Vol. 60 • No. 10

October 2017

# Microwave Journal

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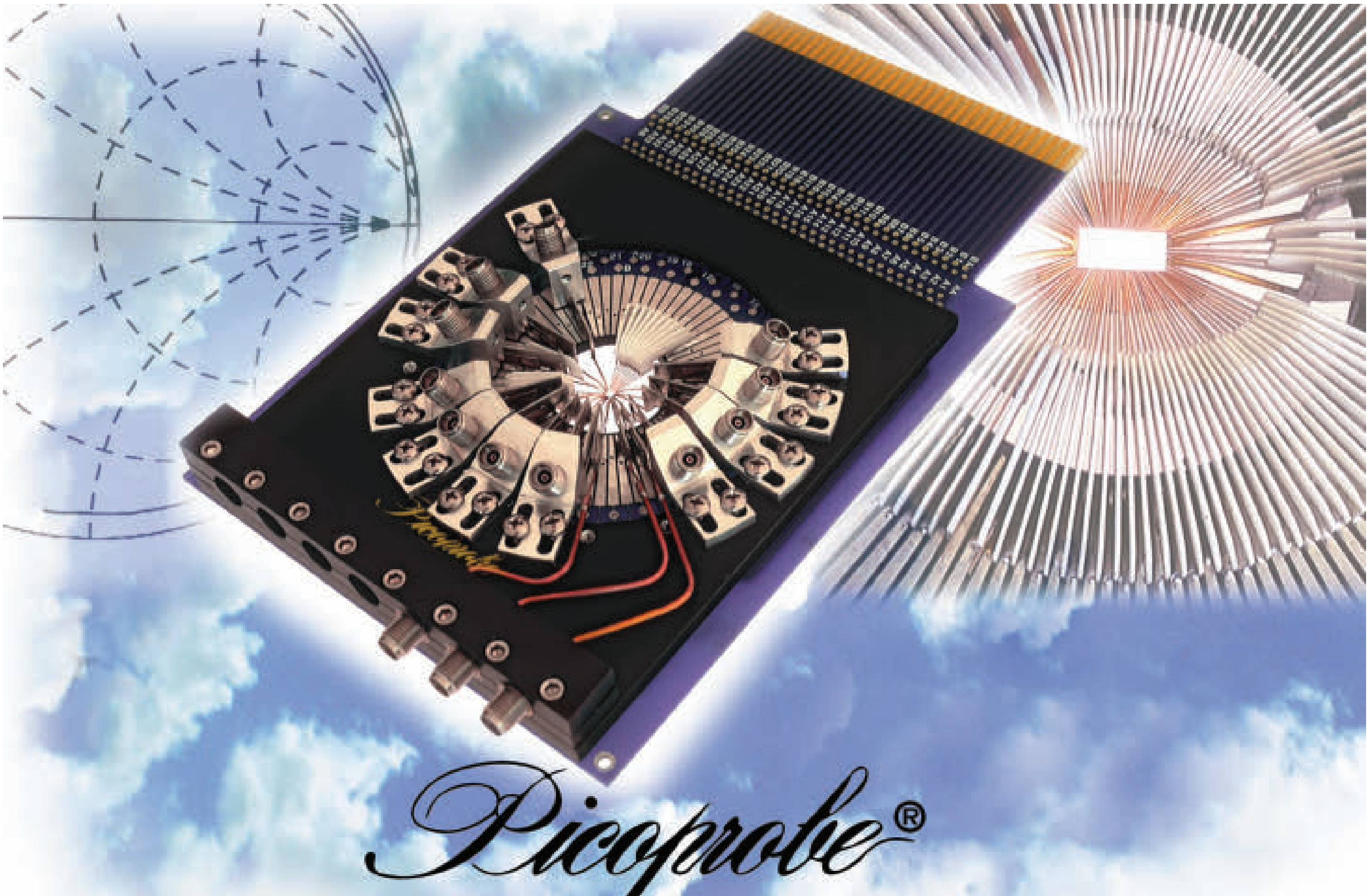


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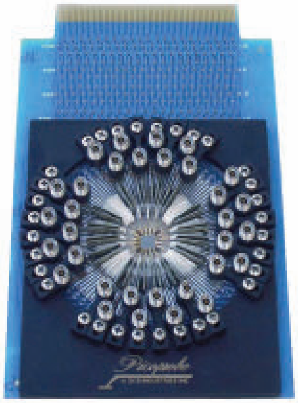

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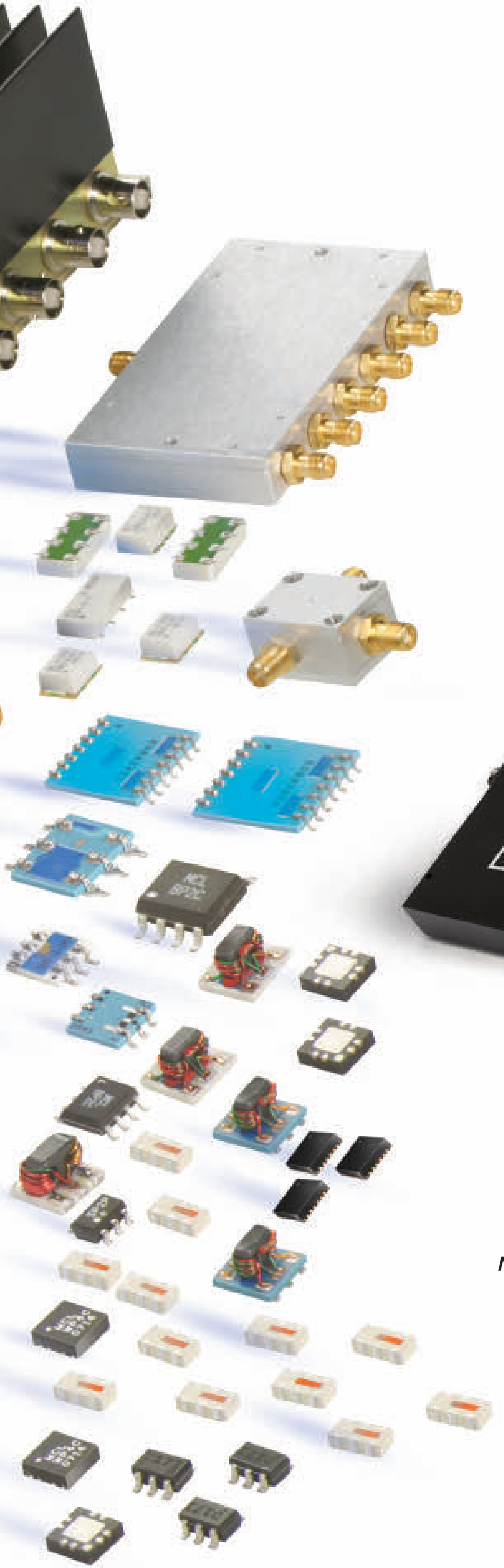



