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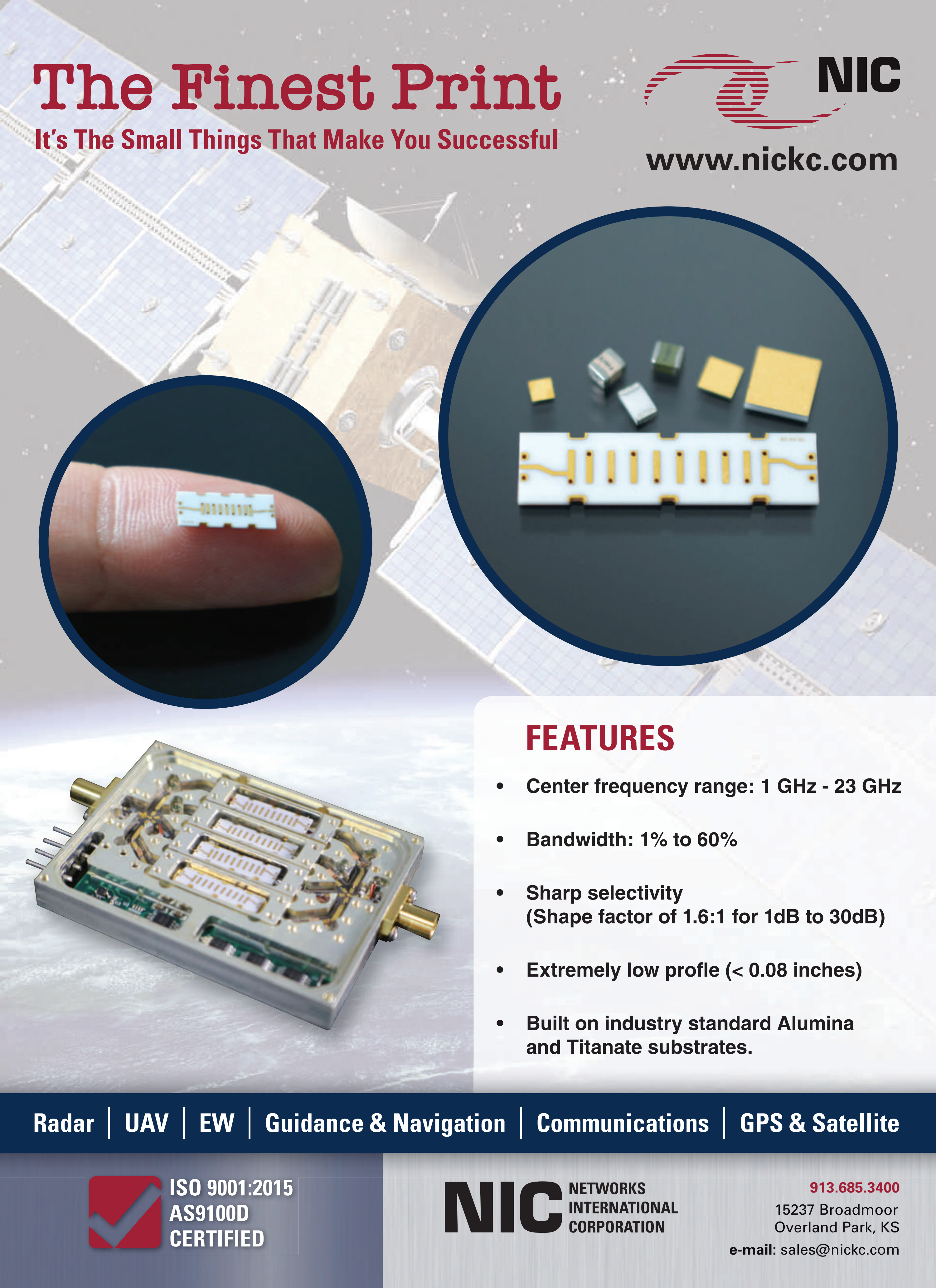
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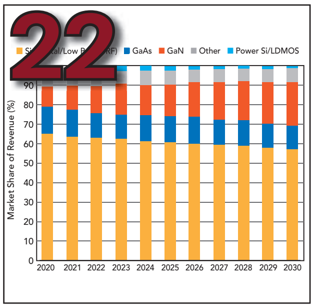

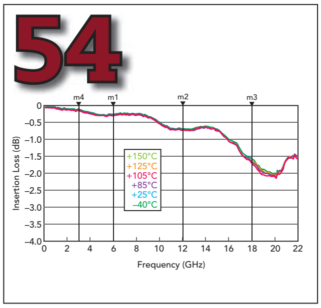

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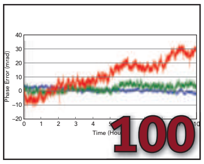

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Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to Microwave Journal, PO Box 1028, Lowell, MA 01853 or e-mail mwj@e-circ.net.com. Subscription information: (978) 671-0446. This journal is issued without charge upon written request to qualified persons working in the RF & microwave industry. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

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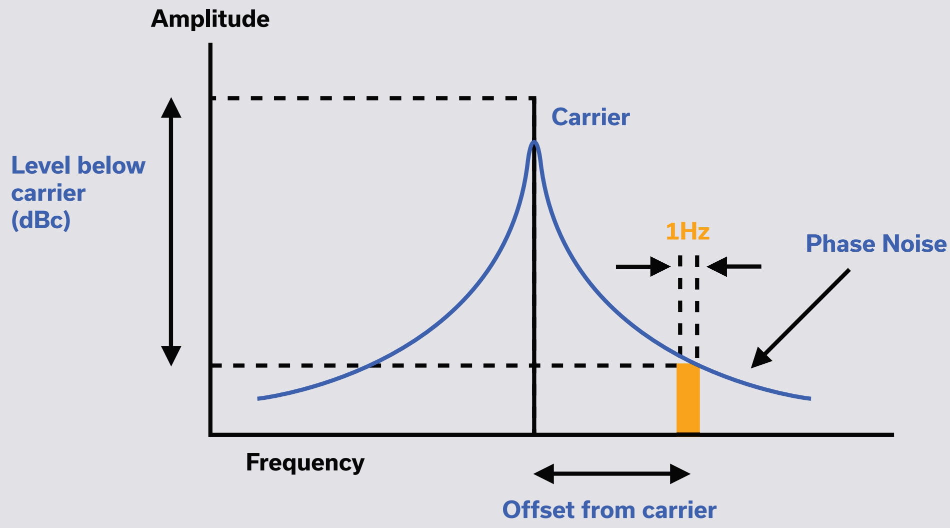

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The Year of Transition and Consolidation

Pat Hindle, *Microwave Journal Editorial Director*

The pandemic continued to affect trade shows this year except the industry was resilient, so instead of having fully virtual events, most adapted and held hybrid events this year with a portion of the audience attending live and the rest online. Mobile World Congress kicked off this trend in our industry by swapping the dates of their Barcelona and Shanghai events, since China was in better shape earlier in the year to have a physical event with about a third of the normal audience attending in person. The next large hybrid event was IMS2021 in Atlanta with about a quarter of the normal attendees present in person. That was followed two weeks later with a full week of virtual activities. Our EDI CON China event also took a hybrid approach with a virtual event in May followed by two smaller in-person events, one in July (Shanghai) and one in December (Shenzhen).

As 2022 approaches, we think that events can return to fully in-person gatherings as virtual events are no replacement for the real thing. EuMW managed to delay the fall 2021 London event until February 2022 and plans to hold it in person, as well as CES and Mobile World Congress doing the same. IMS2022 will be held in Denver and should be in a time frame that we have returned to normal in-person events, we hope to see many of you there for a great reunion of the industry.

Despite the pandemic, 5G rollouts continued at a rapid pace but were certainly slowed to some extent. The Global mobile Suppliers Association tracked over 1,000 5G devices that had been announced and 180 5G networks had been launched in 72 countries/territories around the world by the end of Q3. The association's research also found 465 operators in 139 countries/territories are investing in 5G networks in the form of tests, trials, pilots, planned and actual deployments at that time.

With 5G ramping up and going into full production, 2021 was the year that many 6G research programs were kicked off in earnest. The Brooklyn 5G Summit has been convening annually for many years but this year transitioned to 6G, holding their event in October virtually. Most experts agreed that 6G will start initial rollouts in about 2028 with 2030 being the time frame of significant deployments (standardization phase 1 will likely start from 2026 as part of 3GPP Release 20). The biggest innovation in 6G is likely to be in the use of sensing with the same signals used for communications. According to the experts at the Summit, "we don't know the exact applications yet, but this certainly opens many areas of opportunities for future services. We will connect the physical world to our own human world, thanks to the massive scale deployment of sensors and artificial intelligence and machine learning with digital twin models and real-time synchronous updates. These digital twin models are crucial because they allow us to analyze what's happening in the physical world, simulate possible outcomes, anticipate needs and then take productive actions back into the physical world."

Another trend in 2021 was the standardization of networks and systems. These open systems standards promise to enable a more competitive and vibrant supplier ecosystem with faster innovation. We have seen Open RAN gaining momentum this year with the industry now working together to realize open 5G systems from hardware to software. Then we saw Open RF form to do the same thing for mobile devices. This organization is just starting up, so it will be interesting to see how it evolves. Then in the defense industry, Sensor Open Systems Architecture (SOSA) has taken hold in the industry after several years in the making and many companies are now offering SOSA compliant products.

This year the industry saw a large consolidation of small microwave companies plus several larger acquisitions. Quantic Electronics was an active acquirer of small companies and now has 12 brands under its umbrella. SemiGen was acquired by Naprotek. Maury Microwave acquired dBm Corporation after being acquired by Artemis Capital Partners earlier in the year. AMETEK acquired NSI-MI Technologies. For larger companies, Analog Devices completed the acquisition of Maxim, making them a giant in the industry. Skyworks completed the acquisition of the infrastructure and automotive business of Silicon Labs. Qualcomm acquired NUVIA and outbid Magma International for Veoneer, who makes automotive safety systems including radar sensors. TE Connectivity acquired the antennas business from Laird Connectivity and Renesas acquired Dialog Semiconductor.

On the defense side, Mercury was active acquiring Pentek and Avalex Technologies Corporation. An Arlington Capital Partners' affiliate acquired L3Harris Technologies' Electron Devices and Narda Microwave-West divisions, which will operate independently as Stellant Systems and CPI purchased TMD Technologies groups. On the quantum front, both Keysight and Rohde & Schwarz made key small acquisitions to strengthen their efforts in that market.

Several companies went public recently as GlobalFoundries did an IPO, Starry agreed to go public via a merger and Guerrilla RF went public in a reverse merger transaction. Finally, Sivers Semiconductors acquired Mixcomm and I believe this could be the start of consolidation of the mmWave 5G/satcom companies that could happen next year.

It was another very interesting and active year in 2021. Happy Holidays and we hope to see you in person in 2022! ■

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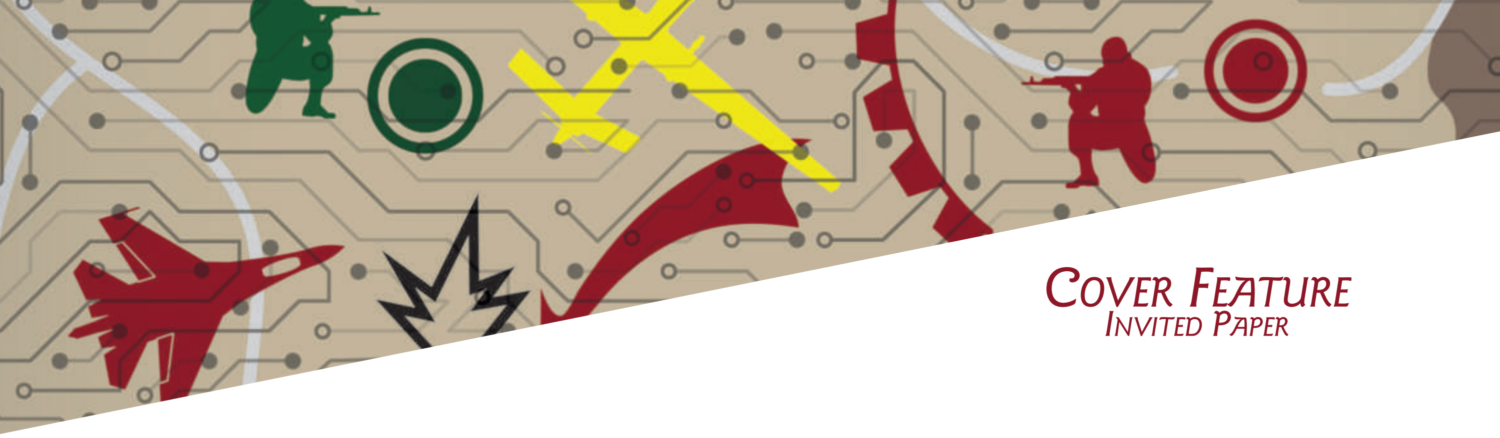

COVER FEATURE
INVITED PAPER

Defense Market Trends and the Impact on Semiconductor Technology

Eric Higham
Strategy Analytics, Newton, Mass.

With chip shortages in the consumer electronics market, 5G and the latest handset offerings from Apple and Samsung dominating electronics and semiconductor news, it is easy to forget the key role the defense industry has played and will continue to play in the evolution of the compound semiconductor supply chain. From the MIMIC and MAFET programs with GaAs and, more recently, the development of GaN, defense agencies have supplied the funding and applications that have enabled these compound semiconductor technologies and other portions of the supply chain to grow and mature. The motivation behind this nurturing is a need for the highest performance technologies and products in defense applications, and the driver is global defense spending. ***Figure 1*** shows the latest Strategy Analytics forecast for global defense expenditures.

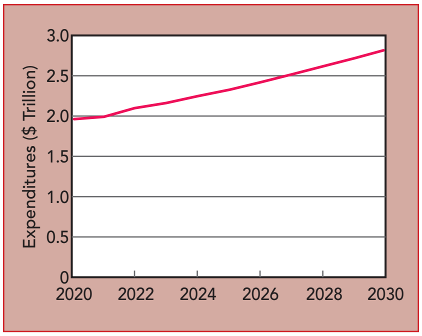

Fig. 1 **Global defense spending. Strategy Analytics forecast.**

The growth rate for global defense spending is not large, but the size of these expenditures makes this an attractive market. Defense spending in 2020 reached nearly $2 trillion, and we expect it to reach $2.8 trillion in 2028. A good portion of this spending goes toward the yearly expense of supporting and maintaining a standing army, but we expect that the portion of the defense spending used for material, equipment, R&D and training will approach an estimated $900 billion in 2030. The result is a large yearly injection of revenue into the electronics and semiconductor supply chains.

SEMICONDUCTOR TRENDS

Winnowing the expenditures from the top-level budget to equipment and semiconductor content, the available revenue to the supply chain shrinks; yet it is still a substantial number. ***Figure 2*** shows the latest Strategy Analytics segmentation of semiconductor content in electronic warfare, radar and communications systems. Even though the expenditures are smaller at each step down the procurement chain, our latest forecast estimates semiconductor content in components will reach $6.5 billion in 2030. The details behind these numbers show some interesting trends.

The first significant trend for the semiconductor industry is that semiconductor revenue grows at a faster rate than top-level expenditures. This shows the reliance on electronics to support battlefield and mission strategies that increasingly reflect the concept of a global information grid with more networking and data capabilities. The second observation is the large share of defense market revenue occupied by Si semiconductors. Because of the performance, environmental and mission requirements, defense electronics are rarely as sleek and fashionable as their commercial equivalents, but they need as much or more processing with encryption and security capabilities. The final trend is the rapid growth of GaN. This forecast has GaN component revenue approaching $1.5 billion for defense applications in 2030. GaN has become the dominant RF power technology. Its performance characteristics support evolving battle philosophies that rely on higher operating frequencies, wider instantaneous bandwidths, better efficiency and higher linearity.

In the late 80s and early 90s, the

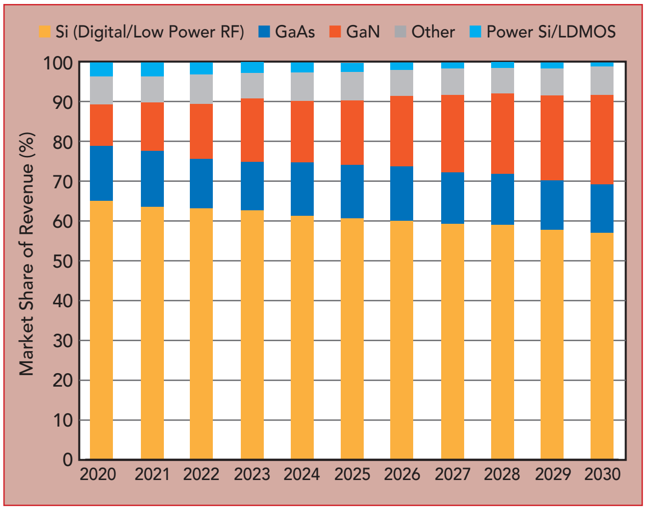

Fig. 2 **Defense component revenue segmentation by semiconductor technology.**

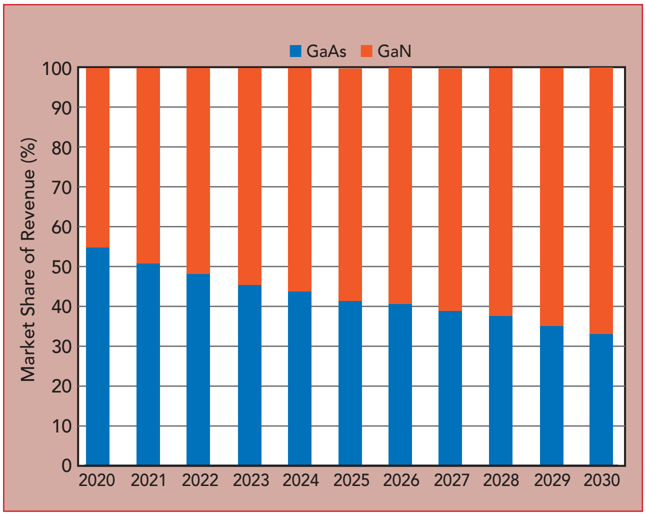

Fig. 3 **Defense component revenue split: GaAs vs. GaN.**

U.S. Department of Defense (DoD) supplied funding, mentoring and system applications that enabled GaAs device technology to transition from digital to RF applications. In addition, the defense industry was instrumental in developing the processes and manufacturing, test and assembly ecosystems to the point where the performance and price of GaAs devices became attractive for commercial applications. In the early days of the GaAs-defense partnership, most of the RF components in the system block diagrams used GaAs technology. As other technologies mature, most notably Si and GaN, they are capturing market share from GaAs, and while GaAs no longer commands the overwhelming share of revenue in the block diagram, the defense market is still important for the GaAs industry.

Figure 3 shows the split in device revenue for defense applications between GaAs and GaN, and it illustrates the growing importance of GaN for defense systems. Despite an expected growth in GaAs revenue, Strategy Analytics' latest forecast shows GaAs losing market share quickly to GaN. In 2020, GaAs device revenue was still substantially larger than GaN's for defense applications, but we are forecasting GaN device revenue will be nearly twice as large as GaAs device revenue in 2030.

However, GaN and GaAs device revenue trajectories have become intertwined. As GaN grows, much of the market share captured by this technology comes from tube-based amplifiers, as these and other defense applications require high RF output power. The transmit amplifier chain usually has GaAs stages driving the GaN output stage. So the market share captured by GaN from tubes, combined with new production using GaN, will help GaAs revenue grow. We predict that revenue from GaN and GaAs devices will approach \$2.2 billion in 2030, a significant opportunity for device manufacturers.

UNDERLYING DRIVERS

Defense applications do not create the same volumes as consumer devices, but devices for defense are characterized by higher

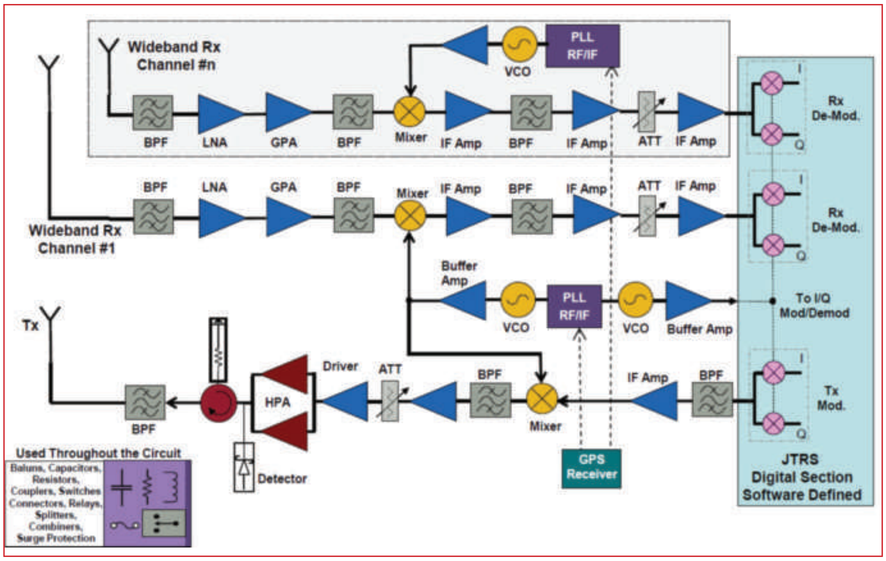

Fig. 4 Military radio block diagram. *Source:* Richardson RFPD.

prices, and this contributes to the attractiveness of the opportunity. ***Figure 4*** shows a representative radio architecture that illustrates the breadth of the RF opportunity in defense. While the block diagram shows a radio architecture, electronic warfare and radar block diagrams, while differing in intent and complexity, also rely on a superheterodyne architecture.

The block diagram shows the array of active and passive elements in a radio. In the transmit chain, digital information at the intermediate frequency (IF) is up-converted to the transmit frequency by a mixer locked to the local oscillator reference frequency using a voltage-controlled oscillator (VCO)/phase locked loop (PLL) combination. The transmit signal is amplified through a multi-stage amplifier chain to the antenna.

To better process the wideband incoming signal, the receiver is channelized, i.e., with each channel filtered to a specific band. The incoming signal is amplified and filtered before reaching the same type of mixer/VCO/PLL combination, in this case down-converting the RF signal to an IF frequency. From here, the digital/processing section of the radio, shown at the right of Figure 4 extracts the data encoded on the incoming signal.

While this simple analysis does not do justice to the complexity and capability of tactical radios, we see the variety of low- and high-power amplifiers, control and signal conversion components and assorted filters and other passive elements sprinkled around the block diagram. The digital section in the figure is not detailed, but it contains an impressive array of digital, baseband, processing, security and encryption, all in Si. As we consider that fielded systems may have multiple transmitters and receivers, it is easier to see component revenue in the defense segment reaching $6.5 billion by 2030.

DEFENSE CAPABILITY EVOLUTION

The diagram in Figure 4 illustrates a radio architecture constructed from standard components from a variety of suppliers. The sharp-eyed will notice that the digital section references the Joint Tactical Radio System (JTRS). In 2011, the U.S. Army cancelled the JTRS Ground Mobile Radio, the centerpiece of this effort, but these development efforts did serve as a gateway to the evolution of software-defined radios (SDRs), and other tactical radio programs are using some of these waveforms.

Early implementations of system architectures used GaAs-based components for the vast majority of the active RF components. As technologies and requirements have evolved, the conversion stages (i.e., the oscillator, amplifier and mixer) are now Si ICs. The PLL/

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Those developments are some of the specific component and technology changes that the defense industry has incorporated over time, but where is the industry headed? ***Figure 5*** conveys Strategy Analytics' thoughts on the evolution of capabilities that will be important to the defense supply chain. Not surprisingly, the evolution aims toward more functionality, more reliance on software and higher performance for all the components.

Transmitters will evolve to higher instantaneous bandwidths to accommodate more and wider channels. Where the bandwidth of a system is too wide, the transmit chain will require a more efficient method for using multiple transmitters. Receivers will also need to manage wider band and higher frequency input signals, with better sensitivity. The industry is making great strides in analog-to-digital and digital to analog converters and digital signal processing elements to improve the resolution and sampling speed of the RF signal, enabling the conversion from RF to digital closer to the antenna and at higher frequencies.

For the processing and control functions, the operating spectrum for defense systems is becoming much more congested and contested. SDRs that can be configured and programmed for changing conditions in real time are evolving to integrate cognitive capabilities that enable systems to automatically adapt to the environment. The logical extension of this capability relies on the maturation and adoption of machine learning algorithms and techniques and on artificial intelligence. Defense agencies are reluctant to delegate complete responsibility for decisions to software, especially ones with lethal consequences. This "man in the loop" philosophy is likely to wane over time as technology and algorithms advance.

CHANGING U.S. DEFENSE PHILOSOPHIES

In addition to the hardware and software evolution we have discussed, the U.S. military is considering changes to fundamental battlefield philosophies. U.S. battle strategy has been succinctly summarized as one of "overwhelming force," i.e., transporting a massive number of assets, whether troops, vehicles, airborne or naval platforms, to the front lines of the conflict. The goal of this approach is to deter a conflict from happening. If the conflict does intensify, the next step in the strategy is limiting the enemy's command, control and intelligence capabilities by seizing control of the electromagnetic spectrum so U.S. forces have free rein of the field of battle.

The concern for the DoD is that other countries have had 30 years

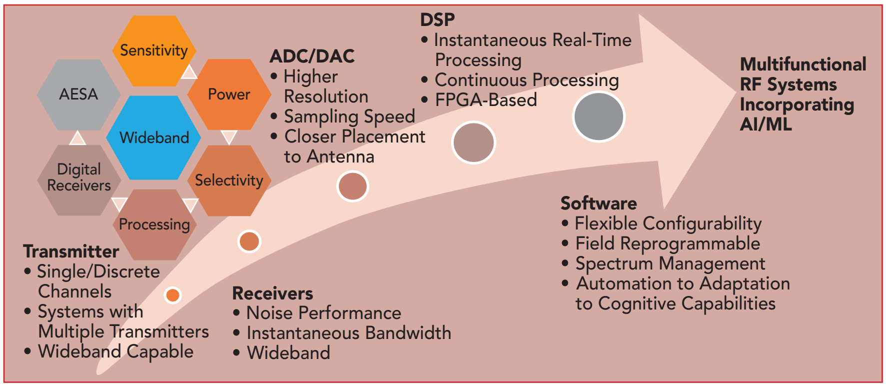

Fig. 5 Evolution in defense technology capabilities.

to observe these tactics in the Gulf War and the war in Afghanistan. The "Great Power Competition," the uneasy balance of power among the U.S., China and Russia, is heating up: China's defense spending growth rate is about double that of the U.S. and Russia is spending more on defense as their oil-based economy recovers. With so much time to observe U.S. tactics, defense spending from potential adversaries aims toward anti-access/area-denial (A2/AD) strategies to blunt the U.S.'s ability to control the electromagnetic spectrum in the battlefield. While the U.S. continues to fund the largest defense budget in the world, China's and Russia's budgets are among the five largest. In addition to A2/AD, spending in those two countries aims at developing platforms incorporating next-generation hypersonic, stealth and directed energy technologies, with China also spending heavily to improve and expand their naval capabilities.

