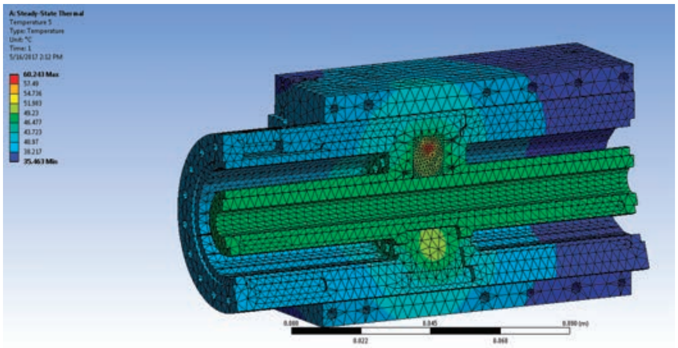
How Is Spatium Being Used Today?

Qorvo's method of spatial combining is called Spatium®. With coaxial construction, Spatium provides an efficient, broadband and compact way of combining multiple MMICs in a single step. In fact, Spatium can typically combine 16 amplifiers in one step, with only 0.5 dB combining loss. In addition, Qorvo designed a thermal path on the back of the MMIC to the cooling plate, to help with thermal management. (See the figure below for a thermal simulation using Qorvo's Spatium QPB1006.)

Here's how Spatium MMICs can be used in different applications:

- **Electronic warfare:** Spatium can be used in airborne, land, or naval ECM equipment, typically in the transmitters for the antennas.
- **Satcom:** Spatium is used in Ka-band satellite earth stations that operate at 100 W and 27-31 GHz, covering both military and commercial bands. It is used in ground stations on the transmitter side at the antenna hub in block up-converters (BUCs).
- **Testing:** Spatium can be used in high-power microwave signal generators or as a load pull on high-power devices, during input impedance to figure out how devices will respond. In these environments, a higher-power amplifier is needed to fully characterize these devices.

Example of Thermal Simulation Using Qorvo's Spatium QPB1006: Cooler performance, better reliability



Three new Spatium products are intended for designing new EW equipment, operate within 2-18 GHz, and could replace legacy tubes. The products can also be used in test equipment where a high-power stimulus is needed. Less noise and more linearity than legacy TWTAs mean measurements taken with Spatium will have greater fidelity.

Spatial combining offers the ability to deliver hundreds of watts over broad bandwidths and can be specially designed, in many cases, for a new box or to fill an existing TWTA space.

This is the first time there's been this type of power, bandwidth and efficiency available for solid-state devices. It offers a viable option for 20- to 30-year-old platforms (aircraft, ship, etc.) with non-fixable vacuum tubes; they can now be replaced with reliable, solid-state equipment.

Top Trends and Overcoming Design Challenges in Small Cells

What Are Some Of The Latest Trends Related To Small Cells?

- **LTE for usage in unlicensed bands:** Also known as LTE-U and licensed assisted access (LAA), unlicensed spectrum is starting to be implemented in small cell base stations. This unlicensed band access overlays LTE over the Wi-Fi band and provides carriers with another pipeline where they can control and guarantee quality of service (QoS).
- **Increased number of bands per system:** A couple of years ago, a lot of small cell base stations were just for single band. Many are now dual band, and moving forward in the next year or two, customers are developing and implementing triple-band systems. This will increase the system-level requirements for small cell solutions, both in terms of the number of components required and the complexity of the overall system design.
- **Customers designing with more efficient systems:** Systems targeted for shipment later this year are implementing linearization, which requires power amplifiers that are much more efficient than they are today. Today, systems are designed where the power amplifiers typically operate in backed-off mode, which means that the system just works without worrying how the PA performs. Linearization uses feedback so that the signal gets "cleaned up" by the baseband chipset and allows PAs to operate with much higher efficiency, translating into lower power consumption for the system.
- **Continued growth:** The small cell market has been emerging for a while, but over the past two years we have seen significant growth, at 50% year over year. Multiple analysts such as IHS Technology and Mobile Experts expect that small cell deployments will total more than 1 million small cell base stations for 2017.

What Are Common Or New Challenges Customers Have When Designing For Small Cell Applications?

- **Increasing number of bands per system:** Customers historically are designing these small cell systems for MIMO applications (multiple input/multiple output), which typically have 2 transmitters and 2 receivers per frequency band. As base stations incorporate multiple channels, it means more components – for instance, a three-band system would need six separate PAs (2 transmitters x 3 bands = 6 PAs) – which adds complexity, size and power consumption. Customers need the systems to be easy to design, easy to use (i.e., internally matched components), and efficient.
- **Ensuring good isolation and band separation for the transmit/receive channels,** specifically for Band 3 (1.8 GHz). The band separation is only 20 MHz, which requires very high isolation out of the duplexer.