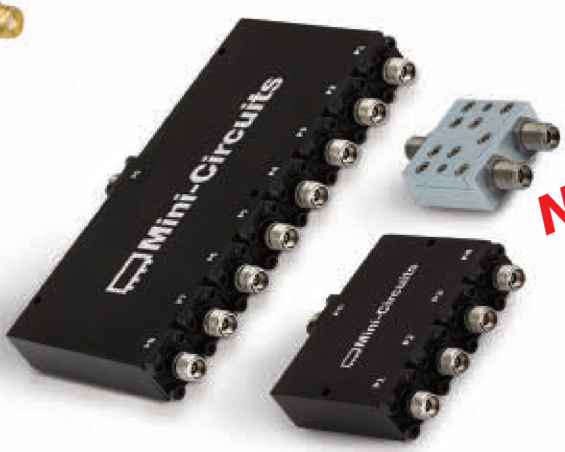

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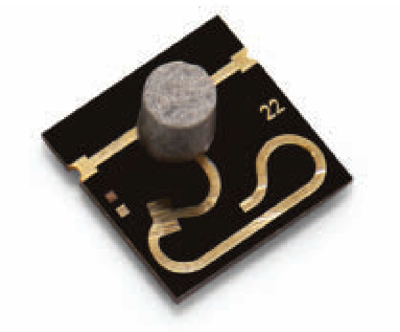

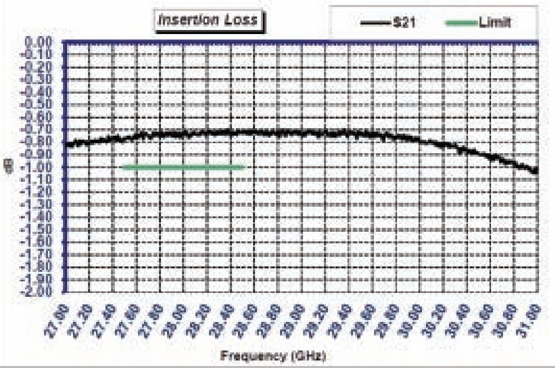


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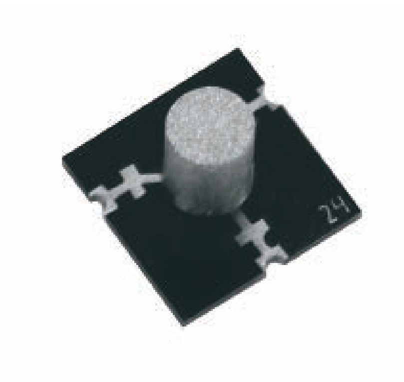

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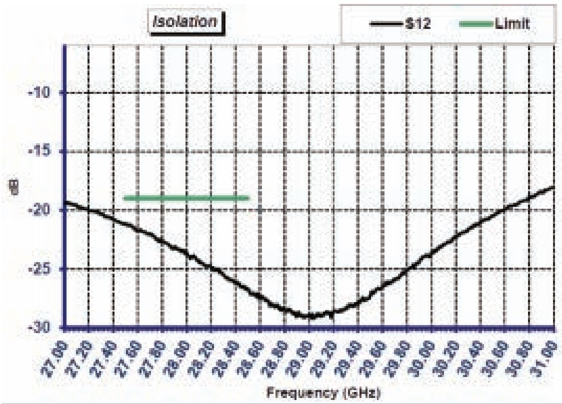


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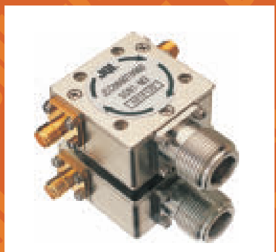

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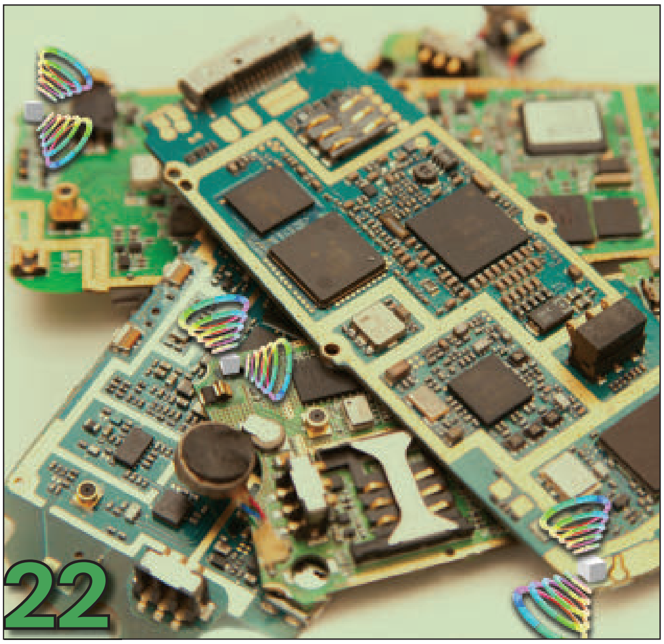