The U.S. DoD recognizes that conflicts with U.S. involvement may occur in areas a great distance from the U.S. This presents a logistical challenge. The possibility of having multiple simultaneous conflicts in those areas exacerbates the challenge, and the DoD is concerned that trying to maintain an overwhelming force strategy on multiple fronts simultaneously will require a substantial investment, yet only result in a marginal force advantage.

In DARPA and DoD circles, "mosaic warfare" is an alternative strategy getting significant traction. It relies on capability overmatch, rather than overwhelming force. While it still relies on clear and significant superiority, the superiority comes from technology and capability rather than personnel and equipment. DARPA senior management coined the mosaic warfare term because it describes their vision of assets as tiles that can be arranged into different mosaics. In this vision, the tiles may be as simple as a sensor on a soldier or as complex as an F-35 or an aircraft carrier. Planners and commanders would arrange these tiles in differ-

TABLE 1 MOSAIC WARFARE KILL CHAIN Source: DARPA

	Distributed Kill Chain	*System-of-Systems*	*Adaptive Kill Web*	*Mosaic Warfare*
Example	NIFC-CA	SoSITE	TBD	TBD
Description	Manual integration of existing systems	Systems prepped for multiple battle configurations	Semi-automated ability to select pre-defined effects web prior to mission	Ability to compose new effects webs at campaign time
Benefits	• Extends effective range • Increases engagement opportunity	• Enables faster integration and more diverse kill chains	• Allows pre-mission adaptation • More lethal, imposes complexity on adversary	• Adaptable to dynamic threat and environment • Scaling too many simultaneous engagements
Challenges	• Static • Long to build • Difficult to operate and scale	• Each architecture static limited ability to adapt • Cannot add new capabilities on the fly • Difficulty to operate and scale	• Static "playbook" • Limited number of kill chains • May not scale well	• Scaling limited by human descion makers

ent patterns to address different battlefield scenarios.

Table 1 shows DARPA's vision of the evolution of the "kill chain," the process from identifying a threat to neutralizing the threat. The legacy chains are distributed, meaning the identification, communication, decision and action functions happen in distinct locations. Battlefield philosophies have moved to a system-of-systems approach where the functions are distributed with parallel paths of fixed assets. The evolution to an "adaptive kill web" envisions a matrix with different assets capable of contributing to the identification, communication, decision and action functions and multiple paths through that kill chain matrix. While this allows more flexibility, it is still static, with only a fixed number of different paths.

The mosaic warfare concept envisions a web where the paths can be dynamically adjustable over time as battle conditions change. This end goal reflects a "more with less" philosophy that relies on technology and capability overmatch. By establishing this superiority, the U.S. believes it can conduct multiple military engagements anywhere in the world by quickly mobilizing and arranging mosaic tiles of functionality. Enabling this concept places challenging new requirements, from equipment to semiconductors. The equipment needs to be highly adaptable and scalable with the ability to network and process complex information quickly and efficiently. Semiconductors will need to operate at higher frequencies and bandwidths, with increased efficiency, linearity and processing capability.

CONCLUSION

The path forward for strategy, tactics, equipment and semiconductors is starting to come into focus, but geopolitical developments may change the course and pace of developments in the defense industry. China is becoming increasingly aggressive toward its neighbors in the South China Sea, particularly toward Taiwan. News agencies have reported record numbers of Chinese fighter jet and naval incursions into what China believes is its sovereign territory. U.S.-China trade sanctions and the ongoing semiconductor chip shortage have made Taiwan, the epicenter of Si semiconductor development, an attractive consolidation target in China's "one country, two systems" philosophy. We also learned recently that China launched a nuclear-capable, hypersonic, low altitude missile that circumnavigated the earth without detection.

While military capabilities in Afghanistan are not significant, the recent U.S. withdrawal and resulting instability left a power vacuum. With many of Afghanistan's neighbors in the Middle East and Southeast Asia having nuclear capabilities, countries looking to fill that power vacuum could add fuel to an already combustible situation. The concern is in a region known for instability and ongoing conflicts, added instability could have large ramifications.

We have not discussed the effects of the COVID pandemic because the defense supply chain has proven resilient. Of bigger concern is the global economic recovery. Defense spending links closely to a country's gross domestic product growth, so there will be implications for defense spending if economies recover more slowly than expected. The U.S. is facing a slightly different, yet important offshoot of this linkage. Massive U.S. government economic stimulus packages have spurred economic recovery from the pandemic, but the new U.S. administration appears to prioritize social programs over defense spending in its initial budget. It is still unknown whether longer term defense spending caps will remain in the budget as it makes its way through Congress, but we do expect a slight drop in 2022 defense spending until the priorities of the Biden administration become clearer.

Even though defense expenditures face some uncharacteristic turbulence, we are optimistic that the segment will continue to provide good opportunities for semiconductors. GaN will see fast growth, GaAs will remain competitive and Si analog and digital devices will account for the largest portion of the estimated $6.5 billion semiconductor device revenue in 2030. Systems and philosophies are undergoing rapid evolution, and the implementation of these new requirements will be enabled by semiconductor and component developments. With growth returning to historical averages, we expect to see a healthy defense industry, with many opportunities over the next 10 years. ■

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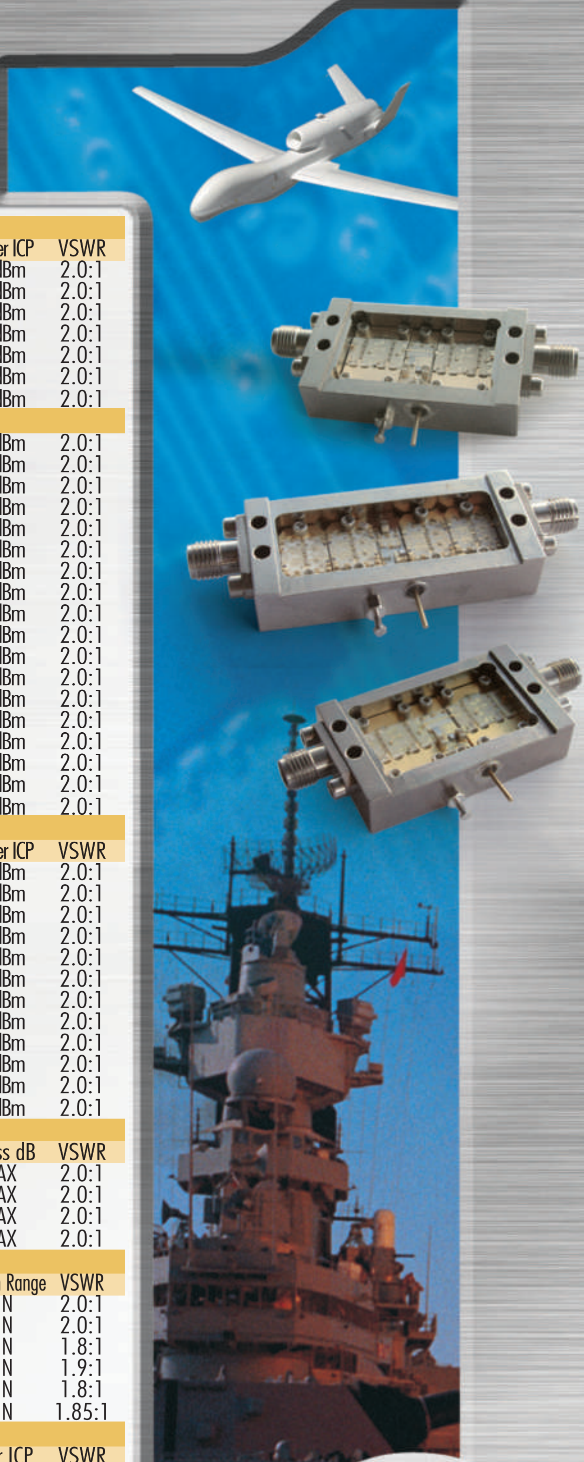

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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NGC Connects Warfighters to the Future

During a flight test of the U.S. Army's Integrated Air and Missile Defense Battle Command System (IBCS), developed by Northrop Grumman, data from Army, Air Force and Marine Corps sensors and weapons systems were fused on a network.

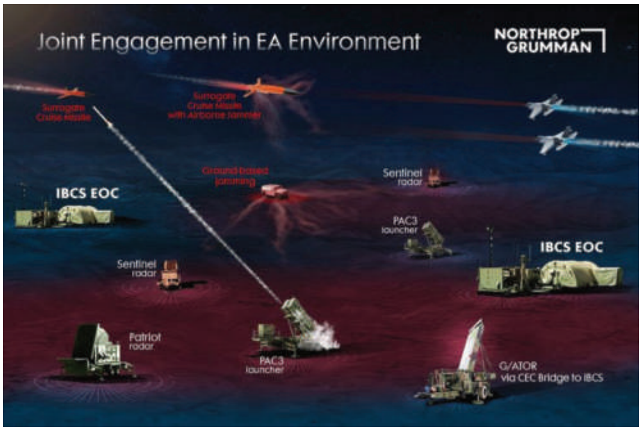
This capability demonstration enabled operators to connect any sensor with the best shooter to see, track and intercept a cruise missile target, despite a highly contested electronic attack environment that jammed some of the radars and would have otherwise denied the intercept. In addition, IBCS shared target flight track data with a Navy C2 system during the event.

The flight test was another in the system's long series of successful intercepts, but it was much more. It was proof of the Joint All-Domain Command and Control (JADC2) capabilities inherent in Northrop Grumman's modular open systems approach to C2 architecture—capabilities crucial to Department of Defense preparations for the battlespace of the future.

In that not-too-distant future, adversaries will threaten with advanced weapons from every domain—land, air, sea, space and cyberspace—and from every direction, all at the same time and potentially at hypersonic speeds. To prevail, it is now recognized by militaries across the globe that stand-alone networks must be more integrated to enable command and control of the full battlespace across domains and services. That connectivity will allow them to perform as a joint force, coordinating defense and strike strategies and saving every precious second.

Among Northrop Grumman's solutions to the broader demands of JADC2 is the innovative Joint Integrated Fires Command, Control and Communications system (JIFC3). It uses as a foundation the resilient, extensible MOSA architecture and incorporates new tools to help commanders quickly coordinate, deconflict and synchronize defensive and strike firing of missiles and other assets.

The approach creates a highly accurate common operating picture as sensors share data to create composite tracks of missiles or other threats that can be used by any effector or weapon system to engage them.



EA Environment (Source: Northrop Grumman)

General Dynamics Land Systems & Epirus Sign Agreement for Directed Energy Weapon

General Dynamics Land Systems (GDLS) and Epirus have teamed up to integrate a counter-drone swarm system on combat vehicles, according to a recent Epirus statement.

The agreement sets up a collaboration to integrate Epirus' Leonidas directed energy system and broader high-power microwave technology into the GDLS-manufactured U.S. Army Stryker combat vehicle and other ground combat vehicles to provide short-range air defense (SHORAD) capabilities, the statement said.

The U.S. Army recently fielded its first platoon of Stryker-based SHORAD systems to Europe. The service chose a team with Raytheon Technologies as the laser module provider to supply four SHORAD 50 kilowatt-class directed energy-capable Strykers.

But the Leonidas system integrated on a Stryker is meant to address drone swarms, not just singular drone threats, a rising problem for the U.S. military as it develops counter-unmanned aircraft systems capability.

The U.S. Army is set to begin development and integration in fiscal 2022 of a high-power microwave capability to destroy small drone threats. The Leonidas system is primarily designed to use high-power microwave capability to take out airborne drone swarms, but can also knock out vehicles and sea vessels, Bo Marr, the co-founder of Epirus, told *Defense News* in an interview.

Epirus has conducted multiple field demonstrations in an undisclosed location in the U.S. Southwest with attendees across the services observing Leonidas' capabilities. The company has demonstrated it is an all-weather system capable of handling below-freezing temperatures as well as very hot climates, according to Marr.

Leonidas (Source: Epirus)

For More Information

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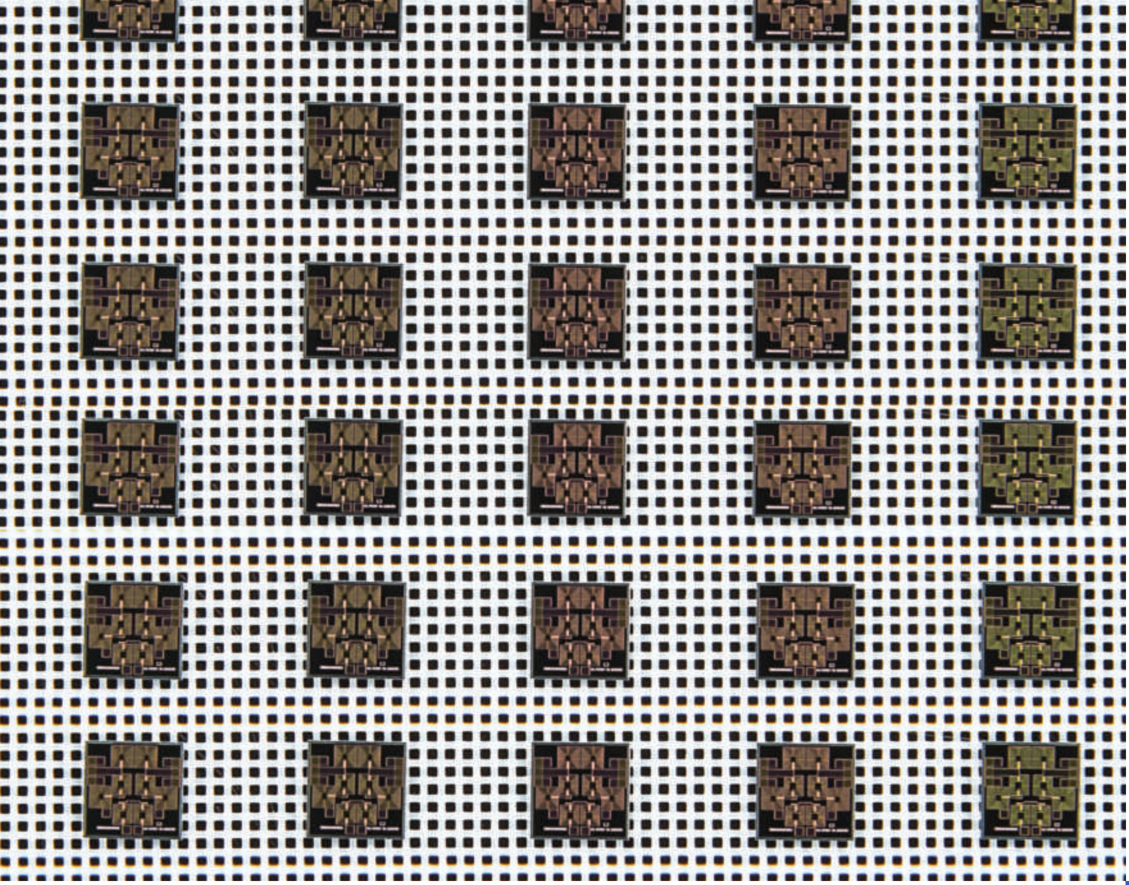
AeroVironment Successfully Demos Maritime Sensor-To-Shooter Capability

AeroVironment, Inc. recently completed a successful maritime demonstration of a Puma™3 AE small, unmanned aircraft system and Switchblade® 300 tactical missile system sensor-to-shooter capability as part of NATO REP(MUS) 21, Europe's largest maritime unmanned systems operational experimentation exercise, hosted at the Portuguese Navy Centre for Operational Experimentation held in Troia, Portugal. The experimentation was part of a U.S./U.K. Interoperability to Interchangeability initiative using unmanned/uncrewed systems.

A key component of the exercise was demonstrating the interoperability of multiple U.S./U.K. control system capabilities to facilitate the transfer through the Puma 3 AE comm relay connection of tactical control and planning tasks of interchangeable, cross-domain assets. This successful demonstration was the result of combined and coordinated efforts of coalition and industry partnerships.

Launched from the USNS Carson City, Puma 3 AE UAS served as an intelligence, surveillance and reconnaissance and targeting asset during the S2S exercise. Post launch, control of the Puma 3 AE was transferred to C-SCAPE, which was acting as the CCS on the USNS Carson City for this mission segment. Using its high-resolution Mantis i45 payload, the Puma 3 AE was used by military operators from the Maritime Operations Center, located in Troia, to positively identify the moving exercise target of interest. The target location was then digitally transferred from Puma 3 AE to a Switchblade 300 via S2S prior to its launch. The S2S functionality was witnessed by U.S. Navy personnel only.

As a demonstration of interchangeability, Switchblade 300 was then launched from a U.K. unmanned/uncrewed surface vessel, the Maritime Autonomy Demonstrator for Operational eXperimentation, and automatically flew to the fast-moving target using the coordinates provided. Once the target was in the field of view of Switchblade 300's optical sensors, the Switchblade 300 mission operator confirmed the target and engaged. During final target approach, Switchblade 300 was waved off just prior to actual engagement of the exercise target to effectively display its patented wave-off capability. Once the exercise was completed, the Puma 3 AE was autonomously recovered back onboard the USNS Carson City via the Precision Recovery System demonstrator while the ship remained underway and on course.



First Non-Cellular 5G Technology Sets Example of New Era Connectivity, Gets ITU-R Approval

In a pioneering decision, the industry's first non-cellular 5G technology standard was recognized by International Telecommunication Union's Radiocommunication Sector (ITU-R) and included as part of the 5G standards in IMT-2020 technology recommendation. Wirepas, a Finnish company on a mission to democratize IoT, is the key contributor to the new standard that sets an example of future connectivity: the infrastructure-less and autonomous, decentralized technology is designed for massive IoT networks for enterprises. It has no single points of failure and is accessible to anyone, costing only a fraction of the cellular networks both in dollars and in carbon footprint.

The new IoT standard, defined by ETSI, brings 5G to the reach of everyone as it lets any enterprise set up and manage its own network autonomously with no operators anywhere in the world. It eliminates network infrastructure, and single point of failure—at a tenth of the cost in comparison to cellular solutions. It also enables companies to operate without middlemen or subscription fees as well as store and consume the data generated in the way they see best fitting for them (on premises, in public cloud or anything in between).

Another democratizing aspect is the frequency. The new 5G standard supports efficient shared spectrum operation enabling access to free, international spectrums such as 1.9 GHz.

Technology-wise the new non-cellular 5G is built on completely different principles from cellular 5G. One of the biggest differences—and advantages—is the decentralized network. In a non-cellular 5G network, every device is a node, every device can be a router—as if every device was a base station. The devices automatically find the best route; adding a new device into the network routing works autonomously as well and if one device is down, the devices will re-route by themselves. It means reliable communication eliminating single point of failures.

The new 5G IoT standard is suited for businesses such as smart meters, Industry 4.0, building management systems, logistics and smart cities. It will assist in the urbanization, building and energy consumption in the construction of these smart cities. It also opens opportunities for new use cases, scaling at mass the levels of communication for the future. The energy transition from fossil fuels to electricity boosts the local renewable energy production and consumption market requiring new communication capabilities. This creates a circular economy and allows for the traceability of goods, raw materials and waste.

"This new 5G IoT standard has been the missing piece in the wide-scale adoption of IoT. We know today only 5 percent of things that will be connected, are connected. To connect the remaining 95 percent, we need to let go of how things have been done in the past and dare to go a different route. We see this new standard as the start of a new era for connectivity," Teppo Hemiä, CEO of Wirepas, concluded.

Developed by ETSI, the new 5G IoT standard, ETSI TS 103 636 series, is currently called DECT-2020 NR. The standard was published last year. The first product, Wirepas Private 5G, will be available in 2022.

5G Deployments Accelerate to Reach 2.6B Subscriptions in 2026

Despite a slight decline in the worldwide mobile subscriber base resulting from the COVID-19 pandemic, mobile network operators across different markets continue to expand 5G network deployments. By the end of 2020, 264 million subscriptions were achieved. ABI Research forecasts that the 5G market will continue to accelerate and reach 2.6 billion subscriptions, a significant contribution to mobile operator revenue of US$942 billion in 2026.

Driven by heavy investment of Chinese operators, China is the key contributor, holding more than two-thirds of the worldwide 5G subscriptions at present. The U.S. is second in 5G adoption with more than 50 million subscribers, followed by Japan and South Korea. "Operators' effort to expand 5G networks, combined with quickly increasing 5G smartphone penetration, will drive 5G subscriptions to reach 507 million at the end of 2021, almost double from 2020," commented Khin Sandi Lynn, industry analyst of ABI Research.

Alongside 5G network rollouts, mobile operators implement strategies to promote 5G adoption and boost revenue. Verizon launched its "5G upgrade campaign," a promotional program to encourage its customers to upgrade to 5G devices. China Mobile, launched a new set of applications such as 4K live streaming and cloud-based 5G games to drive the 5G user base and revenue. As the 5G user base continues to increase, some operators have witnessed improvement in mobile average revenue per user in recent quarters. Similarly, 5G network deployments for industry verticals such as healthcare, automotive and smart transportation and industrial applications are expected to drive mobile operator revenue in the years to come.

Mobile traffic, mainly driven by the need to stay connected during the pandemic, surged almost 60 percent to exceed 591 exabytes in 2020. "Increasing use of mobile networks to access video content, digital payments, online retail and video conferencing have been contributing to the traffic growth. Ongoing 5G rollouts will drive the adoption of higher data packages as well as the use of data intensive applications such as video

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streaming and gaming to fuel mobile traffic growth in the forecast period," Lynn explained. ABI Research forecasts that mobile traffic will expand more than 5x in 2026 compared to 2020. More than half of mobile traffic will be generated by 5G networks.

5G Connectivity is Fundamental to Europe Achieving Climate Targets

The accelerated rollout of 5G connectivity across Europe and the U.K. will have an immediate and catalyzing impact in reducing CO2e emissions, according to a new study commissioned by Ericsson.

As European nations ramp up efforts to address climate targets, a new Europe-wide analysis finds that implementing 5G technology across four high-emitting sectors—power, transport, manufacturing and buildings—could create 55 to 170 Mt of CO2e emissions savings per year, the same saving that would be achieved by removing 35 million cars. That is one in seven cars on Europe's roads.

The study reports that at least 40 percent of the EU's carbon reduction solutions, up until 2030, will rely on fixed-line and mobile connectivity. These solutions, such as the development of renewable energy generators, could reduce EU emissions by 550 Mt of CO2e, which is nearly half of the emissions created by the entire EU energy supply sector in 2017 and 15 percent of the EU's total annual emissions in 2017, the year chosen as a benchmark for the analysis.

> "At least 40 percent of the EU's carbon reduction solutions will rely on fixed-line and mobile connectivity."

Adding in the savings from applying 5G to the four high-emitting sectors would bring the total emissions reduction to nearly 20 percent of the EU's total annual emissions in 2017. The equivalent of the total annual emissions of Spain and Italy combined.

Despite the potential at stake, new forecasting of the 5G rollout from the annual Ericsson Mobility Report paints a concerning picture for Europe. At the end of 2020, 5G covered around 15 percent of the world's population. In 2027, just three years before global emissions will need to have halved to stay on track to limit global warming to 1.5°C, new forecasts predict that global rollout will still only be at around 75 percent.

Significantly, North America and Northeast Asia are estimated to enjoy more than 95 percent population coverage by 2027. In contrast, Europe is estimated to be significantly behind its economic competitors with more than 80 percent population coverage.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Rogers Corp. has announced its acquisition of **Silicone Engineering Ltd.**, a European manufacturer of Si material solutions based in Lancashire, U.K. Silicone Engineering expands Rogers' existing advanced Si platform and provides Rogers a European Center of Excellence to service customers requiring premium Si solutions for applications in the EV/HEV, industrial, medical and other markets. The transaction closed on October 8, 2021. Terms were not disclosed. Rogers' expects the transaction to be accretive to 2022 earnings per share. Trailing 12-month revenues for Silicone Engineering were approximately £30 million, and Silicone Engineering's profitability is comparable to that of the Elastomeric Material Solutions business unit.

Sivers Semiconductors AB has entered into an agreement to acquire 100 percent of the share capital of **Mix-Comm Inc.**, a U.S.-based mmWave challenger fabless semiconductor company, for an initial purchase price of USD 135M (approximately SEK 1,173 million) on a debt-free basis. The consideration will be paid through a combination of USD 22.5 million (SEK 196 million) in cash and USD 112.5 million (approximately SEK 978 million) in 39,335,664 newly issued Sivers shares based on the 10-day volume weighted average price of a Sivers share prior to signing of the agreement.

Naprotek LLC, a provider of high-reliability, quick-turn electronics manufacturing, has completed the acquisition of **SemiGen Inc.**, a privately held company based in Londonderry, N.H. This increases Naprotek's capabilities to include advanced RF/microwave products, assembly and test services and expands its reach across the U.S. Founded in 2009, SemiGen provides products and services to the RF/microwave community across markets including defense, satcom, space and advanced communications. Their products include passive and active semiconductor components ranging from attenuators, capacitors, diodes, filters and resistors to complex thin film circuits. Their manufacturing services span from RF/microwave and PCB assembly to performance testing and in-house ion beam foundry.

Orolia announced that it has entered into a definitive agreement to acquire **Seven Solutions**, a global innovator in White Rabbit sub-nanosecond time transfer and synchronization technology. This transaction is subject to customary closing conditions and approvals required by the Spanish government and is expected to close before the end of the year. The merger with the tech company based in Granada, Spain, will enhance Orolia's portfolio for defense, aerospace, data centers, telecom, financial services, smart grids and other critical infrastructure industries, and will enable the next generation applications dependent on ultra-precise, resilient timing and frequency technology.

Akoustis Technologies Inc. announced that it is acquiring a 51 percent majority ownership position of **RFM Integrated Device Inc.**, with the right to purchase the remaining 49 percent in 2022. Akoustis will host an investor call to provide a business update and outlook, followed by a Q&A session. The conference call will be webcast live on the company's website and will be available for playback. Akoustis intends to leverage its leadership in high frequency BAW with RFMi's growing portfolio of RF filter products to expand its reach into multiple markets and grow its portfolio of multi-chip-modules. Akoustis also intends to leverage RFMi's WLP products which are currently made in factories certified to the IATF16949 automotive quality standard.