How Does Qorvo Help Our Customers Solve These Design Challenges?

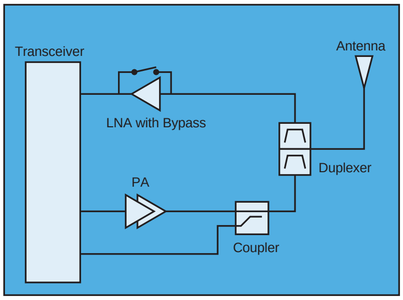
Qorvo has significantly expanded our portfolio of small cell filters and PAs, targeting products for specific frequency bands. Our customers have seen some of the following key benefits:

- **Filters for small cells:** Qorvo's BAW technology delivers high isolation and performance, particularly in our duplexers. Our small cell duplexers provide very good passive intermodulation (PIM) by reducing nonlinearities that may be introduced in the duplexer – which our customers have said is very important.
- **Small cell power amplifiers:** Qorvo PAs are internally matched and designed to provide temperature compensation inside the circuitry. This means our PAs are effectively plug and play and easy to use, which allows customers to easily design their system.

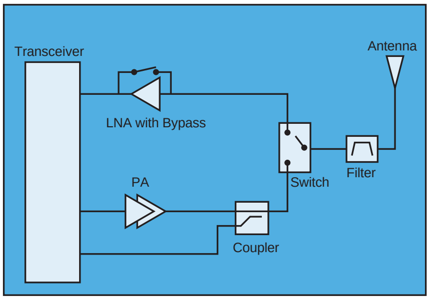
Qorvo has a complete small cell portfolio and is the only supplier to provide the entire RF front end, including LNAs, PAs, filters/duplexers and switches. All of our small cell products provide:

- High linearity
- High isolation
- Low power consumption
- Low link budget

Small Cells FDD



Small Cells TDD



Qorvo 5G Product Highlights

QPF4001
Single-and-dual-channel GaN FEM
- Frequency: 28 GHz
- Package dimensions: 5x4 mm

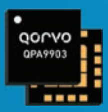
QPF4002
Single-and-dual-channel GaN FEM
- Frequency: 28 GHz
- Package dimensions: 5x8 mm

QPF4006
GaN FEM
- Frequency range: 37-40.5 GHz
- Package dimensions: 4.5x4x1.8 mm

QPF4005
GaN FEM
- Frequency range: 37-40.5 GHz
- Package dimensions: 4.5x6 mm

QPQ6108
SAW duplexer
- High input power: 29 dBm on DL
- Package dimensions: 2.5x2 mm

QPA9908
High-efficiency PA
- High input power: 5V 4W pk
- Package dimensions: 5x5 mm

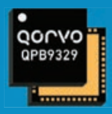


QPA9903
High-efficiency PA
- High input power: 5V 4W pk
- Package dimensions: 5x5 mm

QPA9940
High-efficiency PA
- High input power: 5V 4W pk
- Package dimensions: 5x5 mm

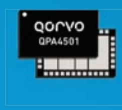
QPA9942
High-efficiency PA
- High input power: 5V 4W pk
- Package dimensions: 5x5 mm

QPA9120
2-stage wideband gain block
- Frequency range: 1.8-5 GHz
- Package dimensions: 3x3 mm



QPB9329
Dual-channel switch LNA module
- Frequency range: 4.4-5 GHz
- Package dimensions: 6x6 mm

QPL9503
LNA
- Frequency range: 1-6 GHz
- Package dimensions: 2x2 mm



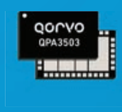
QPA4501
GaN PA module
- Frequency range: 4.4-5 GHz
- Package dimensions: 6x10 mm

QPD0020
DC-4 GHz GaN power transistor
- High input power: 25W 48V
- Package dimensions: 4x3 mm

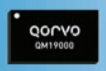
QPD0030
DC-4 GHz GaN power transistor
- High input power: 45W 48V
- Package dimensions: 4x3 mm

QPD0050
DC-3.6 GHz GaN transistor
- High input power: 75W 48V
- Package dimensions: 7.2x6.6 mm

QPA3506
3.4-3.6 GHz GaN PA module
- High input power: 5W 28V
- Package dimensions: 6x10 mm



QPA3503
3.4-3.6 GHz GaN PA module
- High input power: 3W 28V
- Package dimensions: 6x10 mm



QM19000
5G RFFE for wireless mobile devices

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