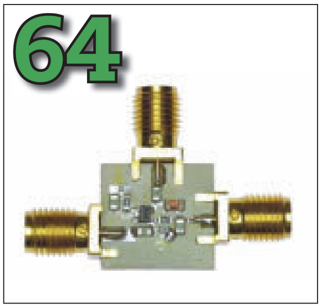


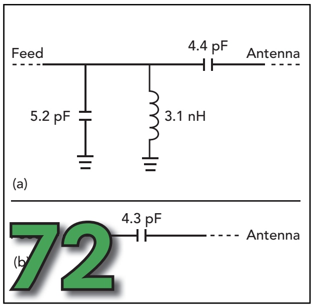


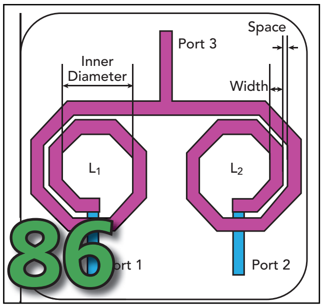


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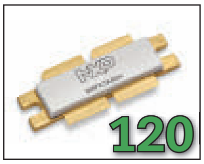


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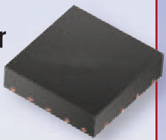

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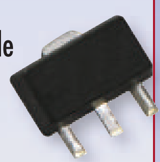

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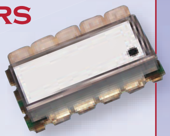

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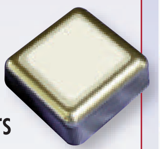

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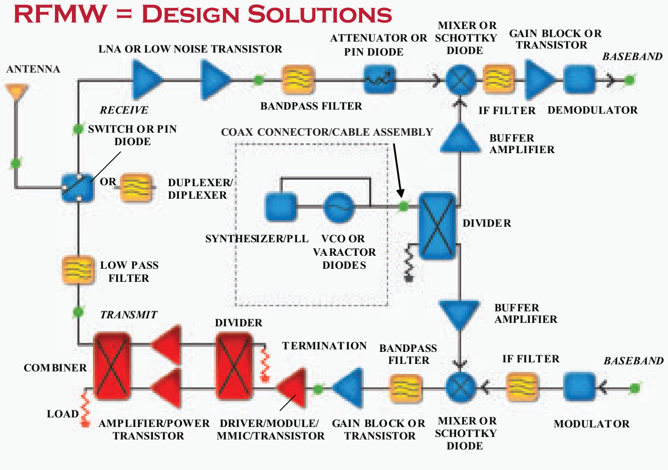


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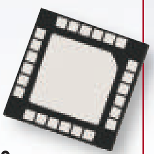

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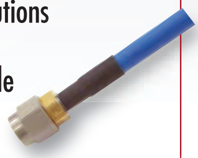

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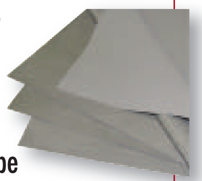

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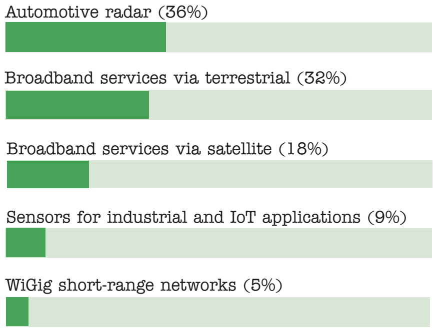


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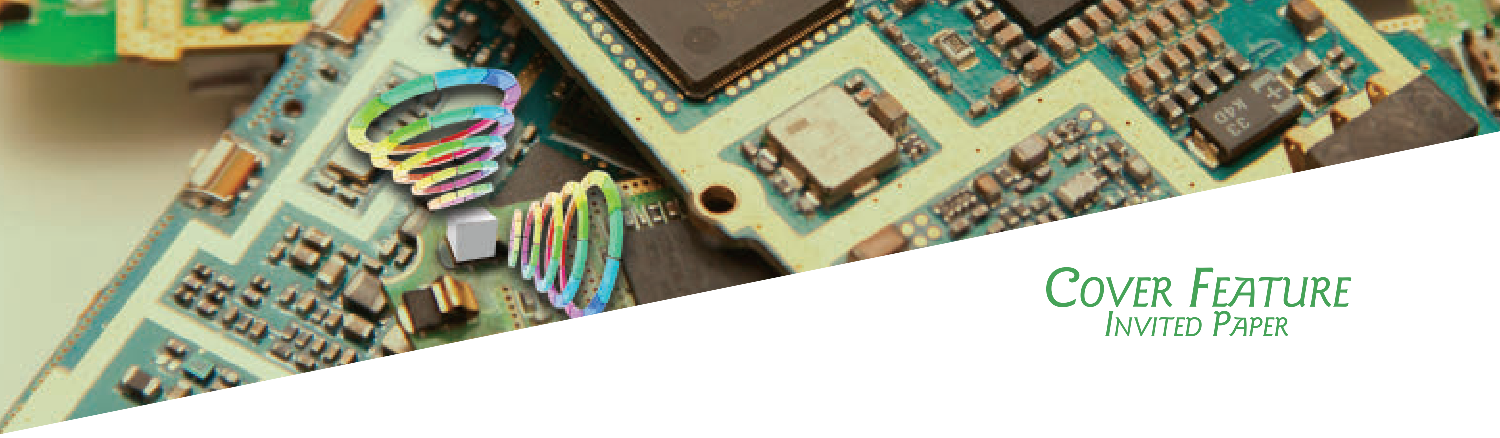




# Antenna-Less Wireless: A Marriage Between Antenna and Microwave Engineering

J. Anguera, A. Andújar and C. Puente
*Fractus Antennas, Sant Cugat del Vallés, Barcelona, Spain*

For many decades, antenna and microwave engineering have been adjacent yet fairly separate disciplines. Both have experienced such a high degree of specialization and sophistication that experts in one area would rarely dispute the expertise of someone in the other. While microwave engineers have largely focused on taming the radio waves through all sorts of active (amplifiers, oscillators, active tuners, etc.) and passive (filters, couplers, splitters, etc.) devices, antenna engineers have been exploring new and creative ways to free the waves through increasingly complex fractal-based and related antenna geometries. However this divide may radically change with the introduction of "antenna-less" technology, a technology which makes antenna design much more similar to filter design than to conventional antenna engineering.