Guerrilla RF Inc. announced it has raised more than $7 million in the initial closing of a private placement offering as well as the completion of a reverse merger transaction. Founded in 2013, Guerrilla RF is a supplier of MMICs which target wireless infrastructure applications, including 5G and automotive. The company has a well-established revenue stream with 2020 sales totaling $8.09 million. Despite the disruption caused by COVID-19, Guerrilla RF has continued to thrive with sales increasing by 990 percent over the past three years.

COLLABORATIONS

Anritsu Corp. announced that **Autotalks**, a vehicle-to-everything (V2X) communication solutions provider, has endorsed its RF calibration and validation test based on Anritsu's Universal Wireless Test Set MT8870A. The test solution supports all Autotalks Cellular-V2X (C-V2X) chipsets designed for advanced safety use cases. Anritsu's MT8870A long-established measurement methodologies enable customers to address all wireless technologies required for autonomous driving system and lower cost-of-test from early development through mass production.

General Dynamics Land Systems (GD), a global leader in providing innovative, high technology and next-generation ground combat solutions to customers, announced a strategic teaming agreement with **Epirus**, Inc., a high-growth technology company developing directed energy systems that enable unprecedented counter-electronics effects. GD and Epirus will collaborate to integrate the Leonidas directed energy system and broader high-power microwave technology into the U.S. Army's Stryker and other manned and autonomous ground combat vehicles for enhanced mobile short range air defense (SHORAD) capabilities. In addition to Stryker upgrades, the company also is developing a class of robotic combat vehicles that feature modular architecture to maximize scalability and support future mission needs.

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Around the **Circuit**

IQE plc, a global supplier of advanced compound semiconductor wafer products and material solutions to the semiconductor industry, announced the commencement of a long-term strategic collaboration with **GlobalFoundries® (GF)** to develop vital GaN on Si technologies for mobile and wireless infrastructure applications. GF is a global leader in feature-rich semiconductor manufacturing and the result of this collaboration will be a GaN on Si offering at GF's Fab 9 facility in Burlington, Vt., using wafers supplied by IQE. Due to its unique material properties, GaN is the material of choice for high-power, high frequency applications and the global deployment of 5G networks has relied heavily on the use of such GaN technology.

LitePoint announced a collaboration with **Microchip Technology Inc.** to deliver simplified design validation and turnkey manufacturing test solutions for next-generation IoT systems, based on Microchip's Bluetooth and Wi-Fi chipsets. As part of the collaboration, LitePoint has released a version of its IQfact+™ test automation software tailored for Microchip's new WFI32E01 series of Wi-Fi MCU modules. LitePoint's IQfact+ is a turnkey, chipset-specific test development software that enables rapid-volume manufacturing with minimal engineering effort. With IQfact+, wireless system developers get access to proven software that enables control of devices under test and the test system with calibration routines that are uniquely optimized to reduce time and maximize throughput.

HCH, a subsidiary of **Haier**, has partnered with **Vayyar**, an Israeli high-tech company and leader in RF imaging, to create a new IoT ecosystem built around the industry's most advanced touchless sensor technology. Haier's huge marketing presence in China will enable Vayyar to expand its footprint and offer disruptive RF imaging-based products that will define the standard of care in China. The strategic relationship has been initially established to benefit rapidly aging populations in China and beyond, for whom falling is a leading cause of injury and premature mortality. Around 120 million Chinese seniors live alone and by 2040, there will be 402 million people aged 60 or older in China.

Verizon Communications Inc. and **Project Kuiper**, an advanced low earth orbit (LEO) satellite network from Amazon.com, Inc., announced a strategic collaboration to develop connectivity solutions for unserved and underserved communities. As part of the collaboration, Project Kuiper and Verizon have begun to develop technical specifications and define preliminary commercial models for a range of connectivity services for U.S. consumers and global enterprise customers operating in rural and remote locations around the world. Project Kuiper is an initiative to increase global broadband access through a constellation of 3,236 LEO satellites around the planet.

NEW STARTS

Passive Plus Inc. has launched a brand-new website, www.passiveplus.com, with a sleeker design and a more user-friendly interface showcasing PPI's product offering and technical resources. Included on the website is a new engineering tool—C.A.P. or Capacitor Application Program, www.passiveplus.net. C.A.P. allows engineers to insert capacitor requirements (cap value, frequency) producing scattering matrices, ESR, Q & Impedance charts and data sheets according to the engineer's specifications. Component information, such as series datasheets, S-Parameter data and Modelithics® Modeling Data can also be found on the website.

ACHIEVEMENTS

Keysight Technologies Inc. announced it is first to gain approval from the **Global Certification Forum** (GCF) for 5G new radio protocol conformance test cases based on 3GPP Release 16 (Rel-16) specifications. The industry milestone, confirmed at the conformance agreement group meeting held in October, enables device vendors to accelerate verification of designs that support 3GPP Rel-16 features. Implementation of 3GPP Rel-16 improves 5G network coverage, capacity, security and latency, as well as 5G device power consumption, mobility and reliability. Keysight continues to support a leading number of 5G RF, RRM and protocol conformance test cases mandated by GCF.

NXP® Semiconductors announced a new automotive wireless charging reference design, the first to be certified by the **Wireless Power Consortium** (WPC), the global standard development body for wireless power, for its new Qi 1.3 standard. The reference design consists of a Qi-certified board with an NXP wireless charging MWCT family MCUs, as well as optional NFC, secure element and CAN/LIN transceiver. The solution also features a software package that includes NXP's wireless charging Qi 1.3 software library and a complete suite of customizable software solutions that help make it easier for developers to bring a Qi-certified wireless charger to market.

In 1971, the foundations for a success story were laid: Wolfgang Karl and Werner H. Heilmann jointly founded **INGenieur Union** (engineer union) in Constance and began producing spring-loaded test probes and the first test fixture systems. What began with seven employees has developed into an internationally successful company. Today, more than 400 people in over 65 countries work for **INGUN** worldwide. Even 50 years after its foundation, the company produces exclusively at its headquarters in Constance. Made in Germany is one of their guiding principles. At 50years.ingun.com, the company not only looks back at its past, but also presents its new corporate design and gives an outlook on where the company is heading in the future.

Gel-Pak, a division of Delphon and worldwide leader in protective carriers for semiconductor, optoelectronic and medical devices, was honored earlier this month with an East Bay Innovation Award for its new Lid/Clip Super System LCS2TM. More than 200 nominees from across Northern California's Alameda and Contra Costa

Counties were highlighted at an awards ceremony, during which the winners were announced. Developed in partnership with global military electronics manufacturer **BAE Systems**, Gel-Pak's LCS2 product protects thin semiconductor and compound semiconductor chips by preventing them from migrating out of the pockets of waffle pack chip trays during shipping and handling.

EM Solutions, a Brisbane, Australia-based subsidiary of Electro Optic Systems Holdings, has completed development of its new satellite terminal antenna diversity system (ADS) by achieving **Wideband Global SATCOM** (WGS) certification, allowing it to be used with terminals accessing the military WGS. The ADS is able to automatically sense and switch traffic between dual antennas when one of them is blocked from satellite view, and it can split traffic between the dual antennas—even to different satellites—when both have satellite visibility. The system has previously been certified for operation on the commercial Inmarsat GX network.

CONTRACTS

Leonardo DRS announced that it has been awarded a position on a **U.S. Air Force** contract to build range electronic warfare threat systems for combat training, under the Range Indefinite-delivery/Indefinite-quantity Support Effort (RISE). The contract is worth up to $950 million over five years. Under the contract, awardees will provide technology prototyping, production, sustaining engineering and additional technology demonstration activities to support the build of range threat systems for training use. The company's electronic warfare threat simulators range in size and complexity from hand-held, low-cost radar warning receiver simulators, to full effective radiated power fifth generation digital threats.

Thales has been awarded its first delivery order from the **U.S. Army** to provide the AN/PRC-170 Javelin Radio. Under the Army Single Channel TSM Radio program, and in support of Capability Set fielding's into the integrated tactical network, the AN/PRC-170 Javelin is ideally suited to expand reliable and affordable voice, data connectivity and streaming video to the tactical edge. Under this award, and in partnership with the U.S. Army, Thales is delivering the smallest form factor TSM, Mobile Ad-Hoc Networking (MANET) capable radio. This enables Warfighters to have increased flexibility in multi-domain operations and ensures a modern, highly resilient tactical network.

AiRANACULUS®, a private, Mass.-based technology company providing early stage research, development, prototyping and consulting services, announced it has been awarded a **NASA Small Business Innovation Research Phase I** contract for development of an advanced space communications architecture to support upcoming missions to the moon and Mars. The contract contributes to the NASA Space Communication and Navigation (SCaN) program's objectives to dramatically increase the performance, efficiency and reliability of

mission communications networks. Overcoming challenging network requirements could benefit the Artemis program, NASA's plan to land the first woman and the next man on the moon in 2024 and establish a sustainable presence by the end of the decade.

PEOPLE

Filtronic plc announced that it has appointed **Dr. Tudor Williams** as director of Technology. Dr. Williams joins Filtronic from the Compound Semiconductor Applications (CSA) Catapult, where he had been head of RF and Microwave for the past four years and interim technical director since the start of 2021. Tudor has a degree in Electronic and Communications Engineering from the University of Wales, Swansea, and a Ph.D. in RF Engineering from Cardiff University. He also previously worked at SELEX as a MMIC design engineer and at Mesuro as an engineer and engineering manager, leading U.K. R&D strategy. During his career he has engaged with many of the major defence primes, government departments and global semiconductor players.

Southwest Microwave Inc. announced the appointment of **Don Bradfield** as president by the company's board of directors, effective immediately. Based at the company's Tempe, Ariz., headquarters, Bradfield will oversee domestic and international operations of the Security Systems and Microwave Products Divisions, including Southwest Microwave, Ltd., located in Worcestershire, U.K. In his previous role as general manager of the company's Microwave Products Division, Bradfield expanded the manufacturing operation, introduced a range of new high frequency connectors for specialized aerospace and military applications and oversaw NIST and ITAR compliance initiatives.

QuadSAT's Senior RF Engineer **Dr.-Ing. Cosme Culotta-López** will be serving as a technical coordinator on the board of directors of the Antenna Measurement Techniques Association (AMTA) from January 2022. Culotta-López has been an active member of AMTA since 2017 and has been awarded with Best Paper Awards from AMTA in 2019 and 2021. AMTA is a non-profit, international organization dedicated to the development and dissemination of theory, best practices and applications of antenna, radar signature and other electromagnetic measurement technologies. Culotta-López's plans, according to his position statement, will specifically focus on academia, engaging with the research community in universities and other public research institutions to further involvement with AMTA.

REP APPOINTMENTS

Richardson Electronics Ltd. announced a new global distribution agreement with **Maury Microwave**. Since its founding in 1957, Maury Microwave has served as a trusted technology solutions partner to many of the world's leading manufacturers in the wireless technology chain, including companies serving RF demand in defense, space and commer-

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PLACES

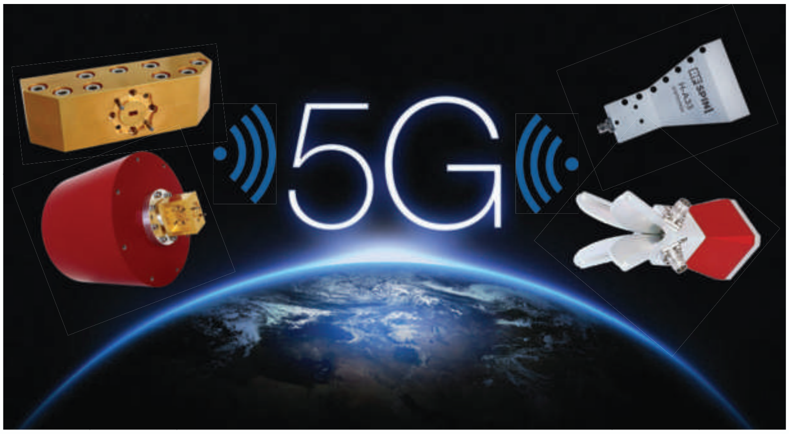
AmpliTech Group Inc. announced plans to relocate its existing manufacturing locations and headquarters into a new, expanded 20,000 square-foot facility on Long Island. AmpliTech has leased the facility, located at 155 Plant Avenue, Hauppauge, N.Y., for an initial seven-year term. The new facility substantially expands AmpliTech's existing 13,100 square-foot footprint and combines, for the first time, the company's design, engineering and sales and marketing teams under one roof, enabling greater collaboration, operational efficiency along with significant room for growth. This new facility will incorporate a state-of-the-art enhanced class 10K clean room to support production of the company's space-grade products.

UL, the global safety science leader, announced that it will open expanded electromagnetic compatibility (EMC) and wireless laboratory in Carugate, Italy. The enhanced facility will feature an end-to-end service solution for EMC and wireless testing for a wide range of industries, including consumer electronics, information technology equipment, telecommunications, medical, industrial, lighting and small and large appliances. UL's EMC-Wireless laboratory expansion will allow for an increase in testing capabilities for wireless professional appliances, connected industrial devices as well as connected consumer medical and in vitro diagnostic devices. It will also increase testing capacity and speed, thanks to multiple equipment and facility upgrades.

Northrop Grumman Corp.'s continued investment in the future of defense microelectronics systems takes another leap forward with the creation of its "Micro-Line" (µ-Line) in Apopka. The company's new µ-Line establishes a wafer post-processing and test source tailored for defense applications. The µ-Line facility for semiconductor wafer post-processing provides Northrop Grumman with an assured source for the development and production of critical microelectronics packaging technologies. Products processed at the µ-Line will serve as essential building blocks to some of the world's most advanced RF and electro-optic infrared defense systems. The µ-Line offers a complete suite of back-end wafer post-processing capabilities, including passivation, solder bumping, dicing, advanced inspection and test for up to 300-mm (12-inch) wafers.

THE FUTURE OF COMMUNICATION

For those who have noticed slow video streaming or download rates for their large digital files on their smartphone or other mobile communications device working on 4G LTE, 5G is the answer. It operates within many of the frequency ranges as 3G and 4G LTE, but it provides much-needed bandwidth for growing numbers of worldwide wireless users and their applications. 5G can be implemented in low-band, mid-band or high-band millimeter-wave 24 GHz up to 54 GHz.



Waveguide transmission lines not only handle more power with much less loss at millimeter-wave frequencies than coaxial cables, but when interconnected to waveguide horn antennas they can combine for the high gain, typically 25 dBi or more at mid-band for even "standard-gain" waveguide horn antennas, and the outstanding directivity needed to maintain line-of-sight (LOS) links at millimeter wave frequencies. Moreover, waveguide horns are also physically small enough to be total unobtrusive within the many indoor 5G infrastructure setups.

When 5G links require even more gain, top component suppliers such as **Impulse Technologies** are ready with high-gain waveguide horn antennas from innovative developers such as Anteral and RF Spin. With waveguide horn antennas, millimeter waves will be the future of 5G.

57%

5G Network technology is projected to cover 57% of the market worldwide by 2025.

3 BILLION

By 2025, there is projected to be 3 billion 5G mobile subscriptions.

Anteral releases a High Performance Diplexer for 5G E-band Backhaul Systems with point-to-point radio links at 71/76 GHz and 81/86 GHz and can deliver up to 10 Gbps in a dense radio environment. The technology used makes it less sensitive to manufacturing tolerances, which is perfect for mass production. Its fabrication robustness makes this diplexer ideal for industrial applications. Anteral also provides a Dual Polarized Lens Horn Antenna for 5G & 6G (E & D-Band) Backhaul Systems ideal for High-Gain Lens Horn Antennas.

RF Spin offers the QRH50E antenna, which is an enhanced version of the broadband bestseller that helps hundreds of the world's leading players develop, test, and deploy 5G networks. This is an advanced antenna with exceptional technical parameters and excellent design in aluminum alloy with a frequency range of 5 GHz to 50 GHz. As part of their ongoing efforts to provide cutting-edge tools for the development, testing and implementation of advanced 5G networks, RF Spin launches a pyramidal horn antenna (H-A33) with a frequency range of 22 GHz to 33 GHz.

Impulse Technologies will provide you with the most innovative components and the latest technology to keep you up to speed. To learn more please contact **mleone@impulse-tech.com.**

ANTERAL IMPULSE TECHNOLOGIES INC. AN INTERNATIONAL PROCUREMENT COMPANY RF SPIN

INVITED PAPER

RF MEMS Switch Performance in Extreme Environments

Jonathan Leitner
Menlo Micro, Irvine, Calif.

RF MEMS switches have proven their capability to operate under extremely harsh temperature, shock and vibration environments, debunking the longstanding belief that they are not robust enough to provide the operating life for demanding applications.

When micro-electromechanical systems (MEMS) technology was first released in production devices, it did not take long before it displaced some legacy technologies. Today, it represents a global market potential of at least $12 billion, growing at a rate of more than 9 percent per year. Until recently, however, RF switching, a major application, remained challenging. A dozen companies spent two decades working unsuccessfully on RF MEMS development. After a different approach, RF MEMS switches are now more robust than other switching technologies and can deliver better performance in harsh environments and extreme operating conditions. These advances are timely, as virtually every market seeks components that are smaller, lighter and consume less power, can be produced in high volume and are cost-effective. They must also have long operating lifetimes, even when exposed to broad and varied temperatures, shock, vibration and other stressing environments.

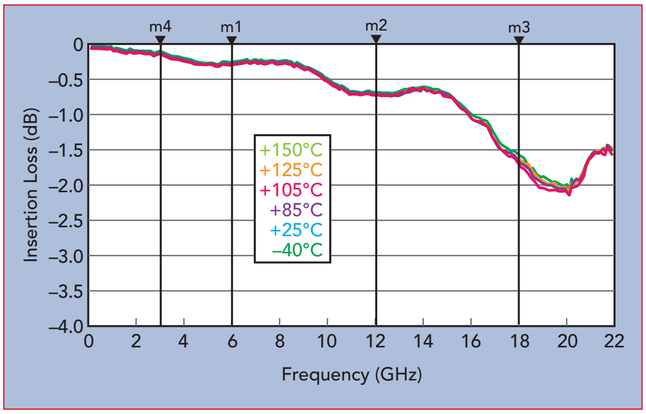


Fig. 1 MM5130 MEMS switch insertion loss vs. temperature.

Although the electromechanical relay (EMR) is comparatively slow, large, heavy, consumes more DC power and has a short operating life, it remains widely used and a mainstay of automated test, telecommunications, defense and other applications. Active thermal management, such as fans, heat pipes and heatsinks, are often required to ensure electronic components can operate and survive in extreme environments, which increases system cost and complexity. EMRs are also challenging for small platforms, where power consumption, size and weight are critical.

For example, a fighter aircraft may have hundreds of RF switches and EMRs that collectively occupy an outsized amount of space and weight for their function and take up hundreds of Watts of power. Built from discrete devices, relays are not particularly fast. In contrast, multiple EMRs can be replaced by MEMS switches in a 2.5 × 2.5 ×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0.9 mm chip-scale package. Even when used in large switch matrices, MEMS switches consume less DC power than a single EMR. A MEMS switch is 1,000x faster and at least 90 percent smaller, consumes virtually no power and can survive more than 3 billion switching operations, even handling relatively high incident RF power.

Although solid-state switches are small, fast and reliable, they consume more power than a MEMS switch and generate heat, requiring thermal management such as heat sinks. Semiconductors are never fully "off," and the leakage currents consume power. Although engineers have been working to overcome the shortcomings of both RF EMRs and solid-state switches for years, the improvements have been a series of compromises rather than an "ideal" solution.

MEMS SWITCH DESIGN

One MEMS switch solution that is viable for RF applications resulted from the initial research conducted by General Electric and spun out in a startup company, Menlo Micro. Menlo Micro is developing MEMS switches for RF and power systems, aiming to create an "ideal" switch, i.e., a high performance switch that can operate in extreme environments without sacrificing performance. Menlo Micro's MEMS switch employs a proprietary fabrication process using electrodeposited alloys, resulting in an electrostatically actuated beam/contact structure that combines mechanical properties like Si's with the conductivity of metal. Menlo's deposition and fabrication process is very similar to standard CMOS, so the switches can be manufactured in high volume, and they scale for voltage, current and power handling. The fabrication process uses through-glass via packaging: short, metalized vias, which eliminate wire bonds and significantly reduce switch size. For RF and microwave applications, this reduces the package parasitics by more than 75 percent, achieving good performance to 26 GHz for Menlo's current switch portfolio, with future devices being designed to exceed 60 GHz.

Another benefit of the MEMS switch is its ability to operate in extended thermal environments—temperatures from -40°C to +150°C—with minimal variation in RF performance. Measurements of Menlo's highest bandwidth production switch, the MM5130, confirm this: insertion loss varies only 0.05 dB over temperature, as shown in ***Figure 1***. This enables Menlo's switches to be used in extremely cold applications, such as liquid nitrogen baths at -196°C and quantum computing dilution fridges at 10 mK.

These MEMS switches solve the problem of metal fatigue, which plagued previous developments. The extremely low mass of the switch beam/contact results in reliability far greater than the reliability of EMRs, with superior resistance to shock and vibration. A Menlo Micro switch, for example, exceeds

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the IEC 60601/60068 standard and passes MIL-STD 810G/H stresses for vibration and shock. It also maintains consistent RF performance when subjected to extreme temperature, shock, vibration and RF power.

MEASURED PERFORMANCE

Menlo Micro has made many measurements to validate the RF performance and environmental ruggedness of its MEMS technology. One test evaluated whether the switches suffer from inadvertent opening and closing of the actuator while undergoing extreme shock and vibration. The test setup (see ***Figure 2***) monitored the switch during stress and analyzed the performance for any unexpected open or close transients. Four specific tests were conducted:

- IEC 60601/60068 standard in the X, Y and Z axes for 30 minutes
- MIL-STD-810G random vibration in the X, Y and Z axes for 30 minutes
- MIL-STD-810H random vibration in the Z axis
- Vibration testing in 6 dB increments above MIL-STD-810H to the maximum level of the vibration table (62 Grms).

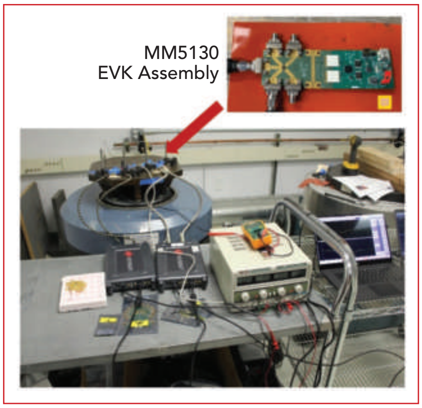

Fig. 2 Setup for shock and vibration testing.

These measurements showed no performance degradation during stress or at the post-stress verification, exceeding the performance requirements of the IEC 60601/60068 standard and MIL-STD 810G/H. One common RF coaxial EMR subjected to the same stress profile failed MIL-STD-810G during the Y-axis test.

In another test, the switches were subjected to accelerated life conditions for mechanical ruggedness (see ***Figure 3***). With Menlo Micro's current beam/contact alloy, a thermal stress of 300°C was required to deform the beam to failure, demonstrating the MEMS operating lifetime is more than a decade under high mechanical and thermal stress. This is shown by the MM-0 curve in Figure 3(b). Traditionally, gold has been used for many MEMS switches and, because of the nature of the metal, a gold-based beam structure exhibits rapid deformation at high temperature and pressure, which is also shown in the figure. Menlo Micro is developing a new alloy process to extend the lifetime of the beam/contact beyond a decade (see MM-2 in Figure 3).

To evaluate performance changes over temperature, switches were subjected to temperature testing while "on" (i.e., with the contact


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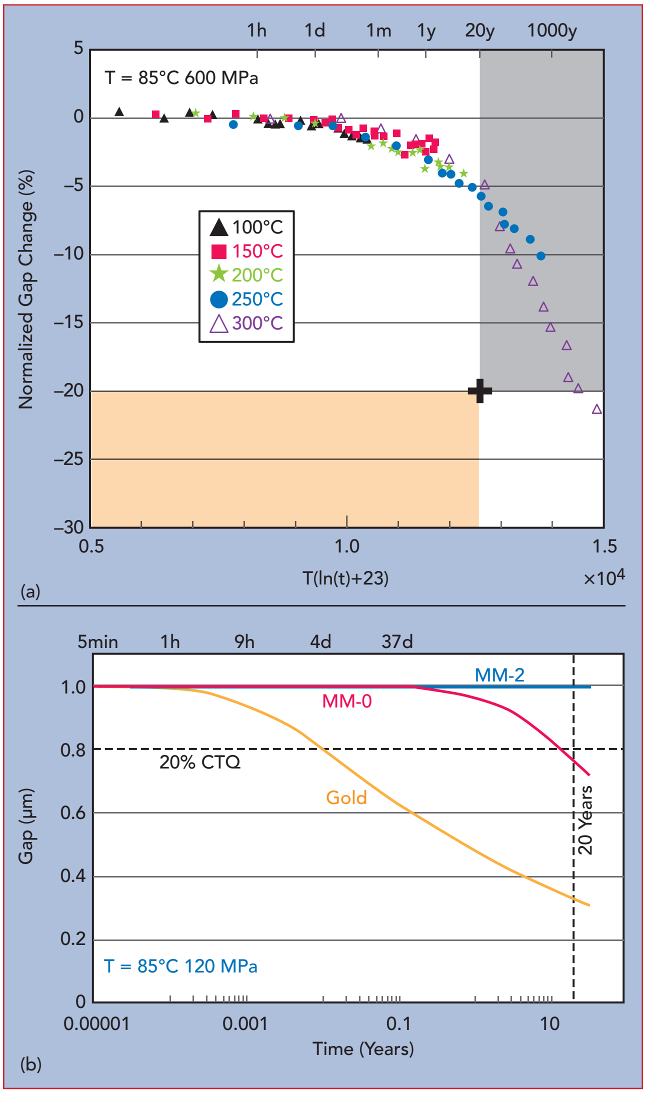


Fig. 3 MEMS switch beam alloy accelerated mechanical life test (a) and performance (b).