Antenna-less technology is based on replacing a complex and usually customized antenna design with an off-the-shelf, standardized, miniature component called antenna booster. Being surface-mount and chip-like in nature, the antenna booster fits seamlessly in an electronic printed circuit board, the same way any other electronic component does, such as a microprocessor, memory, amplifier, filter or switch. It can be assembled with a conventional pick-and-place machine, making the design and manufacture of the next generation of IoT/mobile or wireless devices simpler, faster and more effective.

Miniature chip antennas have been available to antenna and microwave engineers for decades, so what is so radically different about these new antenna boosters that make them worth paying some attention to? The radical innovation is their multiband capability. While conventional miniature chip antennas were based on high-permittivity ceramics and delivered adequate performance for narrowband, single frequency applications (e.g., Bluetooth and GPS), the new antenna-less boosters can deliver full mobile performance within a broad range of frequency bands (e.g., 698 to 2690 MHz) with a single part number. Moreover, their manufacturing is based on conventional low-cost materials (e.g., epoxy-glass substrates or stamped-on-plastics assemblies), making this off-the-shelf solution potentially low-cost at very large production volumes.

An illustration of the radical change that the antenna-less technology means for the design of a new generation of mobile/IoT devices is shown in ***Figure 1***. From the old stubby, external monopole/dipole antennas in early phones to the newest antenna boosters, antenna technology has experienced a tremendous evolution in a race for increasing the number of frequency bands within an always decreasing component size.

Both the challenges of increasing the number of bands and reducing the antenna space have always been met with the mantra that every antenna engineer knows: "one antenna size, one wavelength." Despite the progress of antenna technology in providing more and

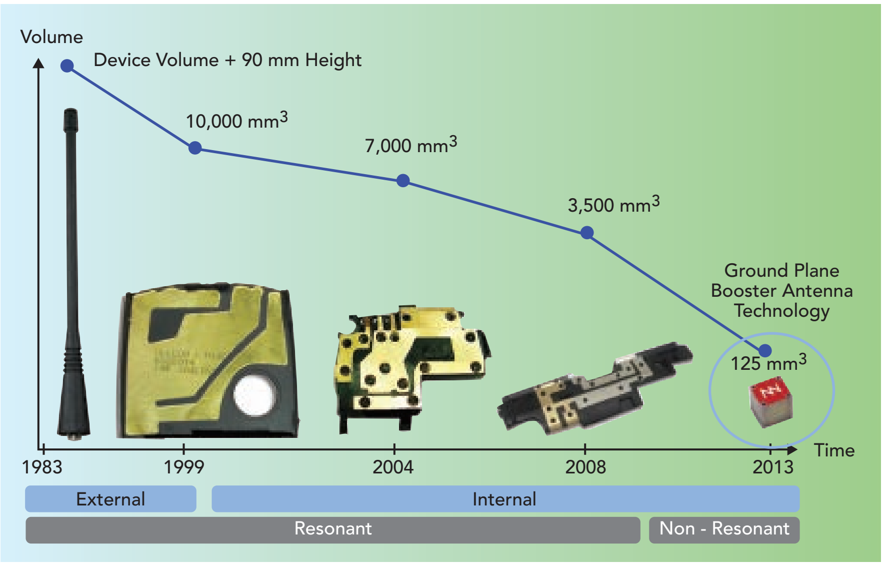



**Fig. 1** Antenna evolution, from the external single-band antennas to the miniature antenna boosters.

more complex shapes to accommodate many bands in a small space, between 2008 and 2012 it seemed that technology had reached a fundamental limit, where antenna size could not be further reduced. After all, the well-known fundamental limit established by Chu and Wheeler in the 1940s states that any device which is much smaller than the operating wavelength (e.g., $\leq \lambda/10$) would radiate poorly or, in the extreme, would not radiate at all. So, how can these tiny antenna boosters that are well beyond the small antenna limit—quite often below 1/30 or 1/50 of the operating wavelength—deliver full radiation performance at mobile frequencies? Moreover, how can they deliver full radiation performance across multiple mobile/wireless wavelengths simultaneously?

## THE PHYSICS OF ANTENNA-LESS TECHNOLOGY

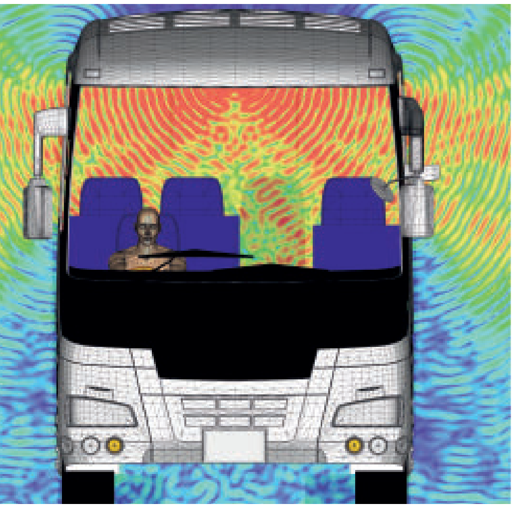
A key aspect of antenna-less technology is understanding the importance of combining one or more tiny antenna boosters with a radiating ground-plane. The ground-plane is typically a metallic counterpoise used regularly in just about every electronic wireless device to provide an even zero voltage reference to the device electronics, while introducing some shielding from electromagnetic interference. The ground-plane is used in most mobile and wireless devices as an integral part of a typically unbalanced antenna architecture, namely a monopole or a patch, either as such or in their shorted versions, i.e., the inverted-F antenna (IFA) and the planar inverted-F antenna (PIFA).

In these typical antenna architectures, the ground-plane has always made a significant contribution to the overall antenna radiation.[1] Now, what the new antenna-less technology is doing is taking that contribution to its limit: the ground-plane becomes the sole radiating element of the system, the booster mainly being a reactive component that balances the ground-plane so that the full RF energy in the form of electric currents is injected strategically onto the radiating conducting layer.

Typically comprising a size comparable to the operating wavelength, the ground layer supports multiple radiating characteristic modes that enable multiple wavelengths to be radiated from the ground layer simultaneously.[2] This way, since radiation is obtained from a ground-plane layer that is already in the wireless device, and the antenna element is replaced by a purely reactive element, the wireless device becomes "antenna-less" in the sense of the original radiating antenna having been replaced by a component that induces radiation yet does not radiate, per se.

These new reactive components in antenna-less systems are the so



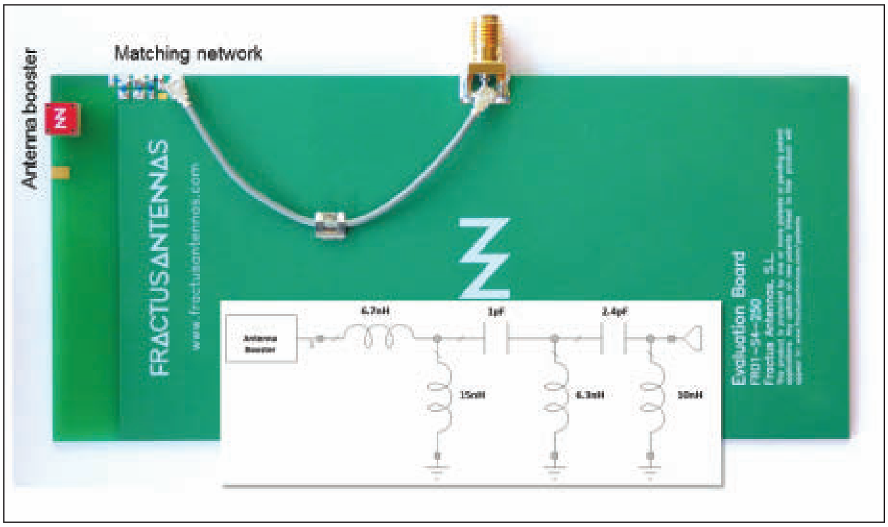


▲ **Fig. 2 The CUBE mXTEND™ antenna booster from Fractus Antennas has a volume of 5 mm$^3$.**

called antenna boosters. An antenna booster is a miniature reactive component, typically smaller than 1/20 or 1/30 of the longest operating wavelength, that can be conveniently embedded into a surface-mount (SMD) component.[3,4] ***Figure 2*** offers an example of a commercially available antenna booster. It can take an electric or magnetic form, featuring either a small conductor or a small gap into a conductor, which becomes fed analogously to its conventional electric and magnetic antenna relatives.[4] Being so small, these boosters are clearly off-resonance, meaning they need a matching network in order to provide a good match to the RF front-end. By designing the proper matching network, following some microwave engineering matching techniques, multiband radiation performance at virtually any mobile frequency band can be easily obtained from the booster-ground-plane set.

In many antenna-less systems, it is of upmost importance that both the booster and the matching network components feature a high quality factor (high Q). Since the radiation mainly comes from the ground-plane, the booster becomes a mostly reactive element, which needs to have low losses to prevent draining the RF power before it is conveniently radiated from the ground-plane. Block-solid metallic elements and Faraday cage-like metallic structures are examples of designs that have successfully been used to implement electric boosters,[2-4] delivering the same overall efficiency as a much larger customized PIFA or IFA antenna.

One of the key benefits of an antenna-less system is precisely that the frequency response of the overall system is tailored through the matching network rather than through the antenna structure and geometry. With a matching network slightly more complex than that of a conventional PIFA antenna—typically three to seven components rather than the conventional one to three—about any frequency response within the 698 to 2690 MHz frequency range can be tailored from a standardized, SMD antenna component. Consequently, rather than struggling to shape the antenna piece to match the inside of the wireless device and, at the same time, deliver the required radiation performance, the antenna/microwave engineer now needs to focus on designing the right matching network for each particular wireless or mobile device. By skipping




▲ **Fig. 3 Example of a five band, single-port mobile antenna system based on the CUBE mXTEND™ antenna booster. The evaluation board includes a booster, a ground-plane and a matching network with six components.**

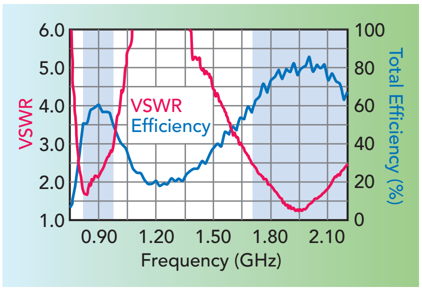
the mechanical engineering of the antenna, the design of a wireless/mobile application becomes faster, simpler and more predictable than ever.

## ANTENNA-LESS 2G, 3G, 4G

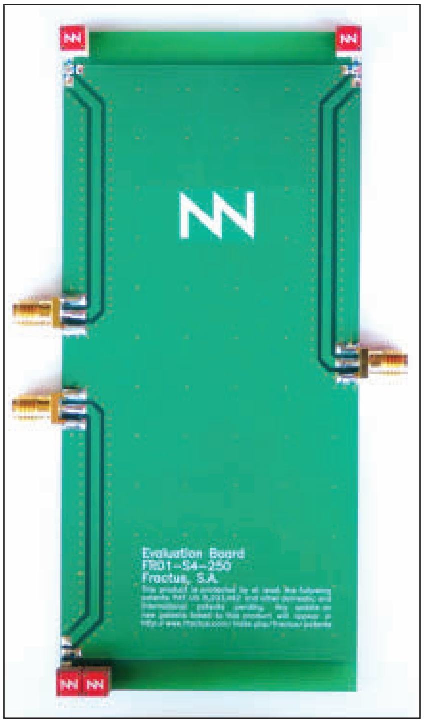
The following example illustrates how a mobile platform can be enabled to operate at five frequency bands with a set including a single antenna booster, a matching network and a ground-plane. The booster is 5 mm × 5 mm × 5 mm in size and operates from 824 to 960 MHz and 1710 to 2170 MHz simultaneously. ***Figure 3*** shows the evaluation board, which includes a booster, a ground-plane and a six-component matching network. Note that 5 mm is only λ/72 at 824 MHz, well below the radiansphere of the small antenna limit.[5] While the tiny SMD component was installed as any other chip antenna, it actually behaved as a booster by injecting radiation currents on a ground-plane about the size of a typical mobile device such as a smartphone. The actual location of the antenna booster depends on the dimensions of the ground-plane. In this particular example, the corner is the preferred location. The location of the antenna booster with respect to the ground-plane plays an important role in determining the efficiency of the whole radiating system. Once the preferred location is selected, the next step is to provide impedance matching. This two-step process will ensure that the antenna system radiates and receives electromagnetic waves with optimum total efficiency.