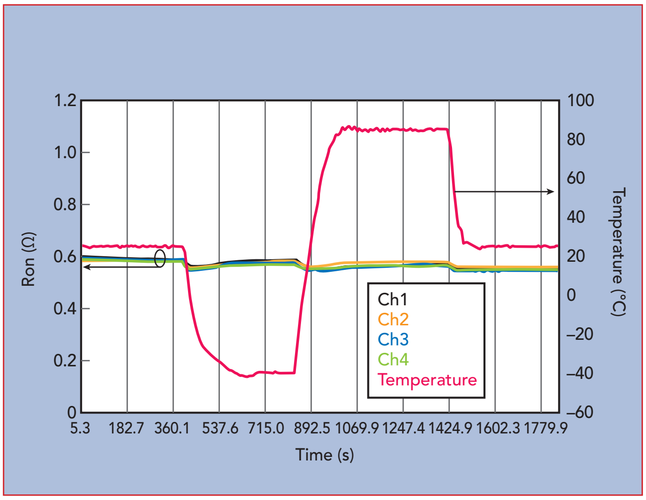
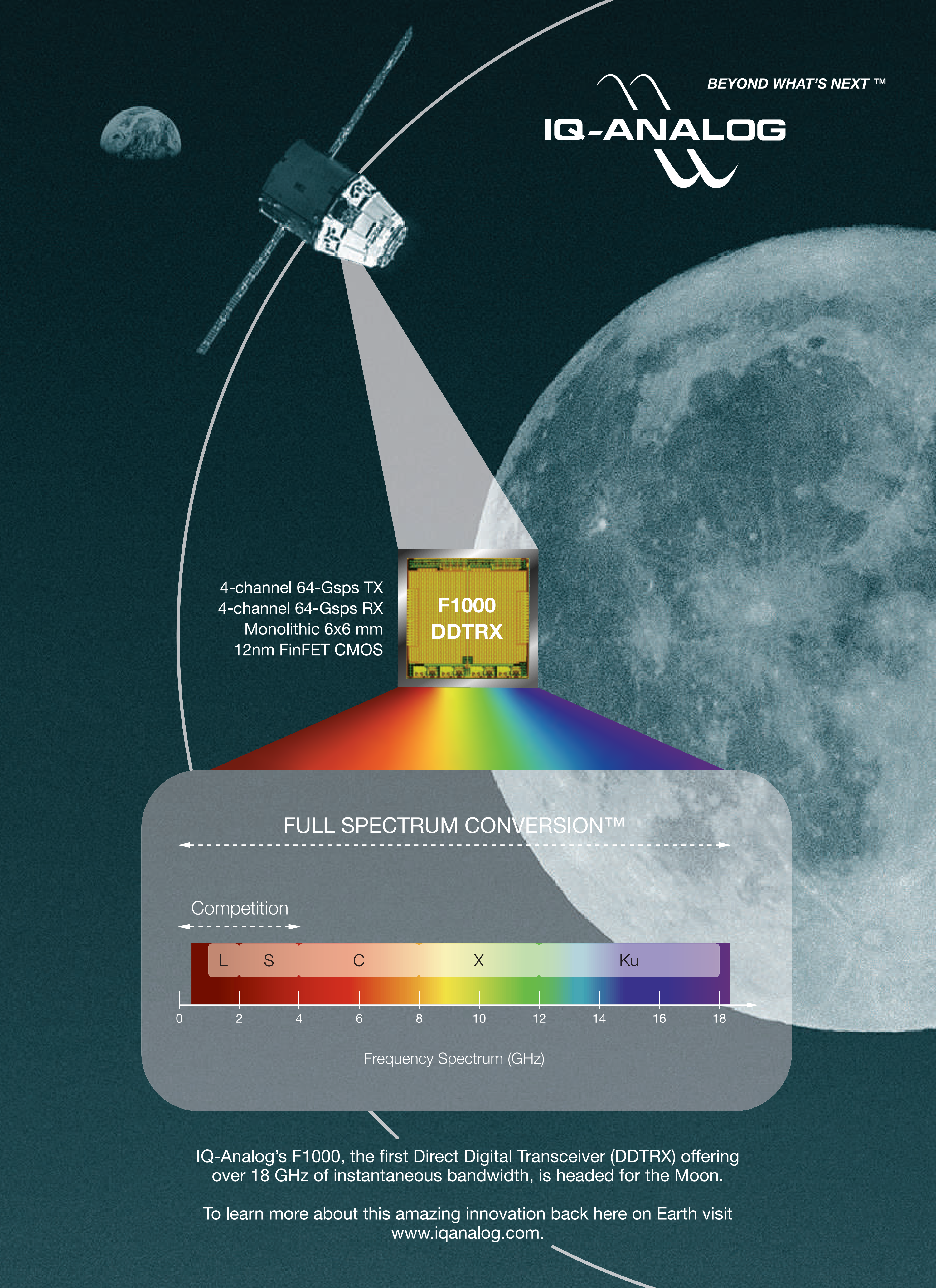


Fig. 4 Ron change during a temperature cycle from –45°C to +85°C.

down). The "on" resistance, Ron, was measured during a thermal cycle from -45ºC to +85ºC. ***Figure 4*** shows the change in Ron in four switch channels was barely discernible. To determine operation at extraordinarily cold temperatures, the switch was tested in a bath of liquid nitrogen at -196ºC (77 K). The switch performed normally without a substantial degradation in performance.

SUMMARY

The performance advantages of MEMS switches for RF applications have been demonstrated during the past several years, as devices have become commercially available in substantial volume. This article has addressed the suitability of MEMS switches in applications with challenging temperature, vibration and shock environments, showing that the mechanical, metallurgical and fabrication process of Menlo Micro's beam/contact technology is rugged, confirming MEMS technology suitable for high reliability and long life applications. ■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2 to 6 GHz, 4 × 4 and 8 × 8 Butler Matrices Based on Slot-Coupled Technology and a Flexible Design Method

Yao Li, Xiao-Wei Zhu, Ling Tian and Rui-Jia Liu
School of Information Science and Engineering, Southeast University Nanjing, China

Wideband (2 to 6 GHz) 4 × 4 and 8 × 8 Butler matrices without crossover circuits are implemented on a three metal-layer structure using hybrid couplers and phase shifters realized with elliptically-shaped coupling structures. A flexible design method for phase compensation is used based on the spacing of the hybrid couplers. Measurements agree with simulation, demonstrating the amplitude and phase performance of the ports. Compared to other Butler matrix configurations, the elliptical coupling structure without crossover circuits has an ultra-wide bandwidth of several octaves.

Butler matrices are used in a wide variety of antenna feed applications, such as beamforming networks. Conventional microstrip line Butler matrices[1-4] use crossover circuits, which are relatively narrowband and difficult to rout. Abbosh[5,6] and Bialkowski[5] describe an elliptical slot-coupled technology for the required 90-degree hybrid couplers and phase shifters. The slot-coupled technology is appropriate for broadband devices, and the multi-layer structure is helpful for designing Butler matrices without crossover circuits.[7-9]

In this work, wideband (2 to 6 GHz) 4 × 4 and 8 × 8 Butler matrices were designed based on slot-coupled technology. A flexible design method for phase compensation was used based on the spacing of the hybrid couplers. Accordingly, each component—the 90-degree hybrid couplers, phase shifters and phase-compensation circuits—can be individually simulated and optimized. Measurement results demonstrate a fractional bandwidth (FBW) of 100 percent.

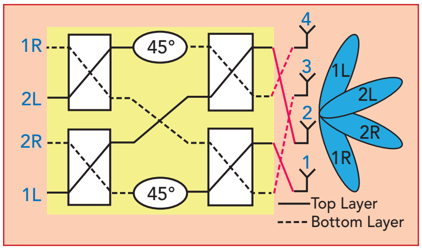

Fig. 1 **4 × 4 Butler matrix.**

BUTLER MATRIX ARCHITECTURES

The Butler matrix is widely used in analog beamforming networks and is composed of N inputs and N outputs. In this article, N is 4 or 8. The number of 90-degree hybrid couplers equals (N/2) $\log_2 N$, and

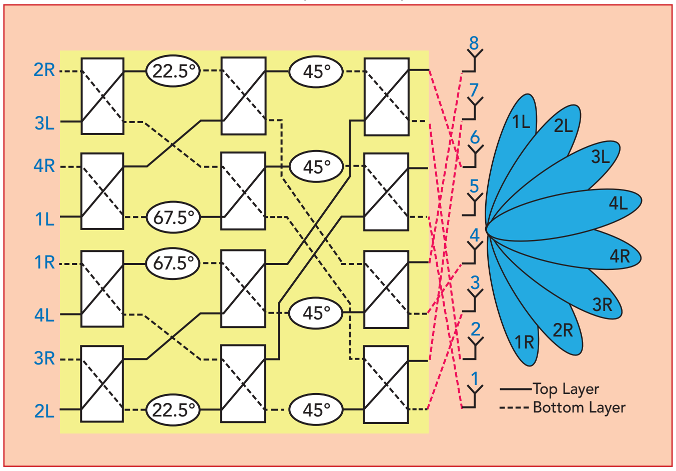

Fig. 2 **8 × 8 Butler matrix.**

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TABLE 1

4 × 4 BUTLER MATRIX IDEAL ANTENNA EXCITATION CURRENTS

Beams	1L	2L	2R	1R
ANT1	1∠0°	1∠0°	1∠0°	1∠0°
ANT2	1∠135°	1∠45°	1∠-45°	1∠-135°
ANT3	1∠-90°	1∠90°	1∠-90°	1∠90°
ANT4	1∠45°	1∠135°	1∠-135°	1∠-45°
Differential Phase	135°	45°	-45°	-135°

TABLE 2

8 × 8 BUTLER MATRIX IDEAL ANTENNA EXCITATION CURRENTS

Beams	1L	2L	3L	4L	4R	3R	2R	1R
ANT1	1∠0°	1∠0°	1∠0°	1∠0°	1∠0°	1∠0°	1∠0°	1∠0°
ANT2	1∠157.5°	1∠112.5°	1∠67.5°	1∠22.5°	1∠-22.5°	1∠-67.5°	1∠-112.5°	1∠-157.5°
ANT3	1∠-45°	1∠-135°	1∠135°	1∠45°	1∠-45°	1∠-135°	1∠135°	1∠45°
ANT4	1∠112.5°	1∠-22.5°	1∠-157.5°	1∠67.5°	1∠-67.5°	1∠157.5°	1∠22.5°	1∠-112.5°
ANT5	1∠-90°	1∠90°	1∠-90°	1∠90°	1∠-90°	1∠90°	1∠-90°	1∠90°
ANT6	1∠67.5°	1∠-157.5°	1∠-22.5°	1∠112.5°	1∠-112.5°	1∠22.5°	1∠157.5°	1∠-67.5°
ANT7	1∠-135°	1∠-45°	1∠45°	1∠135°	1∠-135°	1∠-45°	1∠45°	1∠135°
ANT8	1∠22.5°	1∠67.5°	1∠112.5°	1∠157.5°	1∠-157.5°	1∠-112.5°	1∠-67.5°	1∠-22.5°
Differential Phase	157.5°	112.5°	67.5°	22.5°	-22.5°	-67.5°	-112.5°	-157.5°

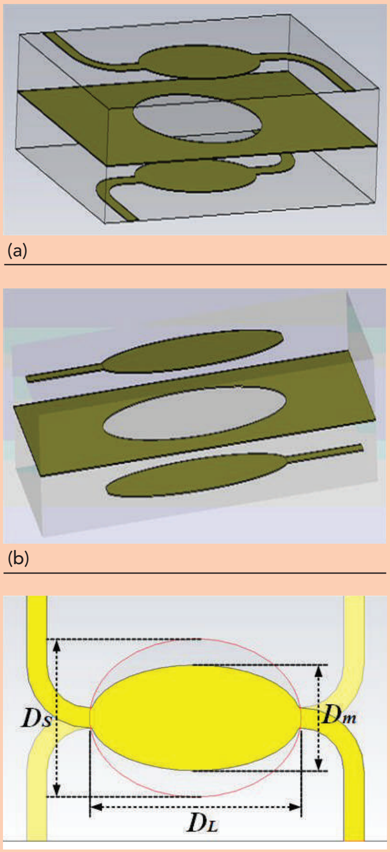

Fig. 3 Elliptical coupling structures: hybrid coupler (a), phase shifter (b) and dimensions (c).

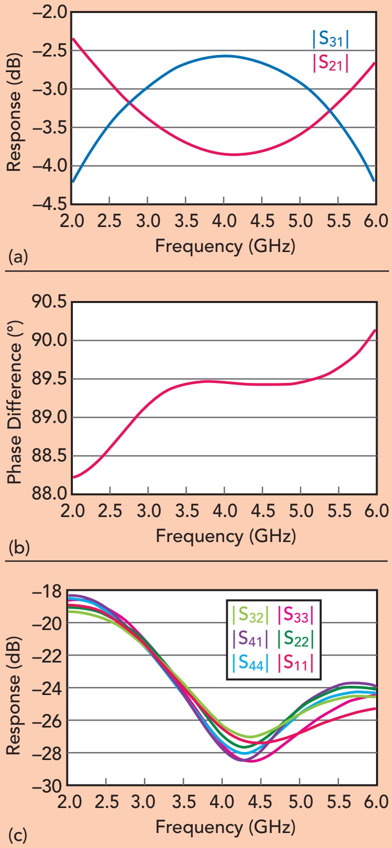

Fig. 4 Simulated transmission (a), phase (b), isolation and reflection (c) characteristics of the 90-degree hybrid coupler.

the number of 45-degree phase shifters is $(N/2)\ [\log_2 N-1]$. One of the N inputs produces uniform amplitudes at the output ports with a determined phase difference.[7] The phase difference between output ports is different for every input port excitation; with four or eight specific values of the phase differences, the antenna array in a switched beamforming system synthesizes four or eight corresponding beams evenly pointing in different directions. The architectures of the 4 × 4 and 8 × 8 Butler matrices are illustrated in ***Figures 1*** and ***2***, respectively, and their ideal operation summarized in ***Tables 1*** and ***2***. A 4 × 4 Butler matrix is composed of four 90-degree hybrid couplers and two 45-degree phase shifters, while an 8 × 8 Butler matrix is composed of twelve 90-degree hybrid couplers, four 45-degree, two 22.5-degree and two 67.5-degree phase shifters.

Elliptical slot-coupled technology is used for both the 90-degree hybrid couplers and phase shifters.[5,6] The multi-layer structure enables the design of the Butler matrices without crossover circuits. ***Figure 3*** shows the elliptically-shaped coupling structures of the hybrid coupler and phase shifter and their

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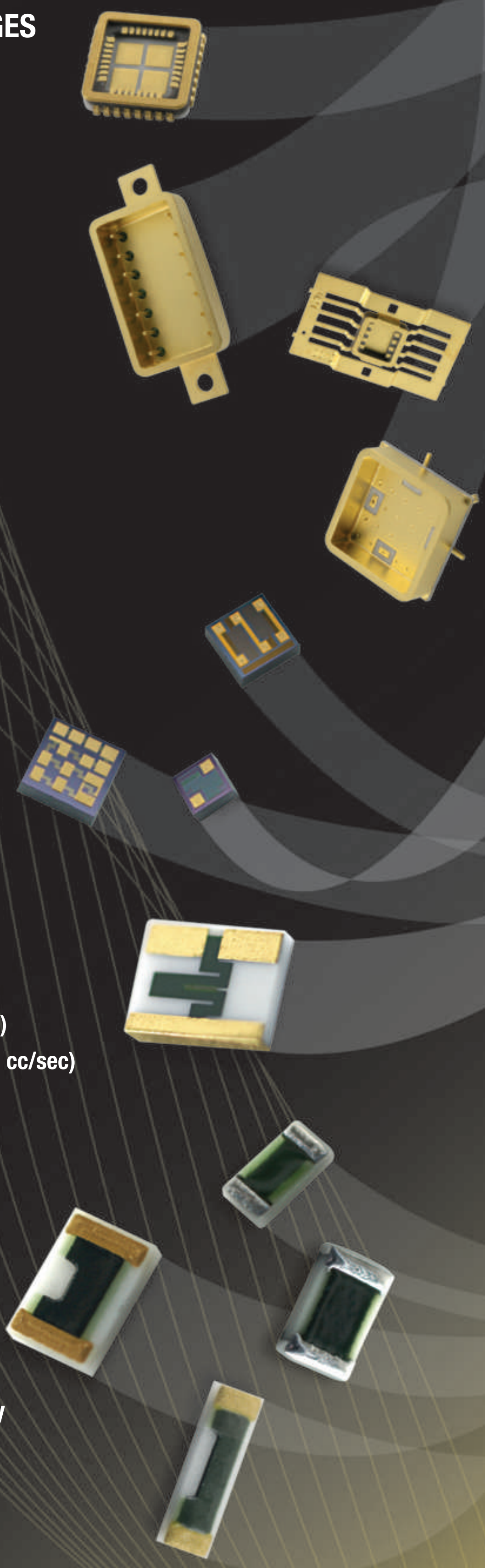

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respective dimensions. The phase shifter of Figure 3b can be viewed as the hybrid coupler of Figure 3a with two ports terminated by open circuits. The last row of Tables 1 and 2 list the phase differences between antenna adjacent ports in Figures 1 and 2 for each beam direction.

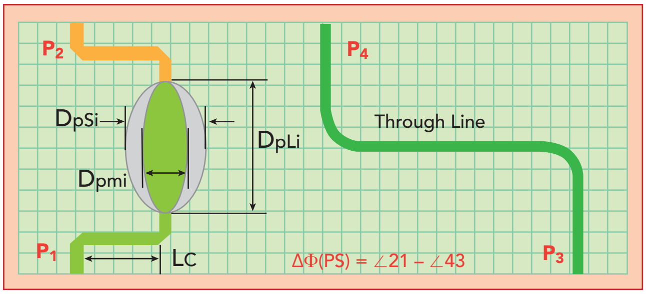

Fig. 5 Phase shifter structure.

Based on the above discussion, prototype 4 × 4 and 8 × 8 Butler matrices and their components were designed and simulated using a Rogers RO4003C substrate 1.016 mm thick, using a dielectric constant of 3.55 and a loss tangent of 0.0027.

90-DEGREE HYBRID COUPLER

The even and odd mode characteristic impedances, respectively denoted by Z_{0e} and Z_{0d}, of the slot-coupled line are[5]

$$Z_{0e} = \frac{60\pi K(k_1)}{\sqrt{\varepsilon_r} K'(k_1)} \qquad (1)$$

$$Z_{0o} = \frac{60\pi K'(k_2)}{\sqrt{\varepsilon_r} K(k_2)} \qquad (2)$$

where K(k) is an elliptical integral of the first kind and $K'(k) = K\left(\sqrt{1-k^2}\right)$. The parameters k_1 and k_2 are calculated from

$$k_1 = \sqrt{\frac{\sinh^2(\pi\omega_s / 4h)}{\sinh^2(\pi\omega_s / 4h) + \cosh^2(\pi\omega_p / 4h)}} \qquad (3)$$

$$k_2 = \tanh\left(\pi\omega_p / 4h\right) \qquad (4)$$

where h is thickness of substrate, ω_p is the width of the top and bottom equivalent microstrip patches and ω_s is the width of the equivalent rectangular slot. Their relationships with the actual dimensions (see Figure 3c) are

$$D_m \approx 1.273\left(\omega_p \times l_p\right) / D_L \qquad (5)$$

$$D_s \approx 1.273\left(\omega_s \times l_p\right) / D_L \qquad (6)$$

$$D_L = \left(\sqrt{l_p^{\,2} + \omega_p^{\,2}} + l_p\right) / 2 \qquad (7)$$

Using equations 1 through 7, the initial dimensions D_m, D_S and D_L were determined and then optimized using ANSYS software. For the 90-degree hybrid coupler, the optimized dimensions were D_m=6, D_S=8 and D_L=12.8 mm. The simulated performance of the hybrid coupler is shown in ***Figure 4***.

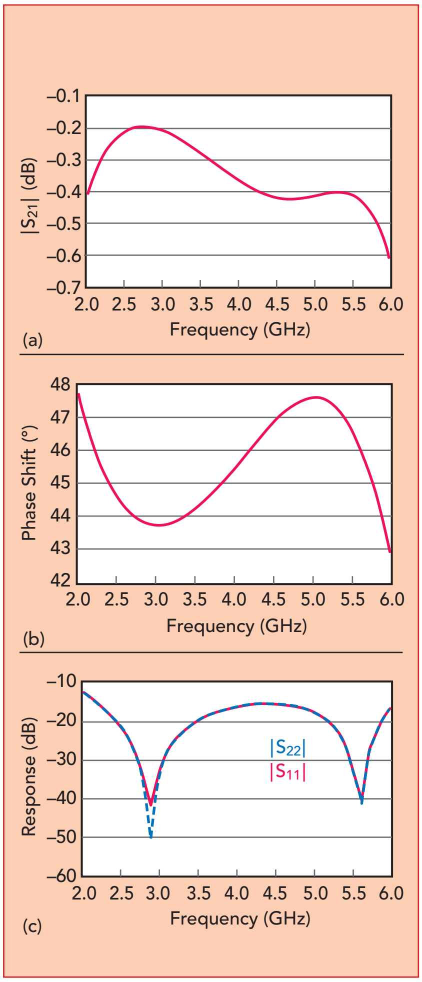

Fig. 6 Simulated transmission (a), phase (b) and reflection (c) characteristics of the 45-degree phase shifter.

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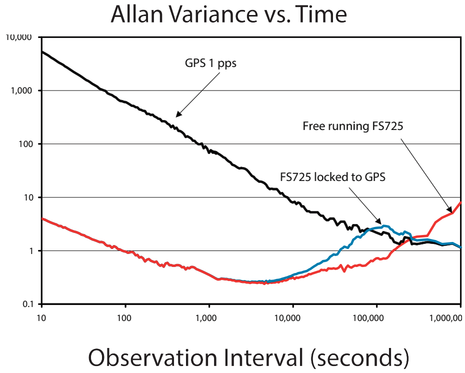


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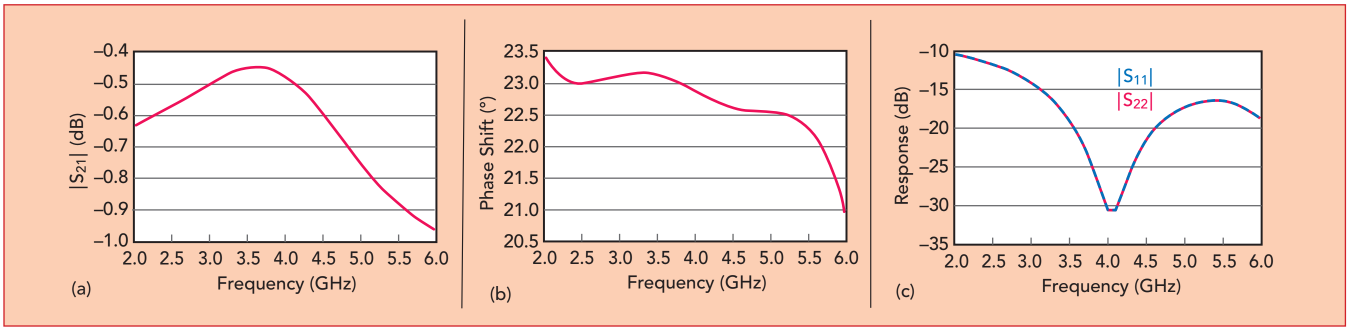


Fig. 7 Simulated transmission (a), phase (b) and reflection (c) characteristics of the 22.5-degree phase shifter.

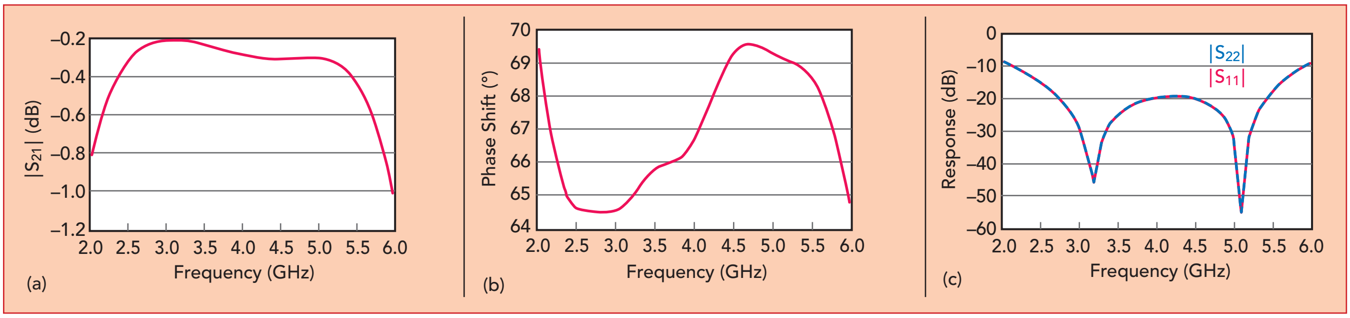


Fig. 8 Simulated transmission (a), phase (b) and reflection (c) characteristics of the 67.5-degree phase shifter.

PHASE SHIFTERS

The phase shifter shown in Figure 2b can be viewed as the hybrid coupler in Figure 2a with two ports terminated by open circuit impedances. Its phase shift is[6]

$$\Delta\phi = \frac{\pi}{2} - \arctan\left[\frac{\sin(\beta_{ef} l)}{\sqrt{1-C^2}\cos(\beta_{ef} l)}\right] + \beta_m + l_m \qquad (8)$$

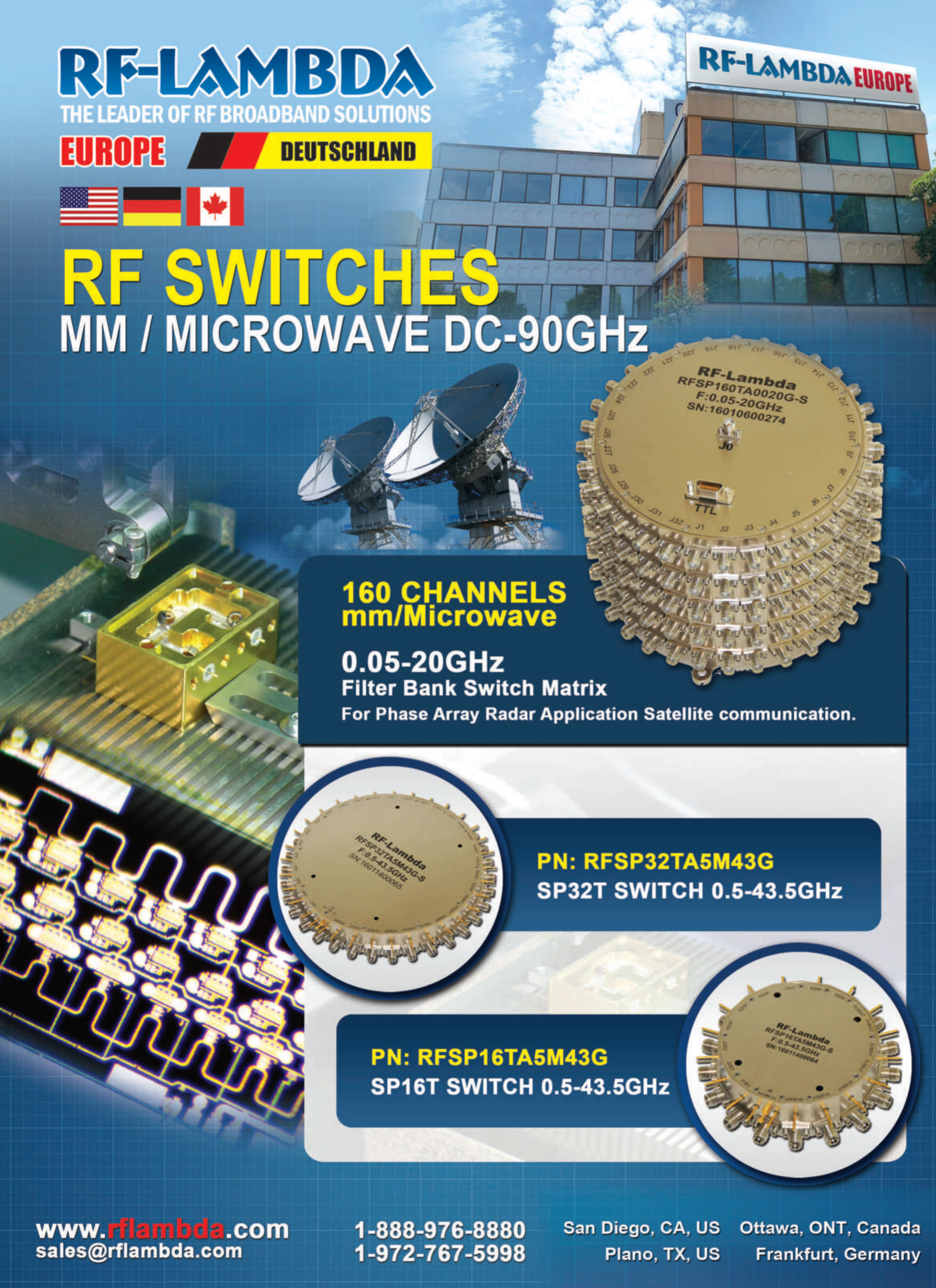
where $\beta_{ef} = \beta_0 \sqrt{(\epsilon_r)}$, β_m is the corresponding microstrip propagation constant, $l=\lambda_m/4$, λ_m is the effective microstrip wavelength and l_m is the microstrip line reference length. $\Delta\phi$ is the phase difference between two transmission paths (see ***Figure 5***).