As mentioned, because the nature of a ground-plane booster is reactive, a multiband matching network is required to simultaneously match both frequency regions (824 to 960 MHz and 1710 to 2170 MHz). Such a design is not as straightforward as a single band matching network, where an L-type or pi-type circuit is generally sufficient. In this particular case, a matching network of six lumped components was designed. The target criteria for this design procedure was how much power from a generator was delivered to the ground-plane booster, and a microwave computer-aided design (CAD) tool was used for the optimization in accordance with that goal. Once the matching network was designed and integrated in the PCB (shown in the top-left of Figure 3), measurements for VSWR and total efficiency were carried out. The results (see ***Figure 4***) showed a VSWR ≤ 3 across the operating bands and an average total efficiency of 56.7 percent and 75.8 percent in the 824 to 960 MHz and 1710 to 2170 MHz frequency regions, respectively.

Designing through an antenna-less architecture implies a change of paradigm, in which the antenna component (the antenna booster)




**▲ Fig. 4 VSWR and antenna efficiency including mismatch losses for the five band, single-port mobile antenna shown in Figure 3.**




**▲ Fig. 5 A three-port mobile platform covering the whole set of bands from 698 to 2690 MHz, using four identical antenna boosters.**

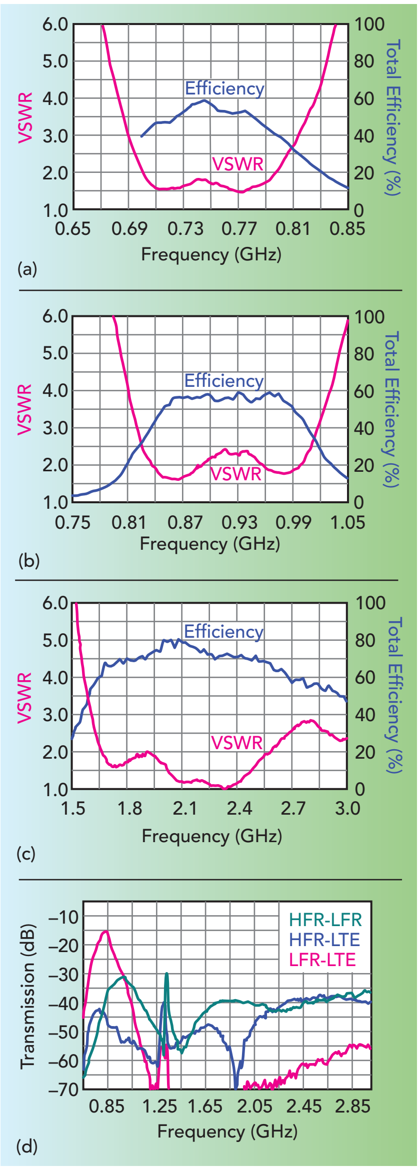
becomes a fixed part, while the RF system is flexibly adapted to the requirements of each wireless platform or device. For instance, let's say that the RF architecture requires expanding the range of frequencies to cover the full mobile range of bands from 698 to 2690 MHz while using three separate input ports for the different frequency regions. This markedly different mobile platform can still be designed using the same booster component as shown (see ***Figure 5***). In this test example, four boosters were installed in three corners of the ground-plane using a three to four component matching network[6] to interconnect each booster to a coplanar transmission line. The lowest frequency port includes two boosters to increase the overall antenna radiation efficiency including mismatch losses at the most challenging LTE700 frequency band. The test results, shown in ***Figure 6***, illustrate how the system is able to deliver an average antenna efficiency of 46 percent, even at such a low band, rising to an average of 70 percent at the higher one. Isolation is always better than 15 dB in the worst case, staying better than 30 to 65 dB for most of the bands and port combinations.

The example given in Figure 5 illustrates some of the key features of this antenna-less technology: its flexibility and modularity. Nearly any RF architecture can be synthesized using the same off-the-shelf antenna booster building blocks. How would the antenna/microwave engineer need to adapt the above design for use in a mobile/Bluetooth/GPS design with three ports? Again, the same three port architecture and antenna boosters could be used to combine the designs of Figure 5, while changing the matching networks to adapt the system to Bluetooth and GPS.

By choosing the antenna booster as the basic building block of the RF design, a microwave/antenna engineer can imagine an extremely wide variety of architectures, where multiple boosters can be combined to address just about any wireless challenge, from introducing diversity to implementing MIMO[7] to developing a robust system which is highly immune to the interaction of the users hand.[8]

## ANTENNA-LESS PERFORMANCE IN A MOBILE PLATFORM

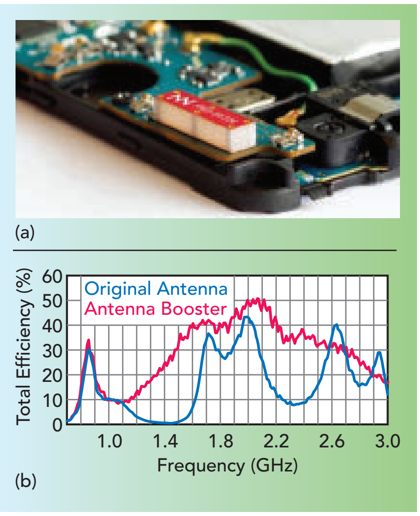
It could be thought that using the ground-plane to support RF radiation currents would make the overall system more sensitive to interference and electromagnetic compatibility (EMC) issues than traditional systems. This is not the case, as systems using conventional PIFA and IFA antennas already use the ground-plane for radiation,[1] so booster-based antenna-less systems




▲ **Fig. 6** **Three-port mobile design efficiency and VSWR for the LTE700 (a), low frequency cellular (b) and high frequency cellular (c) bands. Transmission leakage among the three bands (d).**


is no different. This is illustrated by integrating a booster-based antenna in a multiband mobile platform (see ***Figure 7a***). The results of active measurements and field tests were compared with the same measurements of the original embedded customized PIFA antenna (see ***Figure 7b***). In this case, owing to the slim profile of the smartphone used for the demonstration, a slimmer yet elongated booster was used instead of the cubic antenna booster. Measuring 12 mm × 3 mm × 2.4 mm, the booster was retrofitted on a corner of the PCB inside the mobile device, removing the existing laser direct structuring (LDS) antenna.

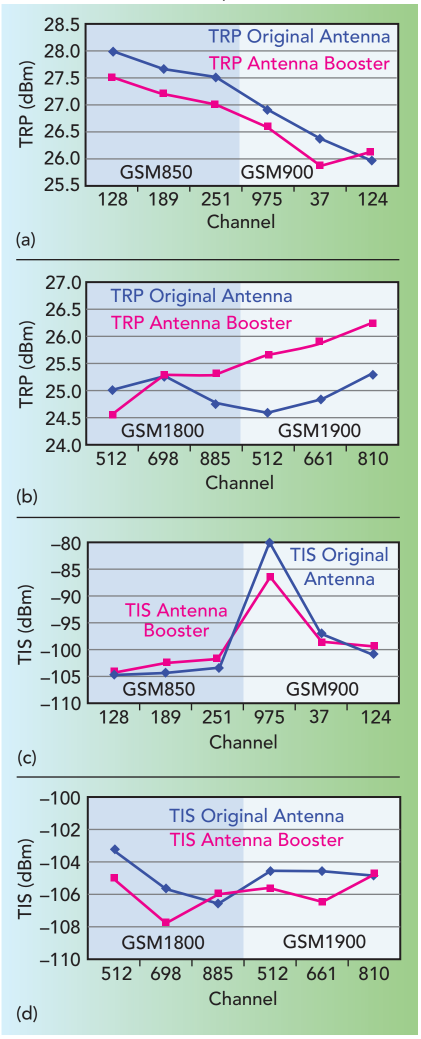
It is worth noting that the volume of the original antenna is 707 mm$^3$, whereas the volume for the antenna booster is only 86.4 mm$^3$—8x smaller. Despite its much smaller volume, the antenna booster integrated inside the smartphone provides the same efficiency from 800 to 960 MHz, better efficiency from 1710 to 2170 MHz and more balanced efficiency from 2500 to 2590 MHz, as Figure 7b illustrates. Moreover, owing to the larger bandwidth made available by the booster-ground-plane combination, an additional frequency band (LTE2300: 2300 to 2400 MHz) that was not featured in the original smartphone is enabled by the alternative antenna-less solution. Beyond the passive test, a



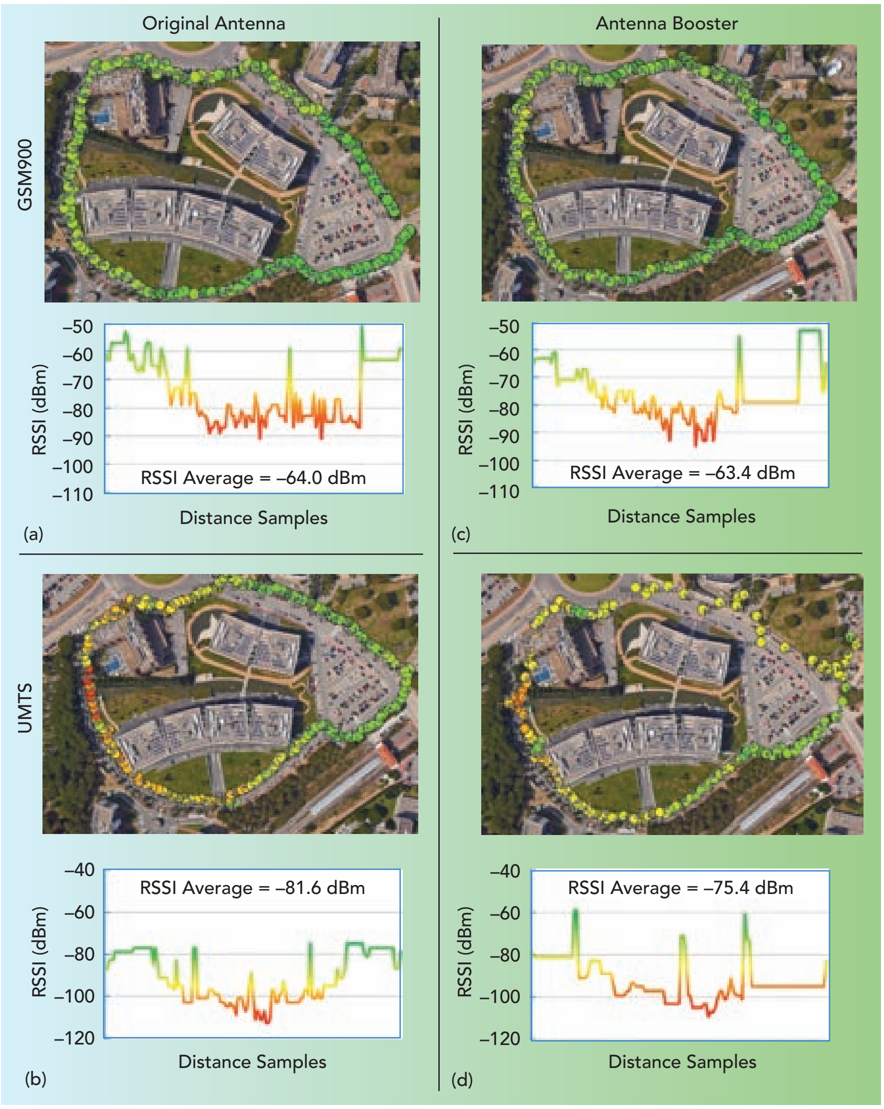

**▲ Fig. 7 A 12 mm × 3 mm × 2.4 mm antenna booster mounted on a corner of the smartphone PCB (a), enabling a comparison of the overall antenna efficiency of the booster-based antenna with the smartphone's original PIFA antenna (b).**