Equation 8 shows there are two degrees of freedom to achieve the desired phase shift: the coupling coefficient C and l_m. In actual application, l_m must be calibrated with a phase-compensated microstrip line. Thus, the phase shift $\Delta\phi$ is determined only by C, and its value is inversely proportional to C. C is defined by Z_{0e} and Z_{0o} as

$$C = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \qquad (9)$$

Equations 1 through 9 define the relationships between the phase shift $\Delta\phi$ and the dimensions D_m, D_S and D_L. Three new variables D_{pmi}, D_{pSi} and D_{pLi} (see Figure 5) are used for the corresponding dimensions of the phase shifters, distinguishing them from those of the hybrid coupler. Similarly, the initial values were calculated and then optimized using ANSYS. The optimized dimensions in mm were:

- 45-degree phase shifter: D_{pm45}=4.35, D_{pS45}=7.4, D_{pL45}=12.1
- 22-degree phase shifter: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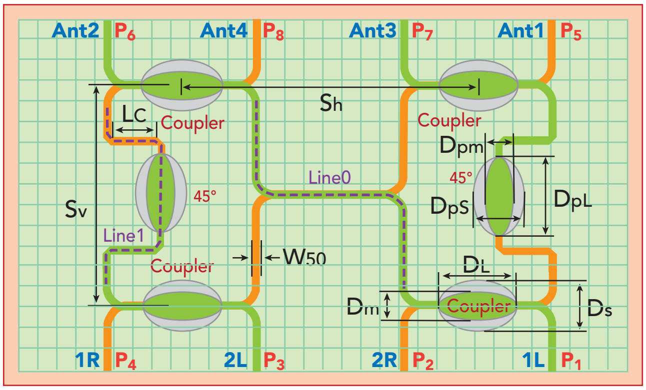

Fig. 9 Layout and dimensions of the 4 × 4 Butler matrix.

D_{pm22}=11.2, D_{pS22}=13.2, D_{pL22}=12.8

- 67.5-degree phase shifter: D_{pm67}=2.7, D_{pS67}=6.2, D_{pL67}=12.2.

The simulated performance is shown in ***Figures 6***, ***7*** and ***8***, respectively.

4 × 4 BUTLER MATRIX SYNTHESIS

After determining the dimensions of the 90-degree hybrid couplers and the 45-degree phase shifters, the 4 × 4 Butler matrix (see ***Figure 9***) was synthesized using the topology in Figure 1. A flexible layout method places components based on the spacing of adjacent couplers. With this approach, each component, including 90-degree hybrid couplers, 45-degree phase shifters and phase-compensation circuits, can be individually simulated and optimized. Also, the input and output ports of the Butler matrix can be flexibly placed.

The phase shifters have phase differences with respect to a microstrip line of fixed length. Unfortunately, the lengths of the through lines in the non-phase-shifting paths between the corresponding connected two couplers are lengthy and dependent (see Line 0 in Figure 9). Therefore, to provide the needed phase shift, the extra microstrip lines, whose lengths are determined by the spacing of the connected couplers, must be compensated in the corresponding phase-shifting paths. Ideally, the phase-compensation circuits should be designed so as to not affect the overall layout. The 45-degree phase-shifting paths all have the same trace format of line 1 with the extended lines of length L_C. Thus, when the spacing of adjacent couplers is determined, denoted by S_h and S_v in Figure 9, the length of line 0 is determined, and the value of L_C is easily adjusted to guarantee a phase difference of 45 degrees between lines 1 and 0. Line 0 can be flexibly routed to maintain a certain line spacing within the same metal layer.

The prototype 4 × 4 Butler matrix was designed and simulated on a Rogers 4003C substrate. Each component, including the 90-degree hybrid coupler, 45-degree

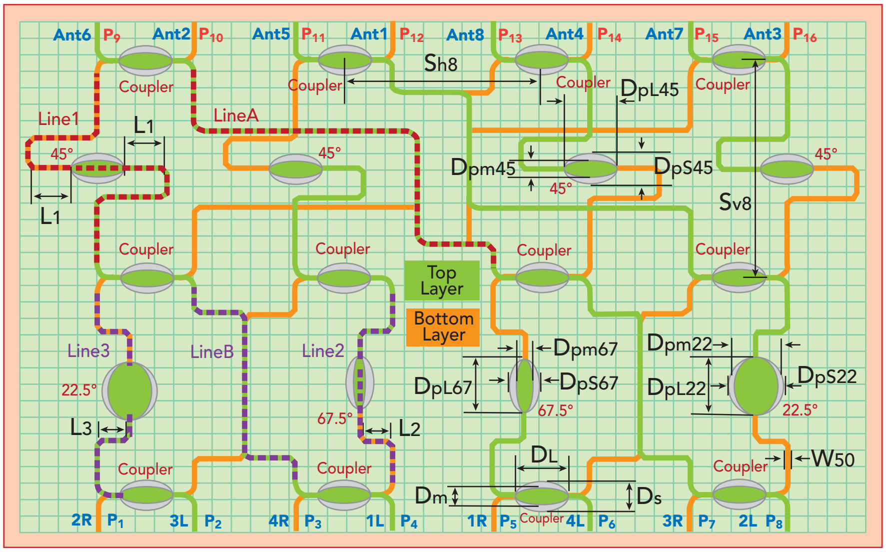

Fig. 10 Layout and dimensions of the 8 × 8 Butler matrix.

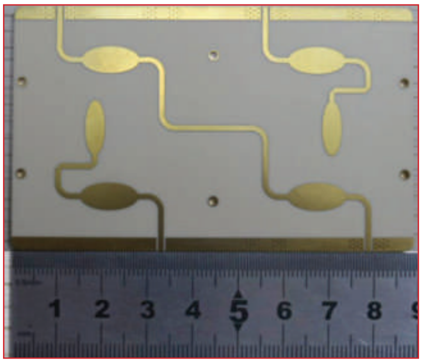

Fig. 11 Fabricated 4 × 4 Butler matrix.

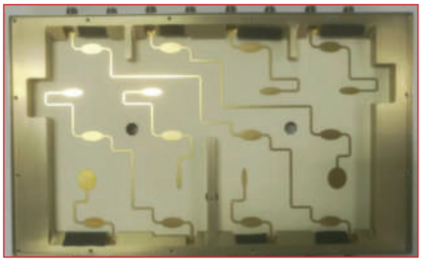

Fig. 12 Fabricated 8 × 8 Butler matrix.

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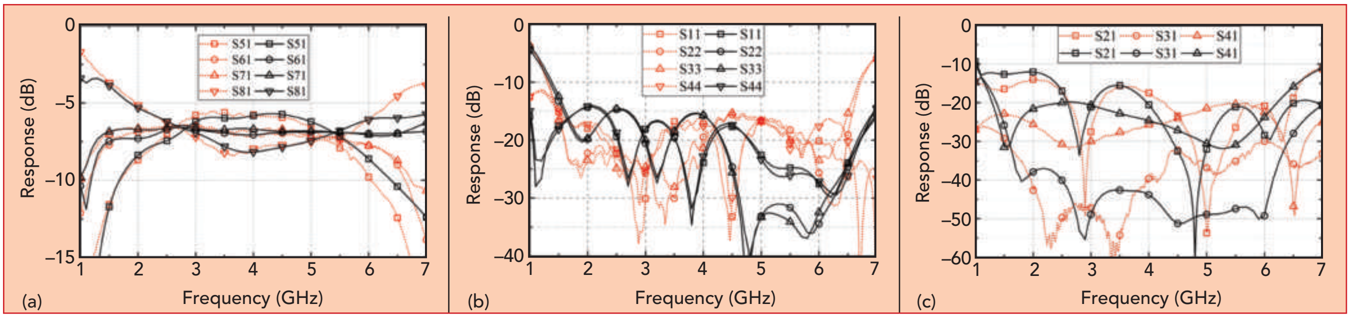

Fig. 13 Simulated (solid black) vs. measured (dotted red) characteristics of the 4 × 4 Butler matrix: transmission (a), reflection (b) and port 1 coupling (c).

phase shifter and the phase-compensation circuit were individually simulated and optimized. Full-wave simulations and optimizations were performed using ANSYS software. Most of the physical parameters have been noted; the remaining physical parameters in Figure 9 are: L_C=6.95, W_{50}=1.15, S_h=45.6 and S_v=34.1 mm.

8 × 8 BUTLER MATRIX SYNTHESIS

In a similar fashion, the prototype 8 × 8 Butler matrix was designed and simulated, using Rogers 4003C substrate and each component individually simulated and optimized. The full-wave simulations and optimizations were performed, and the realizable physical parameters

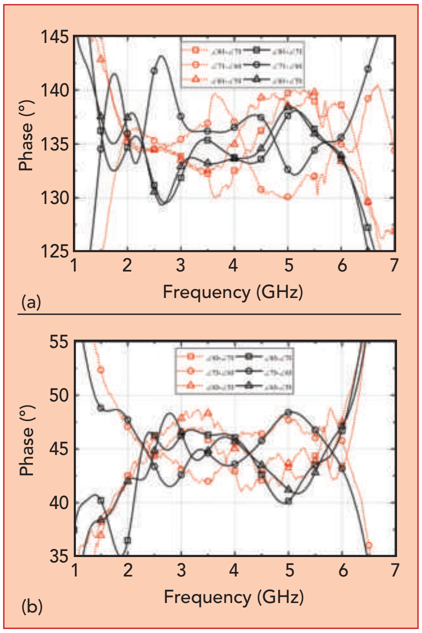

Fig. 14 Simulated (solid black) vs. measured (dotted red) differential phase between adjacent antenna ports of the 4 × 4 Butler matrix: beam 1L with 135-degree differential phase (a) and beam 2L with 45-degree differential phase (b).

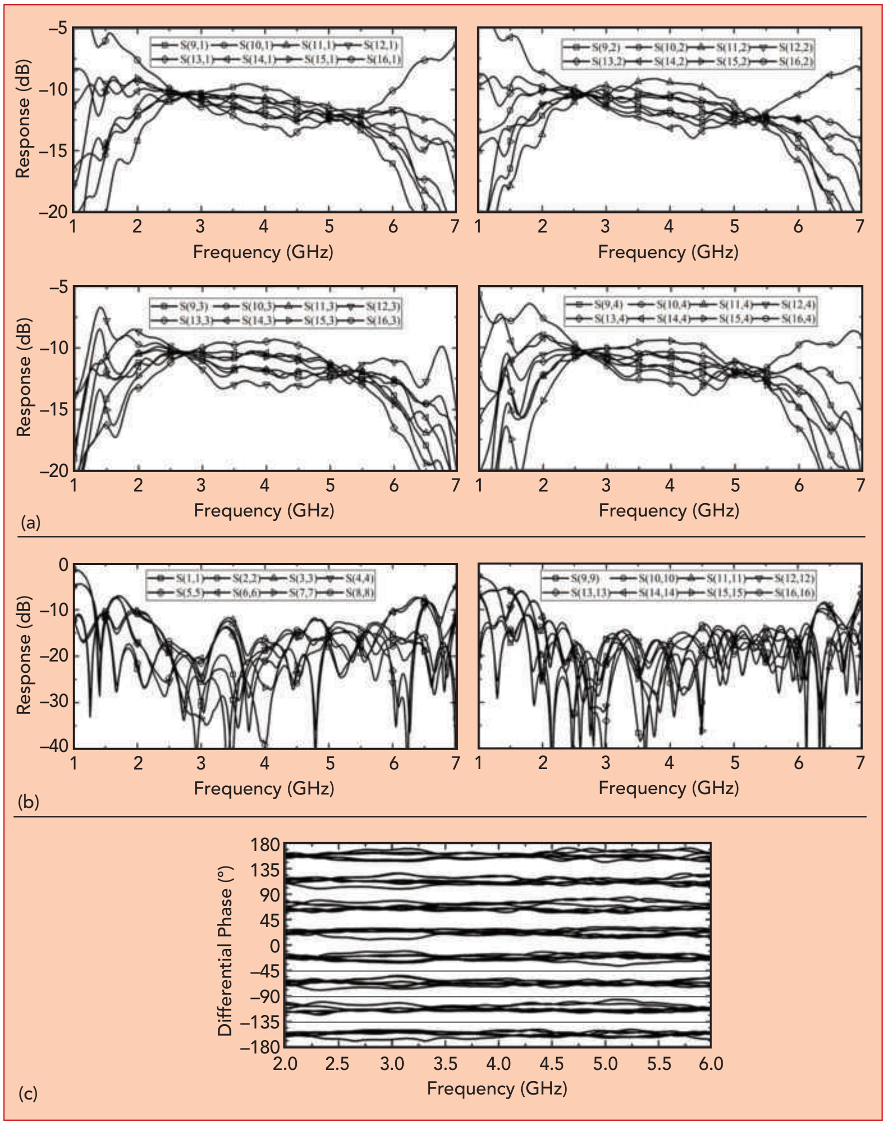

Fig. 15 Measured performance of the 8 × 8 Butler matrix: transmission (a), reflection (b) and differential phase (c) for each beam.

are shown in ***Figure 10***. As with the 4 x 4 matrix, most of the physical parameters have been listed previously. The remaining are: L_1=9.53, L_2=6.35, L_3=6.35, W_{50}=1.15, S_{h8}=46.2 and S_{v8}=50.85 mm.

MEASURED RESULTS

The fabricated 4 × 4 and 8 × 8 matrices are shown in ***Figures 11*** and ***12***, respectively. The sizes are approximately 89 × 54 mm for 4 × 4 Butler matrix and 212 × 118 mm for the 8 × 8 matrix.

Measurements with a Keysight vector network analyzer are in agreement with the simulations, as shown in ***Figures 13*** and ***14***. As the 4 × 4 Butler matrix has a plane of reflection symmetry, shown in Figure 9, the simulated and measured results are only presented when port 1 is excited. The differential phases are shown with ports 1 and 2 excited. In Figure 13a, S_{51}, S_{61}, S_{71} and S_{81} are shown, indicated about 7 dB for the insertion loss with approximately 1 dB of amplitude imbalance. Figure 13b shows greater than 15 dB return loss at all input ports over the entire band from 2 to 6 GHz. Figure 13c shows the isolation characteristics of port 1 from the other three input ports: 15 dB for port 2, 20 dB for port 3 and 30 dB for port 4. The differential phases of beam 1L (with an ideal differential phase of 135 degrees) and 2L (with an ideal differential phase of 45 degrees) are plotted in Figures 14a and b, respectively, showing 5-degree phase imbalance for the

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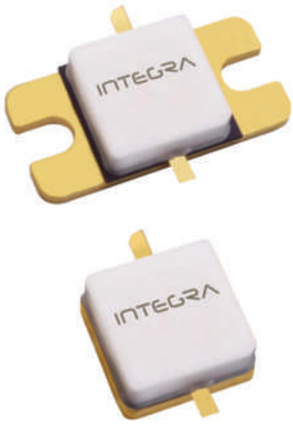

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135-degree phase shift of beam 1L and 3-degree phase imbalance for the 45-degree phase shift of beam 2L. The 8 × 8 Butler matrix has similar characteristics (see ***Figure 15***).

CONCLUSION

Slot-coupled technology was used to design 2 to 6 GHz 4 × 4 and 8 × 8 Butler matrices, and a three metal-layer structure avoided crossover circuits. Phase-compensation circuits were added based on the spacing of adjacent couplers, a helpful design approach. Measurement results agree with the simulations. A 100 percent fractional bandwidth was achieved, which is attractive for wideband beamforming systems.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of China under Grant 61671149, Grant 61861136002 and Grant 61701110. ■

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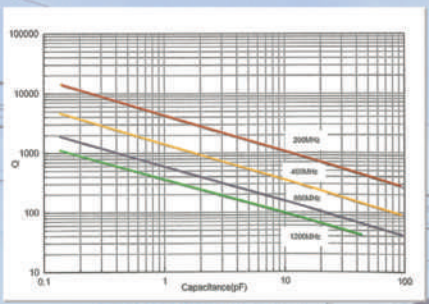

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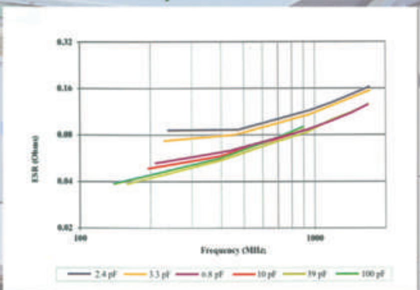

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A 32 to 40 GHz GaAs PIN Limiter-Low Noise Amplifier MMIC with High Power Handling

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This article describes a novel 32 to 40 GHz high-power GaAs PIN diode limiter and low noise amplifier (limiter-LNA) MMIC. To improve small-signal performance and reduce chip area, a unit cell comprises the PIN diodes and matching inductor, and the unit cells are cascaded to match the input of the LNA. The limiter-LNA handles up to 39 dBm CW input power without failure. Small-signal gain and noise figure (NF) were 18 ±0.4 dB and 2.5 to 2.9 dB, respectively, over the 32 to 40 GHz frequency range.

Advancements in wireless communication technology have increased the demand for mmWave integrated circuits. The LNA is a key component of the receiver and must have high gain and low NF. LNAs are typically the first block in a receiver; however, their power handling capabilities are only 10 to 20 dBm CW.[1] Limiters are used to protect these sensitive LNAs with, ideally, sufficiently low levels of leakage power and minimal signal loss and distortion. Traditionally, LNAs and limiters have been designed independently with 50 Ω input and output matching networks, which occupy a relatively large area and add insertion loss, especially in the mmWave band. By integrating the limiter and the LNA into a single chip, circuit real estate is reduced and better performance is achieved by eliminating external connections.[2]

Schottky diode limiter-LNAs are widely used;[1,2] however, they have relatively low power handling capabilities.[3] Compared with Schottky diode limiters, PIN diode limiters have relatively high power handling capability; thus, an integrated PIN diode limiter-LNA MMIC offers the advantages of small size and high power handling. Jones et al.[4] demonstrated a 9 to 16 GHz PIN diode limiter-LNA with 12 dB of gain and less than 2.2 dB NF with 30 dBm CW input power handling. Zhou et al.[5] describe an X-Band balanced PIN diode-based limiter-LNA with a power handling capability of 20 W CW, where the limiter-LNA had 24 dB gain and less than 1.8 dB NF across the 8 to 12 GHz band. Cui et al.[6] describe a 12 to 22 GHz,

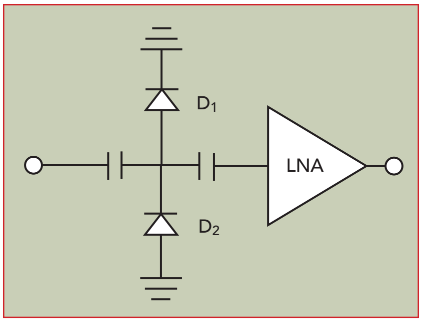

Fig. 1 PIN diode limiter-LNA topology.

10 W PIN diode-based limiter-LNA with a small-signal gain of 26 dB.

In this work, a 32 to 40 GHz high-power monolithic integrated PIN diode limiter-LNA was designed with combined PIN diode and PHEMT technology. To improve small-signal performance and reduce the chip area, the PIN diode limiter network was designed to be the LNA's input matching circuit. The 0.15 µm gate length GaAs PHEMT and the PIN diodes were epitaxially grown and processed on the same wafer. Measurements show the PIN diode-based limiter-LNA is capable of handling 39 dBm CW input power without failure, achieving 18 dB average small-signal gain and 2.5 to 2.9 dB NF over the 32 to 40 GHz band.

DESIGN AND FABRICATION

Concurrent design of the limiter and LNA was the source of improved performance, as the output impedance of the limiter was directly matched to the input impedance of the LNA, eliminating the 50 Ω matching networks typically used between the limiter and the LNA.[3] ***Figure 1*** shows the basic topology.

With a high-power input signal, the PIN diodes, D1 and D2, turn on, the antiparallel diodes clipping both halves of the sinusoidal RF signal to limit the input voltage to a safe value. A significant fraction of the incident power reflects to the source. The PIN diodes absorb some of the input power, as well, decreasing the output power. With a low-power input signal, the diodes are "off" and load the RF path with parasitics.[7]

With a high-power input, the PIN diode junction capacitance is essentially shorted (see ***Figure 2a***), and the conducting RF resistance is about 1 Ω, due to the increased density of charge carriers in the semiconductor. For small-signal levels, the equivalent circuit of the PIN diode can be approximated by C_R in series with R_S[8] (see ***Figure 2b***). The insertion loss caused by C_R can be addressed with impedance matching: the series inductor, L_b, added to the limiter network to compensate (see ***Figure 2c***).

The PIN diodes, with their shunt capacitance, and the matching inductors compose a unit cell. The unit cells are cascaded to form a lowpass filter to provide input matching to the LNA, improving its noise performance. Transmission lines are employed in each cell, their length and

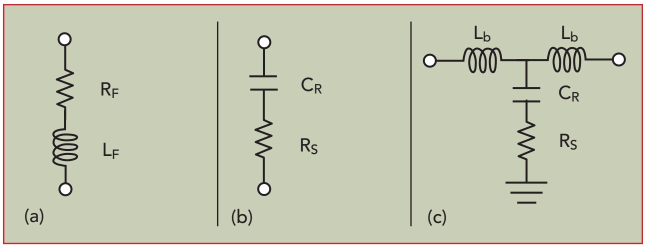

Fig. 2 Equivalent circuit of the PIN diode with high input power (a), low level input (b) and tuning the diode capacitance (c).

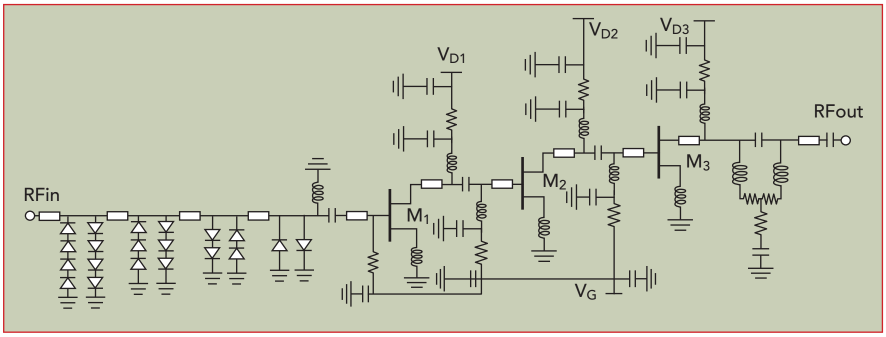

Fig. 3 PIN diode limiter-LNA MMIC schematic.

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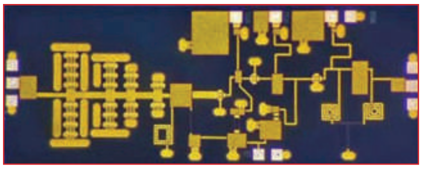

Fig. 4 Fabricated PIN diode limiter-LNA MMIC.

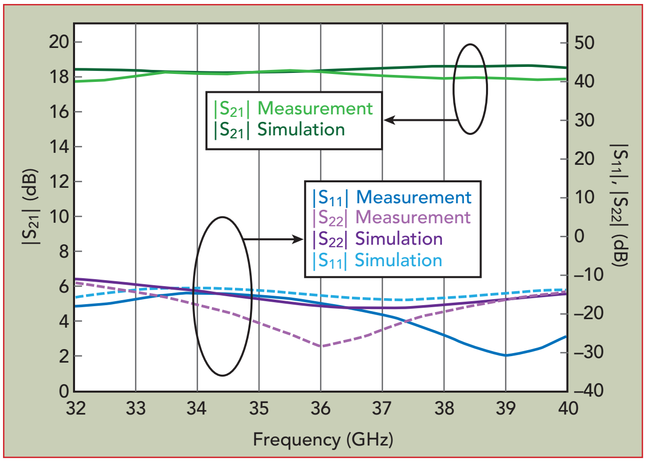

Fig. 5 Simulated vs. measured small-signal performance.

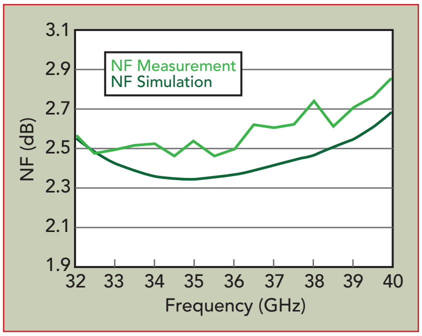

Fig. 6 Simulated vs. measured NF.

impedance optimized to realize the series inductor L_b.

The integrated four-stage PIN diode-based limiter and three-stage LNA were designed and implemented using a process offering both PIN diodes and 0.15 µm PHEMTs. ***Figure 3*** shows the schematic of the limiter-LNA MMIC. The antiparallel diode structure maximizes power handling and, by double stacking the diodes, the shunt capacitance was reduced by 2x. An RF choke inductance shunted to ground provides a DC return path for the limiter.[9] In the LNA network, inductive source degeneration[10] improves both the noise performance and input matching. An equalizer consisting of series inductors, resistors and a capacitor helps flatten the gain by decreasing the low frequency gain, as well as improving circuit stability.

The MMIC was fabricated with a selective epitaxial growth technique on GaAs substrates. The optimized PIN diode epitaxial structure was grown first, followed by definition of the PIN diode and PHEMT active regions. A second epitaxial growth of PHEMT material followed, and the complete PIN-PHEMT process merged the 0.15 µm PHEMT and PIN processes, with base mesa and p-ohmic steps used to create the limiters. Mesa isolation was performed using wet chemical etching, and the T-shaped PHEMT gate was defined using electron beam lithography. Air bridges formed the on-chip inductors and interconnected the PIN diodes and other devices.

MEASUREMENT AND ANALYSIS

The fabricated limiter-LNA MMIC is shown in ***Figure 4***. S-parameters and NF were measured on-wafer at room temperature, with the amplifier biased at $V_{G1} = V_{G2} = -0.4$ V and $V_{D1} = V_{D2} = 2$ V. The current consumption of the entire MMIC was 36 mA, with a power dissipation of 72 mW. ***Figures 5*** and ***6*** compare the measured and simulated gain and NF performance of the limiter-LNA. From 32 to 40 GHz, the measured average small-signal gain was 18 dB with a gain flatness of ±0.4 dB. $|S_{11}|$ and $|S_{22}|$ were better than -14 dB and -12 dB, respectively. The measured NF ranged from 2.5 to 2.9 dB across the full band.

To measure the power handling capability of the limiter-LNA, the die was attached using AuSn solder to a copper-molly carrier, which provided maximum heat conduction. The input power was increased from -30 dBm, measuring the S-parameters and NF before and after 30 minutes of exposure. The limiter-LNA handled up to 39 dBm of CW input power at 36 GHz without failure.

TABLE 1

LIMITER-LNA COMPARISON

Technology	Frequency (GHz)	CW Power (dBm)	Gain (dB)	NF (dB)	Reference
0.1 µm GaAs PHEMT	28-38 30-38	33 37	21 18	< 2.9	2
PIN + HEMT	9-16	30	12	< 2.2	4
PIN + PHEMT	8-12	43	> 24	<1.8	5
PIN + PHEMT	12-22	40	26	< 2.7	6
Schottky Diode	34-36	28.9	-4	4	11
GaN	8-12 7-11	36 40	14 18	1.6-1.8 2.0	12
PIN + PHEMT	32-40	39	18	< 2.9	This Work

A comparison of this limiter-LNA with similar work is provided in ***Table 1***. Compared with other reported Ka-Band PIN diode limiter-LNAs, this limiter-LNA design achieved the highest power handling capability with comparable performance.

CONCLUSION

A 32 to 40 GHz high-power GaAs PIN diode limiter-LNA MMIC has been described. The PIN diode limiter network forms a lowpass filter which serves as an input matching circuit for the LNA. CW input power handling was 39 dBm, the overall NF less than 2.9 dB with 18 dB small-signal gain over the 32 to 40 GHz band. The RF power handling was greater than that of typical Schottky diode limiter-LNAs because of the power handling capability of PIN diodes. This demonstrates the potential of PIN diode limiter-LNAs for mmWave front-end circuits.[7]

ACKNOWLEDGMENT

This research was funded by the National Natural Science Foundation of China (61774054). ■

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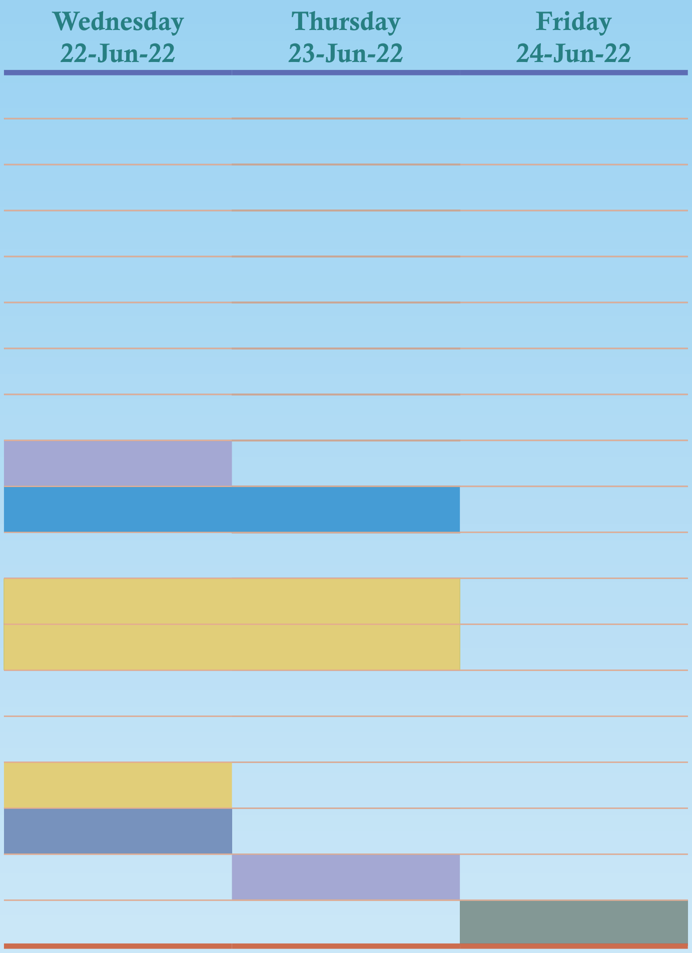

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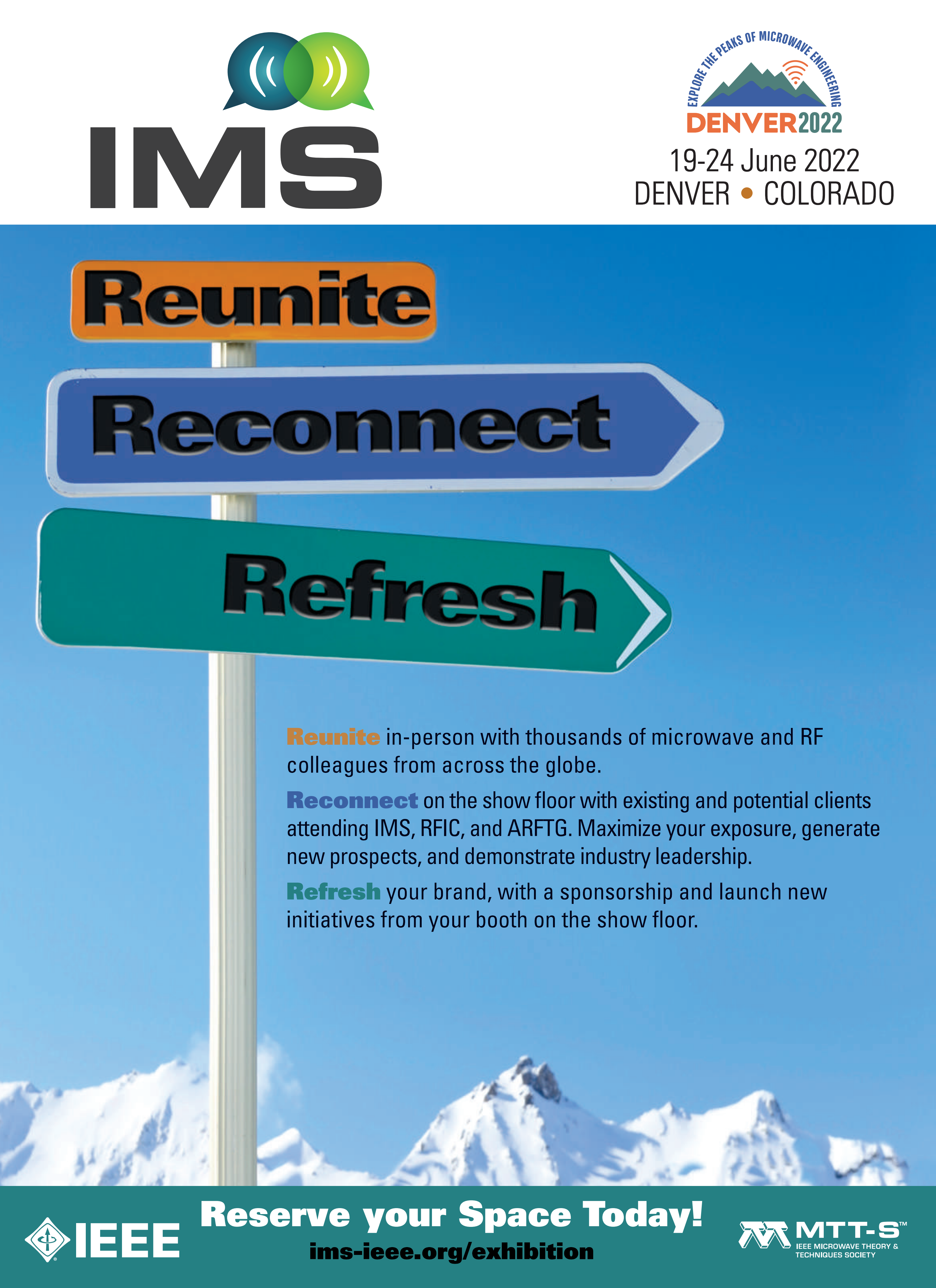
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INVITED PAPER

Not Your Parents' 5G: New Use Cases for Military and Government

Nancy Friedrich
Keysight Technologies, Santa Rosa, Calif.

By assuring 5G product and system performance throughout the design cycle, system designers can reach their goals while advancing military and government capabilities.

Communications for military and government applications has evolved from analog to video, high-resolution imagery and the rapid adoption of new users. Today's critical communications networks serve military, government and public safety personnel with ad hoc communications to boost networks in emergencies and fill coverage holes. 5G cellular further extends the capabilities of critical communications, such as 5G networks on bases, deployed to respond to emergencies, or on the battlefield.

Beyond tactical communications, 5G will enable new applications for military and government, such as autonomous vehicles and robotic surgery, and 5G non-terrestrial networks (NTNs) will help make these a reality. To assure performance, however, these different applications require unique approaches for design and test. By taking a multi-step approach, designers can ensure that products seamlessly integrate into the final design, and the design supports all the promises of 5G for military and government users.

Fig. 1 One of the enabling technologies for NTN is the global navigation satellite system (GNSS).

5G IN SPACE

Using spaceborne or airborne assets, for example, 5G can enable service in areas of the globe that don't have coverage (see ***Figure 1***). Tactical military users can use this capability to establish communications over new terrain, in the air or at sea. First responders responding to emergencies in forests, mountains or other areas where communication is not available can also leverage these capabilities.

Researchers and developers who want to tap into NTNs face several challenges. The 5G NTN standard has not yet been developed, so commercial equipment isn't available—not even prototype commercial equipment—so other ways to research, prototype or develop these systems are required. No matter the final application, however, the architecture will start with the user equipment (UE) or device block. The UE normally communicates with the base station, called the gNodeB in 5G networks. The 5G core network is known as the next-generation core. Unfortunately, commercial off-the-shelf (COTS) UEs and gNodeBs will not work for NTNs because of the amounts of Doppler and delay in spaceborne communications links. The process to develop NTN requires a "crawl, walk, run" approach starting with basic software modeling, with the software modeling tool including the following: downlink and uplink transmit and receive chains of the UE, the gNodeB, the signal propagation to and from the satellite, the motion of the satellite, the antennas and the delay and Doppler through the system.

Using global navigation satellite systems, the UE can establish its own position, frequency and time reference and compute the time and frequency difference from the satellite signal and apply timing advance and frequency adjustments. Each UE will pre-frequency shift its transmission to counter the Doppler shift from the motion of the satellite. The gNodeB must also do this, but in a way common to all the served UEs, no matter their locations. When a UE attaches to the network and looks for a base station, it must assume a greater range of frequency offsets than with a terrestrial link.

Prototypes with COTS devices are not yet available, but NTN links can be simulated in software and prototyped with emulators. Hardware emulators are more easily customizable for mimicking NTN links (see ***Figure 2***). Initial prototyping can be done in a lab or a chamber on a small scale. Once satisfied and when NTN equipment is developed and available, prototyping with actual equipment in the lab or in a chamber is wise, again on a small scale and followed by full-scale implementation with the actual equipment on the target platform. After development, periodic maintenance testing should also be performed.

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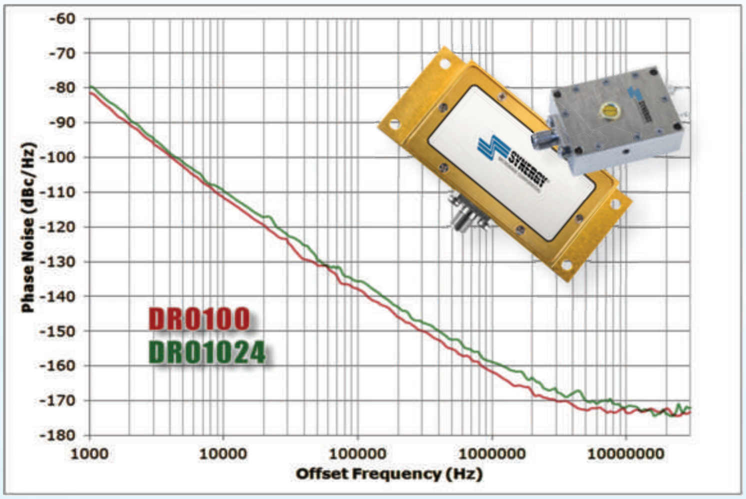

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SDRO900-8XT [1]	9	1 - 10	+8 @ 25 mA	**-112**
SDRO1000-8	10	1 - 15	+8 @ 25 mA	**-107**
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	**-105**
SDRO1118-7	11.18	1 - 12	+5.5 - 7.5 @ 25 mA	**-104**
SDRO1121-7	11.217	1 - 12	+5.5 - 7.5 @ 25 mA	**-106**
SDRO1130-7	11.303	1 - 12	+5.5 - 7.5 @ 25 mA	**-106**
SDRO1134-7	11.34	1 - 12	+5.5 - 7.5 @ 25 mA	**-107**
SDRO1140-8XT [1]	11.4	1 - 10	+8 @ 25 mA	**-102**
SDRO1250-8	12.5	1 - 15	+8 @ 25 mA	**-104**
SDRO1300-8	13	1 - 12	+8 @ 25 mA	**-104**
SDRO1400-8	14	1 - 12	+8 @ 25 mA	**-102**
SDRO1500-8	15	1 - 12	+8 @ 25 mA	**-100**
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DRO100	10	1 - 15	+7 - 10 @ 70 mA	**-111**
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	**-109**
DRO1024H	10.24	1 - 15	+7 - 10 @ 70 mA	**-115**
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Fig. 2 **The 5G NTN testbed combines this channel emulator with a network and UE emulator to enable research, prototyping and development before commercial equipment is available.**

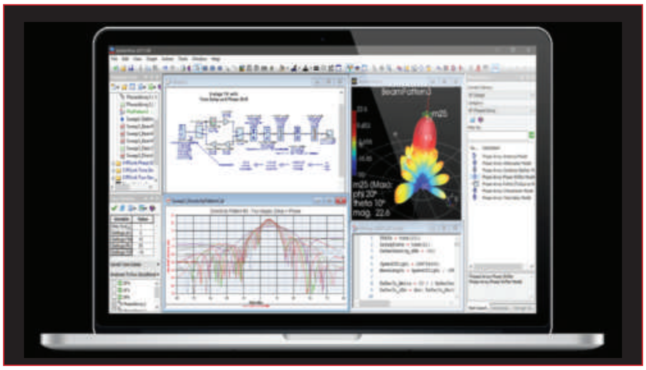


Fig. 3 **Model-based design across baseband and RF can simulate 5G base stations and UEs, radar, communications and DVB signals.**

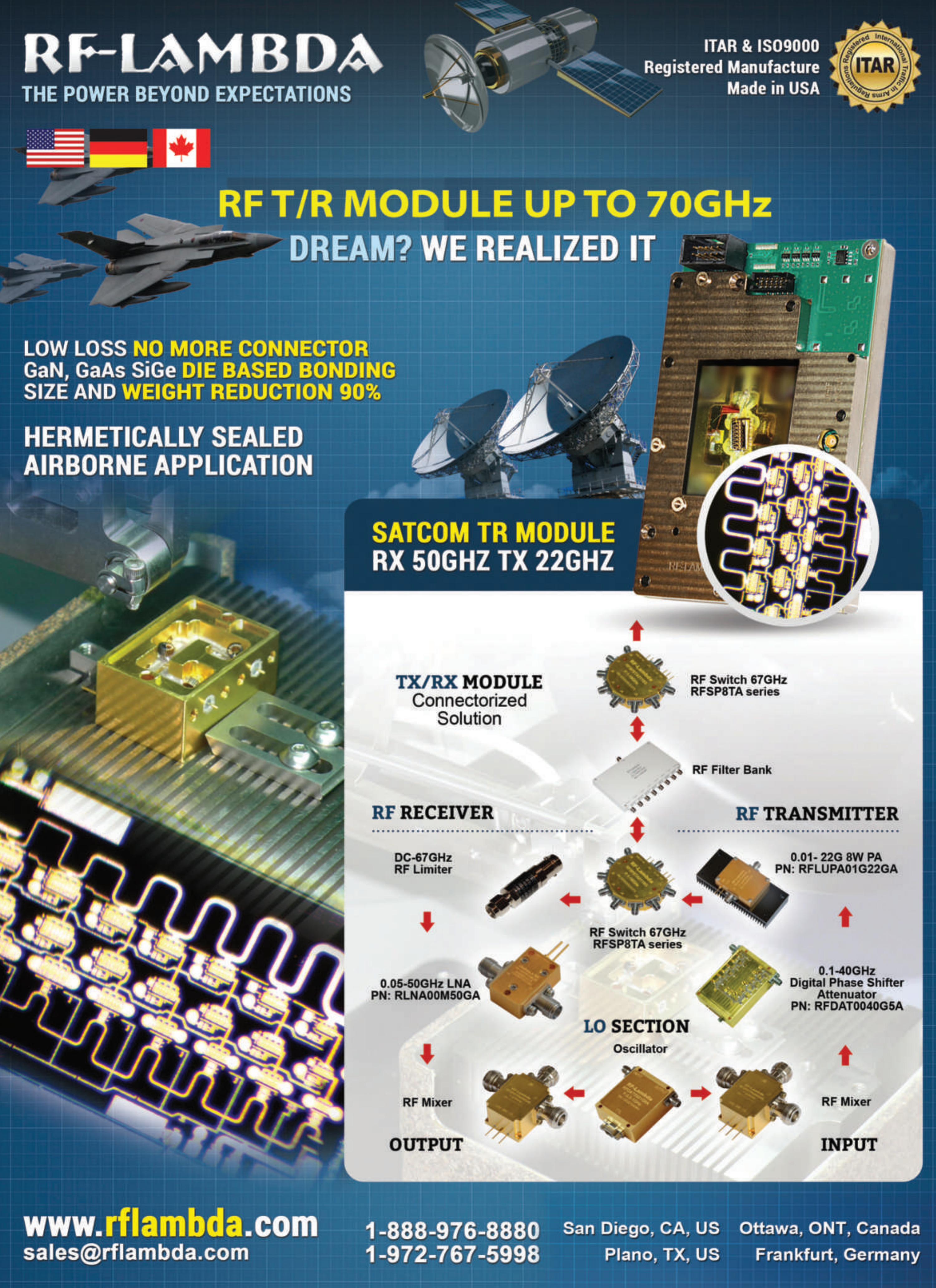
VEHICLES: 5G ON THE MOVE

Soon, we will see 5G links in the air for unmanned aerial vehicles, other aircraft, ships, Humvees and other vehicles. Outfitted with 5G for long-haul communications, these vehicles will use 5G to enable communications, high data rate video conferencing and IoT sensors. Eventually, these capabilities will evolve into integrated systems for self-driving or autonomous vehicles, aiming to eliminate soldiers from some missions. Initially, a hybrid approach will require that soldiers remain in the loop to oversee vehicle performance.

Use cases range from vehicles used on base, which will improve energy efficiency, to field and/or combat vehicles. The development projects spurring this progress focus on advancing methods for vehicles to identify and understand their surroundings. Examples are radar, lidar and other sensors. Artificial intelligence (AI) and machine learning must sort through, process and act on this information. Connecting all the information is critical to system success, setting expectations for 5G performance in a crowded and complex signal environment.

Ships, planes and ground vehicles have different types of transmitters and receivers: telemetry, communications, radar, satellite links and surveillance. All must operate simultaneously without compromising the performance of the other systems or, worse, damaging them. If not designed with adequate margins, for example, radar signals can damage sensitive satellite receivers. Adding 5G to planes, ships and other vehicles makes the RF environment more complicated, with potential electromagnetic compatibility issues. Careful planning must take place so that all the systems can operate simultaneously and safely. By first modeling the communications link and other signals in software, potential issues can be identified and addressed early in the development. The software tool should model the downlink and uplink transmit and receive chains of the UE, the gNodeB, as well as the signal propagation of the other communications systems on the vehicle.

During the planning phase, simulating signals in software can assess electromagnetic compatibility using a 3D model of the deployment platform (see ***Figure 3***). The finite-difference time-domain (FDTD) method is based on volumetric sampling of the electric and magnetic fields throughout the complete space. This method updates the field values while stepping through time, following the electromagnetic waves propagating through the structure. A single FDTD



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simulation can provide data over an ultra-wide frequency range.

Following modeling, confidence is increased by prototyping the signals in the lab, on a small scale, to gauge the performance in the field. Hardware emulators, which can be easily customized and adapted, can be used in place of COTS equipment, with other emulation equipment or signal generators used to simulate the signals seen in the real world environment. Measurements of the prototype can assess electromagnetic compatibility. Once satisfied with the performance of the prototype, full-scale implementation follows, deploying with actual equipment on the target platform. After the system is deployed, periodic maintenance testing follows to assure the continued performance of the system.

ROBOTIC SURGERY

In addition to autonomous vehicles, the military landscape will evolve with greater integration of robotics and exoskeletons, all employing AI. Advances in AI will ease soldiers' workloads and physical burdens while improving situational awareness. Using 5G will enable development of robotic surgery, an application that will transform medical care for military personnel.

In a conflict, medical response time determines survival. With extensive injuries and blood loss, the time to perform life-saving procedures is very short. With robotic surgery, military doctors can quickly perform operations from a distance, using robotic arms and cameras. Housing this equipment on medical vehicles eliminates the need to transport patients to another location before receiving treatment.

For remote surgery to succeed, however, these highly intelligent systems must work under a variety of environmental conditions with no downtime. Eventually, the goal is for these systems to be so intelligent they perform some procedures with minimal or no oversight. The adoption of 5G offers the possibility for connecting soldiers with remote medical personnel by supporting high data rates and latencies approaching real time.

The 3GPP, which oversees 5G standards development, has defined ultra-reliable low latency communications (URLLC) for critical networks. The standard defines the typical latency of an end-to-end connection between the client and server of just 2 to 3 ms and as low as 1 ms. The standard assures the network is configured to provide an ultra-reliable and low latency connection between the device and the cloud. By adapting URLLC to work from space, 5G NTN can provide high reliability on a widespread basis.

URLLC's potential, however, comes at a cost. Harnessing the components required to make URLLC work presents significant challenges across the wireless communications spectrum. Chipset and device suppliers face design and test constraints, and network equipment manufacturers and mobile network operators must address network latency and reliability demands. URLLC requires all the elements of the network—chipsets, devices, networking equipment and controlling software—to deliver to achieve the promise of applications like robotic surgery.

THE FUTURE

These new applications enabled by 5G promise to transform the capabilities of military and government. To support the development of these use cases requires successful development and innovation projects. Successful development can be achieved with the following approach:

- Simulate or prototype the 5G advancement or feature with software
- Perform development and integration testing, where the prototype equipment has the capability to control, observe and repeat testing the functionality
- Characterize the performance of the complete system with the real hardware and software
- Test and assess the security of the finished solution.

Despite their promise, new capabilities will be diminished if they cannot deliver adequate reliability. Service cannot go down in life or death scenarios. As cybersecurity risks increase, data reliability becomes critical. If the data being transmitted is compromised, devices, patients and whole operations are at risk. By assuring product or system performance throughout the design cycle and then monitoring it throughout the system life cycle, advancing military and government capabilities can be achieved. As 5G technology evolves, so do the risks—especially when it comes to reliability and security. The latest developments and processes must be implemented to guarantee the performance users need and assure their safety. ■

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SPECIAL REPORTS

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Phase-Coherent Channels and Switching in Multi-Channel Microwave Signal Generators

AnaPico Inc.
Zurich, Switzerland
Berkeley Nucleonics Corporation
San Rafael, Calif.

Electronically generated signal frequencies always have phase noise or frequency jitter. Over time and with varying ambient temperature, the signals will drift further. Generating accurate and stable signal frequencies and, for many applications, maintaining the relative frequency and phase stability among multiple channels are a fundamental and ongoing challenge. If the phase difference between two signals at the same frequency remains constant—in reality, the phase difference variation remains small over time—the two signals are considered phase coherent. Multi-channel phase-coherent signals are widely used in applications such as quantum computing, radar, beamforming for "smart" antennas and spectroscopy. To support these various applications, AnaPico has developed a portfolio of phase-coherent signal sources.

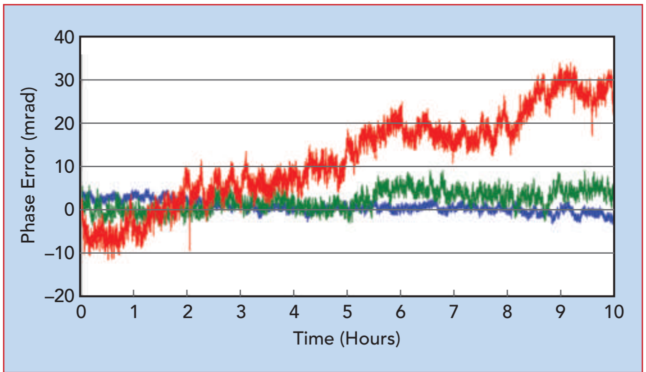

Fig. 1 **Measured phase coherence between channels vs. time.**

ANALOG AND VECTOR MODELS

The APSYN420-X, APUASYN20-X and APSYN140-X multi-channel, phase-coherent frequency synthesizers have upper frequency options of 20, 20 and 43.5 GHz, respectively, with phase noise of -100 to -115 dBc/Hz at 10 kHz offset from a 20 GHz carrier. The maximum output power from these units is up to 25 dBm, and they work with reference input frequencies of 10, 100 and 1 to 250 MHz, respectively, providing reference outputs of 10 and 100 MHz.

The APMS-X series are analog signal generators with multiple, phase-coherent outputs and frequency options of 6, 12, 20, 33 and 40 GHz and a phase noise of -115 dBc/Hz at 10 kHz offset from a 20 GHz carrier. The signal generators provide amplitude, frequency, phase and chirp modulation and output power levels from -90 to +25 dBm, depending on the configuration. Reference input frequency options with the APMS-X series are 10, 100, 1000, 3000 and

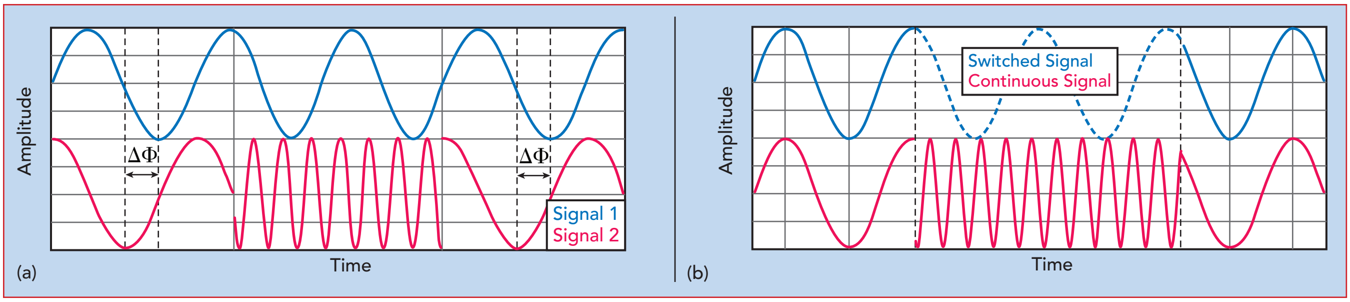

Fig. 2 Phase-coherent switching (a) with phase memory (b) option.

1 to 250 MHz, with reference outputs at 10 and 100 MHz and 3 GHz.

The APVSG-X series are multi-channel, phase-coherent vector signal generators (VSGs) with upper frequency options of 6, 12, 20 and 40 GHz and phase noise of -95 dBc/Hz at 10 kHz offset from a 20 GHz carrier. The series provides output levels from -60 to +15 dBm at 20 GHz, and the output can be modulated with analog amplitude, frequency and phase modulation and I/Q digital modulation with a 400 MHz bandwidth. Reference input options are 10, 100, 1000, 3000 and 1 to 250 MHz, and the VSGs provide reference outputs at 10 and 100 MHz and 3 GHz. The APVSG-X series has a fast control port for fast digital I/Q streaming, fast settling frequency hopping and fast address-driven I/Q playback.

All the signal sources in AnaPico's portfolio have common characteristics: phase coherence of ±0.2 to ±0.5-degree RMS phase variation at 5 GHz over 5 hours, with intermodule synchronization through a high frequency clock. After calibration, the frequency accuracy is ±10 ppb at room temperature, with drift of ±0.5 to ±5 ppb per day, optionally selectable. The units have low-power consumption, about 20 W per channel, and were designed to be compact. Four independent channels fit in a 1U 19-in. rackmount module.

PHASE COHERENCE

Based on years of microwave circuit design experience, AnaPico uses several approaches to achieve excellent multi-channel phase coherence. All output channels are digitally synthesized from a common, high frequency, phase-locked loop (PLL)-based reference; the PLL's controlled lock-in phase has very low phase noise. All the digital frequency synthesis channels use components selected for minimal additive noise, and all channels are packaged in a similar thermal environment to ensure same direction temperature changes and similar long-term drift. To achieve phase coherence between channels in different physical modules with independent frequency references, a 3 GHz synchronization signal is used, provided in addition to the references at 10, 100 and 1000 MHz.

Figure 1 shows the phase coherence performance of the APMS-X series. The blue curve represents the measured phase difference between two channels at 5 GHz. The two channels are in the same rack-mountable module set in a normal laboratory environment and measured over 10 hours. The phase difference varies across a small range: ±0.2 degrees RMS over 5 hours. The green curve shows the phase difference between two channels from two different rack-mountable modules and using the 3 GHz synchronization signal. All other conditions are the same as for the blue curve. Here, the phase difference variation is around ±0.5 degrees over 5 hours. The red curve repeats the measurement shown by the green curve, except a 100 MHz external reference for the inter-module synchronization signal is used rather than the 3 GHz reference. The larger phase error shows the benefit of using a higher reference frequency to achieve better phase stability.

PHASE-COHERENT SWITCHING AND MEMORY

The APMS-X and APSYN140-X series offer phase-coherent switching (option PHS), illustrated in ***Figure 2***. Once two channels are set to the same frequency, they will always have a deterministic relative phase position, i.e., the phase difference remains the same over time. When one of the channels changes frequency, it maintains the constant phase difference once both channels are again at the same frequency. Only the channel which changed frequency exhibits a phase discontinuity (see Figure 2a).

Option PHS also offers a feature called phase memory. Consider a single channel where the frequency hops. When the frequency hops back to the previous frequency, the phase returns to the prior state, as if the frequency never changed (see Figure 2b). For multi-channel sources, the phase memory feature quickly restores the "saved" phase difference after switching signal sources off and on.

Combining the phase-coherent switching and phase memory with the fast frequency settling characteristic of the signal sources enables the signal sources to configure a frequency hopping system that can be used to steer an antenna array with phase differences corresponding to sustained beam directions.

SUMMARY

AnaPico has developed multiple models of multi-channel and phase-coherent frequency synthesizers and signal generators for various market applications. AnaPico's microwave circuit design expertise enables phase coherence and phase-coherent switching with best-in-class phase noise performance among all the multi-channel signal sources in the market.

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Exhibition Dates	Opening Times
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Wednesday 16th February 2022	09:30 - 17:30
Thursday 17th February 2022	09:30 - 16:30

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The EuMW 2021 consists of three conferences, three forums and associated workshops:

- European Microwave Integrated Circuits Conference (EuMIC) 14th - 15th February 2022
- European Microwave Conference (EuMC) 15th - 17th February 2022
- European Radar Conference (EuRAD) 16th - 18th February 2022
- Plus Workshops and Short Courses (From 13th February 2022)
- In addition, EuMW 2021 will include the Defence, Security and Space Forum, the Automotive Forum and the Beyond 5G Forum

The three conferences specifically target ground breaking innovation in microwave research. The presentations cover the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers submitted. For the full and up to date conference programme including a detailed description of the conferences, workshops and short courses, please visit www.eumw2021.com. There you will also find details of our partner programme and other social events during the week.

How to Register

Registering as a Conference Delegate or Exhibition Visitor couldn't be easier. Register online and print out your badge in seconds onsite at the Fast Track Check In Desk. Online registration is open now, up to and during the event until 18th February 2022.

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- Receive an email receipt with barcode
- Bring your email, barcode and photo ID with you to the event
- Go to the Fast Track Check In Desk and print out your badge
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Registration opening times:

- Saturday 12th February 2022 (16:00 - 19:00)
- Sunday 13th - Thursday 17th February 2022 (08:00 - 17:00)
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1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	£430	£120	£600	£160	£600	£160	£830	£230
EuMIC	£330	£110	£460	£150	£460	£150	£640	£210
EuRAD	£290	£100	£410	£140	£410	£140	£570	£200
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	£600	£230	£840	£320	£840	£320	£1,180	£440
EuMC + EuRAD	£570	£220	£800	£300	£800	£300	£1,120	£430
EuMIC + EuRAD	£490	£210	£690	£290	£690	£290	£970	£410
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	£730	£330	£1,020	£460	£1,020	£460	£1,430	£640
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	Date	Delegates*	All Others**	Delegates*	All Others**
Automotive Forum	14th February 2022	£240	£290	£330	£390
Beyond 5G Forum	17th February 2022	£60	£70	£80	£90
Defence, Security & Space Forum	16th February 2022	£20	£60	£20	£60
European Microwave Student School	14th February 2022	£40	£40	£80	£80
Tom Brazil Doctoral School of Microwaves	14th February 2022	£40	£40	£80	£80

* those registered for EuMC, EuMIC or EuRAD ** those not registered for a conference

Workshops and Short Courses

Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumw2021.com at the time of registration for final workshop availability and numbering.

Sunday 13th February 2022			
WS01	EuMC	Full Day	Advances of wireless sensing in harsh and severe environments
WS02	EuMC/EuMIC	Full Day	Terahertz device, circuit and system fundamentals and applications
WS03	EuMC	Full Day	mmWave Plastic Waveguide High Data Rate Communication
WS04	EuMC	Full Day	New trends in microwave and mmWave filters
WS05	EuMC	Full Day	On-chip and scalable RF packaging solutions with integrated antennas for 5G mmWave and 6G applications
WS06	EuMC/EuMIC	Full Day	Progress and status of Gallium Nitride monolithically microwave integrated circuits
WS07	EuMC	Half Day AM	RF reliability status and challenges for 5G mmWave and 6G applications
WS08	EuMC	Full Day	Technology for RF 5G and satcom: from material to packaged demonstrators
WS09	EuMC	Full Day	Research in power and S-parameters measurements at mmWave and terahertz frequencies
SS01	EuMC	Half Day PM	Advanced non-linear characterization and design of highly efficient power amplifiers using load pull data for sub 6GHz and mmWave applications
SS02	EuMIC	Full Day	Fundamentals of microwave PA Design
SS03	EuMC	Half Day PM	5G mmWave OTA measurements – best practices for fast and reliable results
SS04	EuMC	Half Day AM	Terahertz technology, instrumentation and applications

Monday 14th February 2022			
WM01	EuMC	Half Day PM	Optimizing modulation quality measurements on wide bandwidth signals – from conformance through R&D
WM02	EuMC/EuMIC	Full Day	Advances in circuits and systems for mmWave radar and communication in silicon technologies
WM03	EuMC	Full Day	Sensing, imaging and biological tissues characterization using microwaves and mmWaves
WM04	EuMC	Full Day	RF on-wafer calibration and measurement eco-system workshop
WM05	EuMC	Half Day AM	Novel technologies for emerging on-board microwave equipment based on surface mounted electromechanical relays
WM06	EuMC	Full Day	Recent developments in wireless power transfer and energy harvesting
WM07	EuMC	Half Day AM	Beyond 5G: mmWave and terahertz techniques of 6G research
SM01	EuMC	Half Day AM	R&D trends and challenges in RFPAs for medium/high-volume products
SM02	EuMC	Half Day PM	Intuitive microwave filter design with EM simulation
SM03	EuMC	Half Day PM	Phase-noise in next-generation aerospace/defense and commercial wireless communications
SM04	EuMC	Half Day PM	Solid-state microwaves applications in industrial, scientific and medical fields

Wednesday 16th February 2022			
WW01	EuMC/EuMIC	Full Day	Technologies for 6G FEMs
WW02	EuRAD	Full Day	Virtual validation of automotive sensors
SW01	EuRAD	Half Day AM	Joint range-angle superresolution MIMO radar
SW02	EuRAD	Half Day PM	Radar design from the ground up

Thursday 17th February 2022			
WTh01	EuRAD/EuMC	Half Day AM	Advances in drone antenna measurement techniques for Satcom and RADAR applications

Friday 18th February 2022			
WF01	EuMC	Half Day AM	Advanced manufacturing and packaging
WF02	EuRAD	Half Day PM	Paradigm change in automotive mm-Wave radar applications – from technology push to demand pull
WF03	EuMC	Full Day	Innovative THz technologies for imaging, radar and communication
WF04	EuRAD	Full Day	Advanced processing and deep learning approaches for indoor sensing using short-range radars
SF01	EuMC	Half Day AM	AI techniques for microwave antenna and filter design: from theory to practice
SF02	EuMC	Half Day AM	Microwave superconductivity: applications of SQUID and Josephson junctions in microwave circuits

WORKSHOPS AND SHORT COURSES	IN COMBINATION WITH CONFERENCE REGISTRATION				WITHOUT CONFERENCE REGISTRATION			
	Society Member		Non-Member		Society Member		Non-Member	
	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
Half Day	£90	£60	£110	£90	£110	£90	£150	£110
Full Day	£120	£90	£160	£120	£160	£120	£220	£160

1–6 GHz, 600 W Solid-State Linear Power Amplifier

Exodus Advanced Communications has developed a solid-state power amplifier (PA) system for radiated susceptibility testing requirements, such as EMI-Lab and RS103, as well as communications and electronic warfare applications. The AMP2030D-LC PA covers 1 to 6 GHz and produces at least 600 W saturated output power across the band, 400 W typical at 1 dB compression, with 4 dB peak-to-peak power gain flatness. To support the linearity requirements of all modulations and industry standards, the PA uses a class A/AB design, achieving -20 dBc harmonics at rated output and -30 dBc typical two-tone intermodulation with two 48 dBm tones 1 MHz apart.

The PA has extensive control and monitoring, including optional calibrated power monitoring accurate to within ±0.2 dB. Monitoring can be done with the large 7-in. color display or via remote control. The color touchscreen also shows the forward and reflected power—providing the VSWR in real time—and system voltages and currents and the operating temperatures of the PA module heat sinks and internal system temperature. Automatic level control and > 20 dB gain control are accessible using the screen or the remote interface.

A unique feature of the AMP2030D-LC is its compact size: 10U, the smallest and highest power offered for this frequency range. The PA has type N female connectors for the RF input and optional RF sampling ports; to handle the high power, the RF output connector is a 716 female connector.

Exodus Advanced Communications' product line uses LDMOS, GaN HEMT and GaAs PAs, a good share of the devices manufactured by the company. In addition to PAs, Exodus designs low noise amplifiers, modules and systems for applications from 10 kHz to > 51 GHz.

VENDORVIEW

Exodus Advanced Communications
Las Vegas, Nev.
www.exoduscomm.com

Ultra-Flexible RF Cables Eliminate Right-Angle Adapters, Cover to 26.5 GHz

The Littlebend 26.5 GHz ultra-flexible SMA RF cables by HASCO are extremely flexible cables with a minimum bend radius of 0.20 in. (5 mm) and a high retention force of greater than 90 N, which eliminates the need for right-angle adapters, reducing weight and space. The HLB098 cable assemblies are triple shielded, which provides greater than 90 dB isolation. Phase and amplitude are stable with flexing, offering better performance than traditional RG type cables.

RoHS compliant, these lightweight, high performing cables are well suited for many applications needing low profile, high density, internal point-to-point interconnections between RF modules, including defense, communications, test and production applications. They support demanding requirements for phase stability and power handling and are durable in high vibration and temperature environments.

To illustrate the performance, a 12-in. SMA cable assembly (HLB098-S1-S1-12) has 0.5 dB insertion loss at 2 GHz, increasing to 1.5 dB at 26.5 GHz, with VSWR between 1.15:1 and 1.35:1 at 2 and 26.5 GHz, respectively. Amplitude stability is < ±0.08 dB at 26.5 GHz, and the phase stability with flexure is < ±3 degrees at 26.5 GHz when wrapped around a 26.4 mm radius mandrel.

The HLB098 Littlebend ultra-flexible RF cable series expands HASCO's line of flexible cable assemblies to more than 100 unique configurations, including SMA, 2.92 mm, 2.4 mm, SMP and SMPM connectors and lengths from 3 to 48 in. The Littlebend cables are in stock and can ship daily, with additional custom configurations available to order.

VENDORVIEW

HASCO, INC.
Moorpark, Calif.
www.hasco-inc.com/Littlebend

10 MHz to 10 GHz Low Noise Preamplifer for Boosting Small Signals

Langer EMV-Technik has introduced a 50 Ω preamplifier developed to work with Langer's near-field probes, boosting weak signals while protecting sensitive measurement receivers. The PA 3010 covers 10 MHz to 10 GHz and provides 30 dB typical gain, with a 2.5 dB noise figure at 5 GHz. The unit has a typical 1 dB compression point of 18 dBm at 5 GHz and will withstand 17 dBm input power without damage.

The PA 3010 connects with SMA connectors, female on the input and male on the output, and is small: 38 (between the connectors) x 50 x 14 mm. It is powered with 12 V DC and draws 170 mA, provided from a separate power supply "brick" that plugs into the AC power.

Because of the wide frequency range of the PA 3010, it can be used for many measurement and R&D applications, such as RF direction finding of communications signals. A typical application is providing amplification prior to a spectrum analyzer or oscilloscope, for example boosting the signals from Langer's near-field probes, where the preamplifier is connected between the probe and the measuring instrument.

In addition to preamplifiers, Langer EMV-Technik offers many products to support pre-compliant EMC measurements: near-field probes and micro near-field probes, EMC scanners, electrical fast transient and ESD generators and board and IC measurement equipment, including test and demo boards. Langer also provides EMC consulting and experimental seminars, including customized training.

Langer EMV-Technik
Bannewitz, Germany
www.langer-emv.com

500 to 1500 W SSPA Module Capabilities Brochure

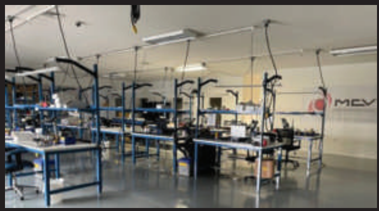
COMTECH PST offers rugged Pulse GaN SSPA modules for X-Band radar applications, operating at 8 to 10.5 GHz. See the new Capabilities Brochure to learn more.

COMTECH PST
www.ComtechPST.com

New ESD Floor at MCV Microwave East

MCV Microwave has recently completed wall-to-wall ESD flooring in Building 2 for integrated subassembly and hi-rel filter production.

MCV Microwave
www.mcv-microwave.com



2021 Test Solutions Product Guide

Mini-Circuits has many additions to their portfolio, including switch matrices and programmable attenuators up to 50 GHz, mesh network simulation racks and complex custom systems. Check out the 2021 Test Solution Product Guide for more info.

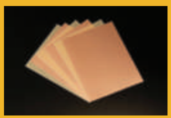
Mini-Circuits
https://bit.ly/3nFlhjd

Spectratime mRO-50

The Orolia mRO-50 is a breakthrough low SWaP-C miniaturized (51 x 51 x 20 mm) rubidium oscillator designed with outstanding stability and ultra-low power consumption (0.45 W).

Orolia
www.youtube.com/watch?v=UXrcwnXGkVo

MEGTRON Selection Guide from Panasonic



The MEGTRON family of circuit board materials products feature a unique dielectric system combined with smooth copper to deliver high speed/low loss performance and superior thermal properties.

Panasonic
https://bit.ly/3ultaNV

White Paper: How Wi-Fi 6E is Reshaping RF Security Requirements

RF security is important where sensitive information must be protected. By understanding the new standard, security professionals can ensure they have the tools to maintain control of the wireless spectrum.

thinkRF
https://thinkrf.com/wi-fi-6e-landing-page/

Spike™ Software Updates from Signal Hound

Updates to Signal Hound's powerful Spike analyzer software are ongoing and improving with their latest version 3.5.18 updates. Learn more about what's new here in this blog post.

Signal Hound

https://signalhound.com/news/

Smiths Interconnect Enhances Website with 3D Product Animation

Smiths Interconnect introduces 3D product animation to enhance customer experience and increase product awareness in the electronic components industry.

Smiths Interconnect

https://bit.ly/3B4ABdS

Testing Avionics Using Modular Instruments

Learn how Spectrum Instrumentation's 200+ modular signal acquisition and generation products are perfect for checking and troubleshooting an aircraft's data communications, power distribution and RF processing systems.

Spectrum Instrumentation

www.spectrum-instrumentation.com/aircraft

New Capability: 75 Ω D38999 Circular RF Cable Assemblies

High performance 75 Ω video connections are critical when HD video feeds from camera to receivers are needed. SV's D38999 contacts have a true 75 Ω impedance construction, thus assuring a high fidelity signal in 3G SDI, 4K and 8K video feeds.

SV Microwave

https://bit.ly/3AZW1cd

Cree Inc., is Now Wolfspeed Inc.

Cree, Inc. officially changed their company name to Wolfspeed, Inc., marking the successful transition to a pure-play global semiconductor powerhouse for high-power and RF applications.

Wolfspeed Inc.

www.wolfspeed.com/new-wolfspeed

Würth Elektronik Launches New Technical Podcast

Würth's online presentations, application notes, blogs, interviews and more are being offered through the new Watts Up Podcast, distributed weekly on multiple audio platforms. Produced, written and voiced by Amelia Thompson.

Würth Elektronik

www.we-online.com/podcast

RFIC 2022: IEEE Radio Frequency Integrated Circuits Symposium

Denver, CO, USA

June 19-21, 2022

RFIC IMS IEEE

RFIC 2022 Call for Papers

The **2022 IEEE Radio Frequency Integrated Circuits Symposium** (RFIC 2022) is the premier forum focused exclusively on presenting the latest research results in RF, millimeter-wave, and wireless integrated circuits.

Continuing in 2022: RFIC has expanded its focus to include systems, applications, and *interactive demonstrations*, including 5G systems, radar systems, terahertz systems, biomedical systems, and optoelectronic systems.

Technical Areas: The symposium solicits papers describing original work in all areas related to RF, millimeter-wave, THz, and wireless ICs and systems. Work must be demonstrated through IC hardware results and measurements.

- **Wireless Radios and Systems-on-Chip**: innovative circuit and system-on-chip concepts related to software-defined radio, cognitive radio, interference cancellation, full-duplex, advanced SOCs for cellular/WiFi, GPS, low-power radio circuits for sensors, IoT, Zigbee, biomedical applications, radio architectures suitable for energy harvesting, wake-up receivers, *etc*.
- **mmWave Communication Circuits and Systems-on-Chip:** >20GHz (*i.e.*, mmWave through THz) circuits and SOCs for wireless communication, including 5G, phase shifters, phased arrays, beamformers, and MIMO transceivers.
- **Radar, Imager, and Sensor Systems-on-Chip**: integrated radar, imaging, spectroscopy, and sensing circuits at microwave through THz frequencies, including vehicular radar SOCs.
- **Transmitters and Power Amplifiers:** for RF through mmWave frequencies and higher, power amplifiers, drivers, modulators, digital transmitters, advanced TX circuits, linearization and efficiency enhancement techniques, *etc*.
- **Front-End Circuits:** LNAs, mixers, VGAs, T/R switches, integrated FEM, amplifiers, filters, demodulators.
- **Analog and Mixed-Signal Circuits:** RF and baseband converters (ADC/DAC), sub-sampling/over-sampling circuits, converters for digital beamforming, converters for emerging TX and RX architectures, power (DC-DC) converters for RF applications, I/O transceivers and CDRs for wireline and optical connectivity.
- **Oscillators and Frequency Synthesizers:** VCOs, injection-locking frequency dividers/multipliers, PLLs, DLLs, MDLLS, DDS, LO drivers, frequency dividers.
- **Device/Packaging/Modeling and Testing Technologies:** RF device technology (both silicon and compound semiconductors), MEMs, integrated passives, photonic, reliability, packaging, modeling and testing, EM modeling/co-simulation, built-in-self-test (BIST).
- **Emerging Circuit Technologies:** MEMs-based sensors and actuators, 3D ICs, silicon photonics, quantum computing ICs, hardware security, novel terahertz solutions, and AI/machine learning applied to RF circuits.
- **RFIC System Applications**: system level innovations in RFICs with applications to communication, biomedical, radar and imaging. May include *interactive demonstration* and presentation. Additional details can be found on the RFIC website.

Format and Location: The 2022 symposium is currently planned as an in-person conference. More details to follow. In person events will be held at the Colorado Convention Center in Denver, CO. RFIC 2022 starts on Sunday, June 19, 2022 with a large selection of workshops followed by two plenary talks and a reception featuring our top industry and student papers. Monday and Tuesday, June 20-21 will be comprised of oral presentations, an interactive demonstration, and panel sessions.

Microwave Week 2022: RFIC 2022 kicks off *Microwave Week*. The week continues with the International Microwave Symposium and then the ARFTG Microwave Measurement Conference. This week, with more than 9000 participants, is the world's largest and most important gathering of RF and microwave professionals in the field.

Industry Exhibition: A three-day Exhibition typically showcases more than 900 Exhibitors who represent the state-of-the-art of the industry covering everything needed for RF and microwave design. More on the format of the 2022 Exhibition is found on both RFIC and IMS websites

Electronic Submission Deadlines

Technical Paper in PDF format:	**16 January 2022 (Sun.)**
Final Manuscripts for the RFIC Digest:	**23 March 2022 (Wed.)**

All submissions must be made at rfic-ieee.org in pdf form. Hard copies are not accepted.

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rfic-ieee.org

MTT-S SSCS EDS

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Author Registration and Paper Submission Steps:

1. All papers must be submitted via the website: rfic-ieee.org.
2. Author registration form: title, author(s) and affiliation(s), and statement of exclusivity. This form also includes a 30-50 word abstract (description of the subject, its importance, and how the work contributes to the field). This information is required and must be submitted via the website: rfic-ieee.org.
3. Authors must use the template provided on the website (above) to format their manuscript. **The manuscript may not exceed 4 pages total and the file size must be less than 2 MB. For PDF files, use Distiller and select "embed all fonts". Please note that we do not accept "*.doc" files.**
4. Authors must adhere to specific guidelines to ensure that the submission complies with our **DOUBLE-BLIND REVIEW PROCESS**. Details are provided on rfic-ieee.org. Pay close attention to how authors should cite their previous work.
5. Submission deadline: **16 January 2022.** *Submissions will be acknowledged instantly.* HARD copy or FAX submissions will not be accepted. Late submissions will not be considered.

Authors of accepted papers will be required to submit a final manuscript for publication, including a clear die photo of the work described in the manuscript.

Paper Selection Criteria: All submissions must be in **English.** Papers will be selected based on the following factors:

- **Originality**: The paper must be unique, significant, and state-of-the-art. Are references to existing literature included?
- **Quantitative content**: The papers should give an explicit description of the work with supporting data.
- **Quality:** Clarity of the writing and figures. What is the context of the contribution to previous work?
- **Interest to attendees**: Why should this work be reported at the RFIC Symposium?

Clearances: Authors must obtain all required company and government clearances prior to submitting a paper. A statement of clearance, signed by the submitting author, must accompany the final manuscript for the paper to be considered for publication.

Double Submission: Authors who do not properly cite their previous work, including concurrent IMS or other conference submissions, or who submit an RFIC manuscript to two or more publications without informing the editor/TPC chair that the paper is concurrently under review by another publication will be reported to IEEE and may be banned from future publications.

Notification: Authors will be notified of decisions on 9 March 2022. Authors of accepted papers will receive copyright release forms and instructions for publication and presentation. Final manuscripts for publication must be received by **23 March 2022.**

Presentation Format:

- ***Oral Presentation Papers:*** Authors will be given 20 minutes to describe novel circuit and system techniques, measurement results, and potential impact to the RFIC community.
- ***Interactive Demonstration Papers:*** Select papers from the RFIC System Applications area will be presented in poster format along with functional hardware demonstration.

All Authors must provide a PDF version of the presentation material for registered attendees to download during and after the symposium.

Visa Requirements: *Due to the short timeframe between paper acceptance and RFIC, contact authors should provide their name as it shows on their passport and correct mailing address.*

Student SUPERPASS: RFIC enthusiastically invites participation from students at all levels to attend Microwave Week. All students will be offered the opportunity to purchase a SUPERPASS allowing access to RFIC, IMS, ARFTG, all workshops, technical lectures, panels, and more. SUPERPASS prices are significantly discounted to encourage participation.

Best Student Paper Award: A student paper award contest will be held as part of RFIC. Student papers will be reviewed in the same manner as all other papers. To be considered, the author must have been a full-time student (9 hours/term graduate, 12 hours/term undergraduate) during the time the work was performed **and** be the lead author and presenter of the paper. *The email address of the student's advisor must be supplied during submission time and will be used to verify student eligibility*. Complimentary registration will be given to the student finalists. *Finalists will present a poster at Sunday's Symposium Showcase.*

Industry Best Paper Award: An industry paper award contest will be held as part of RFIC. Industry papers will be reviewed in the same manner as all other conference papers. Only papers with an industrial first author **and** presenter will be qualified for the Industry Best Paper Award. *Selected finalists will also present a poster for Sunday's Symposium Showcase.*

Invited Journal Articles: Select authors will be invited to submit an expanded manuscript to the RFIC special issue in *IEEE Journal of Solid-State Circuits*. In addition, all authors are invited to submit an expanded version of their papers to a special issue of *IEEE Transactions of Microwave Theory & Techniques*.

Three Minute Thesis (3MT®): A full-day Sunday program on presenting technical work for broader audiences, concluded by a 3MT® competition. Student and young professional participants are selected based on RFIC paper acceptance and a subsequent video submission.



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COMPONENTS

30 GHz Chip Attenuators

APITech's newest Powerfilm chip attenuators are optimized for radar, T/R modules, E/W, mmWave and 5G applications up to 30 GHz (and beyond). Delivering best in class performance, the PCA3060 series handles up to 1 W of power in an 0603 size package. Attenuation values range from 0 to 10 dB in 1 dB increments, 10, 12, 15 and 20 dB. Delivers uniform power reduction over frequency and temperature. Grab your copy of the Powerfilm selection guide.

APITech
www.apitech.com

Digital Attenuator

COMTECH PST Component Division introduced a new digital attenuator for applications in the UHF band. The design operates over the 400 to 500 MHz frequency range intended for use in military or commercial applications. The attenuator provides 0 to 60 dB of range. The accuracy achieved is exceptional when changing attenuator steps. Switching speed is very fast when attenuation needs to be changed. Other frequencies, attenuation ranges and performance characteristics can be achieved for other applications, contact COMTECH PST's sales department.

COMTECH PST
www.comtechpst.com

Stripline Directional Couplers

Stripline directional couplers are available for purchase at Electromagnetic Technologies Industries (ETI). ETI directional couplers meet stringent requirements such as high directivity, low VSWR and a wide frequency range of 0.4 to 67 GHz that is suitable for enhanced RF signal sampling. ETI coupling values are offered at 10, 13, 16, 20 and 30 dB with the necessary coaxial connectors, such as SMA, K, 2.4 mm, 1.85 mm and N-type. Guaranteed to attain high-quality electrical performance, ETI directional couplers are ideal for the most challenging engineering applications.

Electromagnetic Technologies Industries
www.etiworld.com

Radial Leaded Capacitors

A range of radial leaded capacitors available in sizes 1515 to 7565 designed to operate from -55°C to 200°C in C0G/NP0 and Class II dielectrics with voltage ratings of 25 V to 4 k V. These capacitors find typical application in harsh environments such as oil exploration and automotive/avionics engine compartment circuitry. The epoxy coating ensures environmental protection and a rugged configuration for optimum performance. They are also offered without the conformal coating for less harsh applications.

Knowles Precision Devices
www.knowlescapacitors.com

Directional Coupler

VENDORVIEW

KRYTAR Inc. announced the addition of a new model offering 30 dB of coupling over the broadband frequency range of 18 to 40 GHz (K- through Ku-Bands), in a single, compact and lightweight package. KRYTAR's new directional coupler, model 184030, enhances the selection of multi-purpose, stripline designs that exhibit excellent coupling in a single, compact and lightweight package. The directional coupler is uniquely designed for systems applications where external leveling, precise monitoring, signal mixing or swept transmission and reflection measurements are required.

KRYTAR Inc.
www.krytar.com

Limiter

VENDORVIEW

PMI Model No. LM-150M5G-200CW-2KWPK-AGAL is a limiter that operates over the 0.15 to 5.0 GHz frequency range. It has a maximum insertion loss of 2.0 dB and a maximum recovery time of 100 ns. This model is outfitted with SMA female connectors in a housing measuring 1.00" × 0.68" x 0.35".

Planar Monolithics Industries
www.pmi-rf.com

Custom Surface-Mount Filters

3R Wave is now offering through Richardson custom surface-mount filters, including ceramic, LC and substrate integrated waveguide types for frequencies from 10 MHz to 30 GHz. These high performance, low-cost designs can be developed rapidly and are ideal for applications including 5G infrastructure, mobile communications, satcom and defense and radar.

Richardson Electronics
www.rell.com

Front-End Modules

Skyworks' front-end modules (FEMs) are designed for high-power Wi-Fi 6E applications including indoor and outdoor networking, and wireless video streaming. The SKY85784-11 features extremely low EVM floor while simultaneously providing ultra-high linear output power that can meet the regulatory limit, therefore improving overall range coverage. In addition, Skyworks has also released the SKY85780-11, a high performance FEM, which is the only solution on the market to maximize distance and throughput within FCC maximum output power limit.

Skyworks Solutions Inc.
www.skyworksinc.com

Optical Transceivers

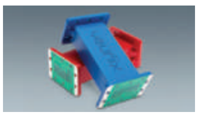
VENDORVIEW

The SpaceABLE® Series allows the interconnection and routing of an overall throughput of more than 15 Terabit/s and permit the use of the full Ka beam antennas bandwidth while being considerably lighter and more scalable than copper interconnects. The SpaceABLE® transceivers are engineered to withstand radiation doses > 100 krad (Si). The modules operate at up to 28 Gbps per channel over an operating temperature range of -40°C to 85°C at ultra-low bit error rates, with an expected life of over 20 years.

Smiths Interconnect
www.smithsinterconnect.com

5G Mitigation Filters

VENDORVIEW



Vaunix has announced the release of a new line of red and blue Lab Brick® waveguide filters designed for use as 5G interference mitigation devices in today's complex satellite communication (satcom) systems. (5) C-Band models are available in these popular designated satcom application frequency bands: 3,780 to 4,200 MHz; 3,820 to 4,200 MHz, 3,900 to 4,200 MHz, 4,000 to 4,200 MHz and 4,020 to 4,200 MHz. Each model features an impressive

insertion loss of just 1.1 dB with excellent rejection and return loss characteristics.
Vaunix
www.vaunix.com

CABLES & CONNECTORS

Ultra-Wideband 3-Way Power Divider/Combiner

MIcable 0.5 to 40 GHz ultra-wideband 3-way power divider/combiner covers multiple microwave frequency bands such as P, L, S, C, X, Ku, K and Ka by a single unit. It has excellent performance with insertion loss 4.3 dB, amplitude unbalance ±0.8 dB, phase unbalance ±9-degree and isolation 16 dB. As the power divider, it can stand for 20 W CW power, as the combiner, the input power with phase unbalance is 2 W. It is good for applications like test, instrument and other wideband systems.
Fujian MIcable Electronic Technology Group Co., Ltd.
www.micable.cn

Flexible Coax Assemblies

STEADY LINK™ Series-C Flexible RF50 Coax Assemblies with Nex10* connectors have been designed to provide durable and reliable connections for transmitters, receivers, antennas and other applications in antenna feeder systems on cell towers. These new assemblies feature low VSWR and strong shielding effectiveness to reduce energy loss and provide protection from outside interference. As such, the Series-C Flexible RF50 Coax Assemblies with Nex10* connectors are well suited for connections in low loss and VSWR signal transmission at high frequency applications.
NAI Group
www.nai-group.com

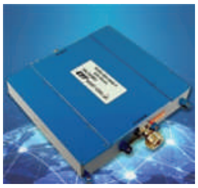
16 AWG, Low Loss SMA Cable Assemblies

Samtec recently released .178", 16 AWG cable assemblies with solder clamp SMA connectors (RF180 Series). SMA straight jack, and straight or right-angle plugs are available. The larger diameter, flexible cable is ideal for applications requiring lower loss over longer distances, with an operating frequency up to 18 GHz. Applications include military/aerospace and test & measurement. N-type and TNCA connectors for RF180 Series are in development.
Samtec
www.samtec.com

AMPLIFIERS

GaN-Based 630-W SSPA

CTT Inc. announced a new compact, GaN-based solid-state power amplifier (SSPA) specifically designed for multifunctional low earth orbit, small satellite and airborne synthetic aperture radar systems.



CTT's latest compact SSPA designs offer 630 W of pulse power output in a compact package. It is engineered specifically to meet the stringent requirements imposed by many multifunction system designs. The new SSPA operating at 9.4 to 9.9 GHz, within the 8 to 12 GHz frequency segment (X-Band), is one of the more "Application Rich" portions of the electromagnetic spectrum.
CTT Inc.
www.cttinc.com

6 to 18 GHz, 100 W

VENDORVIEW

Exodus AMP2033-LC is designed for replacing aging TWT technol-

New**Products**

ogy. A broadband, rugged EMC Class A/AB linear design for all modulations and industry standards. Covers 6 to 18 GHz, produces > 100 W Minimum, 50 W P1dB, with a minimum 50 dB gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb-reliability. Exodus Quiet-Cool technology in its compact 5U-chassis weighing a nominal 75 lbs.

Exodus Advanced Communications
www.exoduscomm.com

Variable Gain Amplifiers

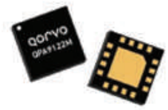
VENDORVIEW

Pasternack has just introduced a new series of variable gain amplifiers to address applications including instrumentation, sensors, radar, wireless communications, automatic gain control loops and more. Variable gain amplifiers give designers the ability to vary the level of the broadband gain response using a DC voltage control and deliver unmatched performance for signal chains that require high dynamic range.

Pasternack
www.pasternack.com

High Gain mMIMO Driver Amplifier

VENDORVIEW



RFMW announced design and sales support for a high gain and high linearity driver amplifier. The Qorvo QPA9122M provides 36.5 dB gain at 2.6 GHz and achieves a peak power of 27 dBm P3dB. The amplifier can provide good DPD linearity performance with up to 200 MHz wide 5G NR signals, making it perfectly suited for 5G mMIMO applications, TDD/FDD systems and wireless infrastructure systems. Housed in a 16-pin 3 × 3 mm SMT package.

RFMW
www.rfmw.com

Low Phase Noise GaAs MMIC Amplifier

Richardson RFPD, Inc. announced the availability and full design support capabilities for a GaAs MMIC amplifier from Analog Devices, Inc. The ADL8150 is a self-biased GaAs MMIC, heterojunction bipolar transistor, low phase noise amplifier that operates from 6 to 14 GHz. The amplifier has low phase noise of -172 dBc/Hz at 10 kHz offset and provides 12 dB of typical signal gain and +30 dBm typical output third-order intercept.

Richardson RFPD
www.richardsonrfpd.com

SYSTEMS/SUBSYSTEMS

Laser Resistor Trimming Systems

PPI continues to expand the range of advanced fixturing and probing solutions for its laser resistor trimmers with a unique combination of backside contacts and topside probing. This complements the capabilities of the RapiTrim family of products that covers all trimming requirements from thick film to thin film to semiconductor wafers. From standard component and circuit trim to complex active-trim scenarios with custom fixturing, the RapiTrim products are the future of resistor trimming.

PPI Systems
www.ppisystems.com

SOURCES

Voltage Controlled Oscillators

VENDORVIEW

Fairview Microwave Inc. has just unveiled a new line of voltage controlled oscillators (VCOs) designed to address a wide range of satcom, electronic warfare, VSAT, ECM, radar and test and measurement applications. Fairview Microwave's new series of coaxial packaged, VCOs includes 15 models that cover broad frequency bands and exhibit excellent tuning linearity, phase noise and harmonic suppression performance.

Fairview Microwave Inc.
www.fairviewmicrowave.com

ANTENNAS

Ultra-Wideband Antennas

The Antenna Company announced a family of ultra-wideband (UWB) antennas to enable high precision positioning and angle-of-arrival applications for low-power sensors, anchors and tags. The antennas support worldwide operation on UWB channel 5 (6.5 GHz) and channel 9 (8 GHz). UWB technology enables a location accuracy of 10 cm for real-time location services such as access control, asset tracking, peer-to-peer communication and contact tracing. Applications which utilize 2-way ranging, time-difference of arrival or phase difference of arrival are also supported.

The Antenna Company
www.antennacompany.com

Quad Ridged Horn Antenna

The QRH40 (Quad Ridged Horn Antenna) from industry leader RF SPIN is the widest bandwidth solution on the market, covering the

New**Products**

frequency range from 4 to 40 GHz. It is designed with two coaxial ports that allow measurements with horizontal and vertical polarization in parallel mode or switching between polarizations using an external switch (optional) without rotating the antenna. This is recommended for radio measurements, radio monitoring, microwave equipment testing and EMC tests. Impulse Technologies has stock and can provide same day shipping.

Impulse Technologies Inc.
www.impulse-tech.com

TEST & MEASUREMENT

75 Ohm Calibration Module

ACM2708 is an automatic calibration module that can be used with CMT vector network analyzers (VNAs) operating in frequency range up to 8 GHz. The ACM 2708 is a 75 Ohm calibration module for use with native 75 Ohm VNAs (S7530) while also covering automatic calibration for 50 Ohm VNAs with the use of 50 to 75 Ohm matching pads. It is a fully automatic USB-controlled and powered electronic calibration module. Minimizing the number of steps required by technicians reduces the risk of human error and expedites the calibration process.

Copper Mountain Technologies
www.coppermountaintech.com

Wave-Glide™ Rail Positioning Systems

VENDORVIEW

Wave-Glide™ rail positioning systems provide an easy and highly repeatable approach to high volume testing of waveguide components. Developed to enhance the operation of VNA frequency extenders, Wave-Glide™ configurations are adaptable to a range of measurement scenarios that rely on good alignment between DUTs and test system ports. Proven advantages include excellent repeatability, fast measurement results and reduced mechanical stress on DUTs and test system hardware.

Eravant
www.eravant.com

SPDT Switch Matrix

VENDORVIEW

Mini-Circuits' model RC-8SPDT-50 is a mmWave switch matrix for applications from DC to 50 GHz. It consists of eight single-pole/double-throw electromechanical switches in a fail-safe, reflective configuration; the switches are rated for two million switching operations. Operated by computer/software Ethernet or USB connection, the 50 Ω switch matrix has 5 ms typical switching speed and is ideal for test and measurement applications. Typical path loss is 0.4 dB or less to 50 GHz while typical VSWR is 1.35:1 or less to 50 GHz. Full-band isolation is typically 80 dB with typical isolation to 100 dB at 12 GHz and below.

Mini-Circuits
www.minicircuits.com

Spectrum Rider FPH

VENDORVIEW

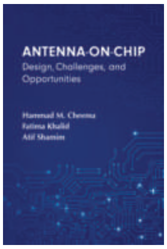
Rohde & Schwarz has extended its popular R&S Spectrum Rider FPH family with the introduction of new base models offering measurement frequencies up to 44 GHz. A

new 44 GHz model has been added to the existing R&S FPH models having measurement frequencies from 5 kHz to 6, 13.6 and 26.5 GHz. In addition, three new versions with tracking generators are available with measurement frequencies up to 13.6, 26.5 and 44 GHz.

Rohde & Schwarz
www.rohde-schwarz.com

MICRO-ADS

BookEnd



Antenna-on-Chip: Design, Challenges, and Opportunities

Hammad M. Cheema, Fatima Khalid, Atif Shamim

Antennas are an essential part of every wireless communication system. The growing trend of applications in the RF and mmWave frequency spectrums has reduced antenna sizes to only a few millimeters, thus making it practical for on-chip implementations. IC designers, who have traditionally remained isolated from antenna design, now need to understand its design process and trade-offs. This comprehensive resource addresses the challenges and benefits of on-chip antenna implementation.

The book presents practical design and integration considerations of ICs and antenna combination and explains how both ends of the system can be utilized in a complementary way. It includes on-chip antenna layout considerations and layout for testability and various methods of characterization. It also includes state-of-the-art on-chip antennas in Si IC technologies and their usage in transmitter and receiver ICs followed by an end-to-end design example. The book concludes with a look at future trends and utilization of on-chip antennas for different applications.

To order this book, contact

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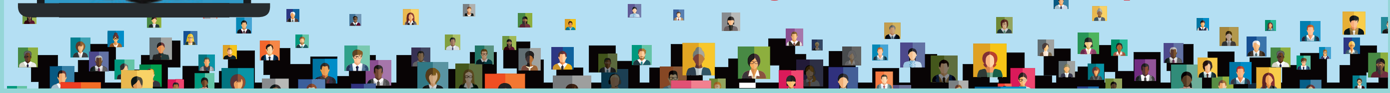

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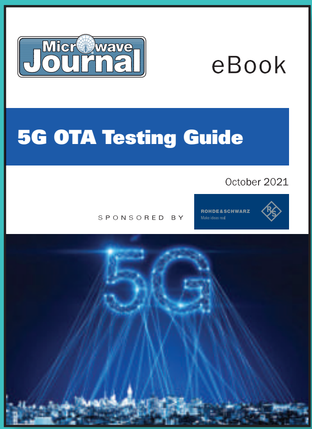

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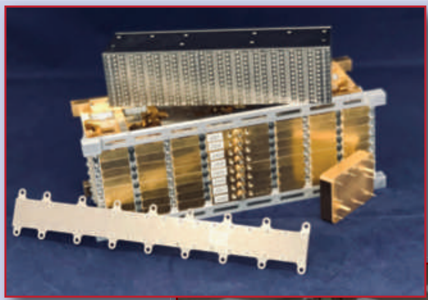
FABS and LABS

TRM Microwave: Building On A Long Heritage for a New Generation of Growth



TRM Microwave is one of the RF/microwave industry's marathoners. 51 years ago, three guys tired of working for a large company formed Technical Research & Manufacturing Inc. and started building components for cable television. Over the years, the name became TRM Microwave, and the company focused its growing capabilities on the defense market. Approximately 90 percent of its business supports defense, the rest space missions.

TRM's products comprise passive RF/microwave components, integrated assemblies and subsystems. A large catalog of RF/microwave circuit functions—beam formers, power dividers, couplers and hybrids—are available as stand-alone products; more often, though, they are the building blocks for integrated assemblies. These extensive component designs give customers confidence that TRM has the knowledge and production capability to execute challenging programs.

As system designers move to replace traveling wave tube amplifiers, TRM is seeing a growing demand to develop combiners for GaN power amplifiers. In addition to low loss, high-power combiners must dissipate the heat generated by the reflected power from the devices. The company's engineers are developing innovative approaches to handle this thermal management challenge, which is opening doors to directed energy and missile programs.

To support its growth, TRM expanded its facility earlier this year, doubling the size of its Bedford, N.H., site to some 25,000 square feet. The firm added a two-story extension to its existing building, then retrofitted the original so the two look the same. The expansion created two manufacturing floors, one for standard production, the other for new product development. The added space enabled the standard production flow to be aligned with the value stream, including an investment in separate environmental rooms with ovens and vibration tables to support each production area. The expansion also included a computer managed carousel stock room for precise inventory control.

TRM's expansion followed a successful three-year mentor-protege program sponsored by the U.S. Missile Defense Agency. Raytheon served as the mentor to help TRM improve its business processes and management. Although the formal program has completed, the lessons and benefits continue through the company's continuous improvement culture.

In January, TRM was acquired by Quantic Electronics, a private equity firm formed by Arcline Investment Management that invests in electronics companies serving high performance and high reliability applications. Quantic's companies, now numbering a dozen, offer different products but largely serve the same customers. Each company operates independently, and Quantic helps cross-pollinate new business opportunities among them. This strategy has already provided a stream of new opportunities for TRM. With time, it will lead to collaboration among the companies, combining their capabilities to offer more integrated solutions. The financial scale of Quantic Electronics will also enable investments that TRM could not manage by itself.

The reason Quantic would find TRM an attractive acquisition is clear: during a half-century, TRM has developed a heritage of technical expertise, customer focus and program execution while retaining the flexibility and agility of a small company with a strong team culture. TRM's goal is solving complex RF/microwave challenges, getting customers what they need, when they need it—because beyond the customer are the men and women serving the nation. TRM wants them to get home safely at the end of the day.

www.trmmicrowave.com

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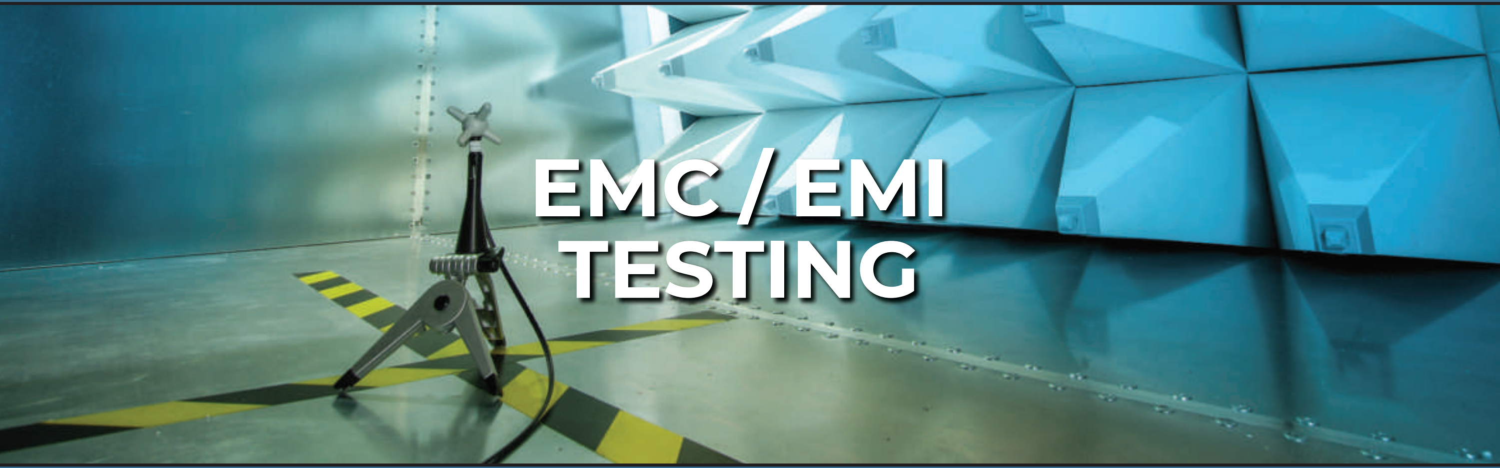

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C8730	Dual	0.009-250	500	40	0.40	N-Female	10.5 x 3.0 x 2.0
C8731	Dual	0.009-250	1000	40	0.40	N-Female	10.5 x 3.0 x 2.0
C11462	Dual	0.009-400	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C8510	Dual	0.009-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C5047	Dual	0.01-100	4,000	50	0.15	7/16-Female	10.0 x 4.16 x 3.5
C1979	Dual	0.01-100	10,000	60	0.10	LC-Female	2.0 x 6.0 x 4.5
C5086	Dual	0.01-250	250	40	0.50	N-Female	5.2 x 2.67 x 1.69
C5100	Dual	0.01-250	500	40	0.40	N-Female	10.5 x 3.0 x 2.0
C5960	Dual	0.01-250	1,000	50	0.40	N-Female	10.5 x 3.0 x 2.0
C1460	Dual	0.01-250	2,000	50	0.15	N-Female	10.0 x 3.0 x 2.0
C4080	Dual	0.01-250	3,500	50	0.20	N-Female	10.0 x 4.6 x 3.5
C11026	Dual	0.01-220	5,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C8390	Dual	0.01-250	10,000	60	0.10	LC-Female	12.0 x 6.0 x 4.5
C5339	Dual	0.01-400	200	40	0.50	N-Female	5.2 x 2.67 x 1.69
C6047	Dual	0.01-400	500	40	0.50	N-Female	5.2 x 2.67 x 1.69
C2630	Dual	0.01-1000	100	40	0.60	N-Female	5.0 x 2.0 x 1.51
C6021	Dual	0.01-1000	500	40	0.45	N-Female	6.7 x 2.28 x 1.69
C6277	Dual	0.01-1000	500	50	0.45	N-Female	6.7 x 2.28 x 1.69
C11146	Dual	0.01-1000	500	43	0.45	SC-Female	6.7 x 2.63 x 2.20
C11047	Dual	0.01-1000	1,000	43	0.45	SC-Female	6.7 x 2.63 x 2.20
C11161	Dual	0.01-1000	1,000	50	0.45	SC-Female	6.7 x 2.63 x 2.20
C1795	Dual	0.1-1000	100	40	0.50	N-Female	5.0 x 2.0 x 1.51
C5725	Dual	0.1-1000	500	40	0.50	N-Female	5.2 x 2.28 x 1.69
C11077	Dual	0.1-1000	1,000	43	0.45	SC-Female	6.7 x 2.28 x 1.69
C3910	Dual	80-1000	200	40	0.20	N-Female	3.0 x 3.0 x 1.09
C5982	Dual	80-1000	500	40	0.20	N-Female	3.0 x 3.0 x 1.09
C3908	Dual	80-1000	1,500	50	0.10	7/16-Female	3.0 x 3.0 x 1.59
C6796	Dual	80-1000	5,000	60	0.20	1 5/8" EIA	6.0" Line Section
C8060	Bi	200-6000	200	20	0.40	SMA-Female	1.8 x 1.0 x 0.56
C8000	Bi	600-6000	100	30	1.10	SMA-Female	4.8 x 0.88 x 0.50
C10117	Dual	700-6000	250	40	0.20	N-Female	2.0 x 2.0 x 1.06
C10364	Dual	700-6000	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10996	Dual	700-6000	700	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C11555	Dual	700-6000	1,000	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10695	Dual	700-6500	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36

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