measurement of the total radiated power (TRP) and total isotropic sensitivity (TIS) was conducted as shown in ***Figure 8***. Results showed good alignment with the passive data: similar TRP was obtained at the 850 and 900 MHz bands (LFR) while higher TRP was measured in the 1800 and 1900 MHz bands (HFR). Regarding the TIS, it is worth emphasizing that the measured value was similar for the two cases at LFR and around 1 dB better at HFR.

While passive and active parameters (efficiency, TRP and TIS) evaluate the performance from a technical perspective, where testing is carried out in a controlled environment such as an anechoic chamber, field tests generally provide complementary information on how the solution behaves in a real world environment, where multipath fading and




**▲ Fig. 8 Comparison of the booster-based antenna with the original PIFA antenna: TRP at LFR (a) and HFR (b) and TIS at LFR (c) and HFR (d).**




▲ **Fig. 9 Objective field test results comparing the original PIFA antenna and the antenna-less system: the original antenna operating at GSM900 (a) and UMTS (b) and the antenna booster at GSM900 (c) and UMTS (d).**

interaction with a human operator is present. A fairly simple field test consists of taking the smartphone with the antenna under evaluation and establishing a phone call with another user. Since a field test attempts to reflect performance in a real situation, an urban scenario is usually chosen for conducting the experiment. In general, two kinds of field tests might be carried out: objective and subjective. An objective field test consists of selecting an urban scenario where a user establishes a phone call with the smartphone incorporating the antenna under test and collects the received power from a base station. One of the benefits of this test is that it not only takes into account a real mobile propagation environment with multipath but also the interaction with the user, i.e., both head and hand. The subjective test, in contrast to the objective test, consists of carrying out the same procedure, but instead of collecting data on the received power, the audio quality perceived by the user is considered.

For the objective field test, the following procedure was established. An urban area with several buildings, train tracks and nearby roads was selected. A first user with the antenna under test integrated in the smartphone walked from a starting point to an ending point forming a closed path. The user held the phone in a standard way.[9] Then, a second user called the first

one to establish a phone call. Using the application GSM Field Test, the received power was collected as a function of the position, while the first user moved at walking speed. The experiment was carried out both for the antenna-less phone and with the original antenna and for two frequency bands: GSM900 and UMTS.

The results, shown in ***Figure 9***, indicate that the received power was, in both cases, stronger at GSM900 than at UMTS, which is consistent with the fact that space losses are higher at UMTS than at GSM (around 7 dB) and also with more power transmitted (3 dB) by GSM900 base stations than UMTS (antenna gains are considered equal). As the results indicate, despite having eight times less volume, the antenna-less solution was able to match or improve the performance of the original conventional antenna in the commercial smartphone. This indicates that not only is the antenna-less system capable of matching the passive performance of a conventional and much larger PIFA antenna, it is also able to deliver adequate performance in real world active wireless or mobile platforms.

## CONCLUSION

Antenna-less wireless architecture provides a new set of tools and methods for approaching the design of a wireless/mobile device. Antenna and microwave engineering merge in this new technology to deliver a fast, simple and effective design architecture. Owing to the standardization of the antenna part using the new class of miniature SMD antenna boosters, antenna-microwave engineers can design an antenna system via a process that is fast, flexible, modular and very similar to a filter design. No more cumbersome mechanical customization is needed. Additionally, because the booster component is fixed, a potential low-cost solution can be obtained through economies of scale.

The experiments and extensive results show that despite the savings in cost and volume in the device, the performance of an antenna-less system matches that of a conventional one. While the volume of the booster is 8 to 10x smaller than that of an equivalent LDS antenna, the results show that both the passive (radiation efficiency, VSWR, isolation) and active (TIS, TIR) parameters generally deliver comparable or better results for the antenna-less case.■

## References

1. P. Vainikainen, J. Ollikainen, O. Kivekäs and I. Kelander, "Resonator-Based Analysis of the Combination of Mobile Handset Antenna and Chassis," *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 10, October 2002.
2. A. Andújar, J. Anguera and C. Puente, "Ground-Plane Boosters as a Compact Antenna Technology for Wireless Handheld Devices," *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 5, May 2011, pp. 1668-1677.
3. J. Anguera, A. Andújar and C. Puente, "Wireless Handheld Devices, Radiation Systems and Manufacturing Methods," *Pat. WO 2014/012842 A1*, July 16, 2012.
4. J. Anguera, A. Andújar, C. Puente and J. Mumbrú, "Antenna-less Wireless Device", *Pat. WO 2010/015365 A2*, August 4, 2008.
5. H. A. Wheeler, "Fundamental Limitations of Small Antennas," *Proceedings of the I.R.E.*, 35, December 1947, pp. 1479-1484.
6. A. Andújar and J. Anguera, "CUBE mXTEND™ (FR01-S4-250)—A Standard Antenna Solution for Mobile Frequency Bands," *User Manual, Fractus Antennas*, June 2017, www.fractusantennas.com/wp-content/uploads/2017/06/UM_FR01-S4-250.pdf.
7. J. Anguera, A. Andújar, R. Mateos and S. Kahng, "A 4 x 4 MIMO Multiband Antenna System with Non-Resonant Elements for Smartphone Platforms," *EuCAP Conference*, March 23, 2017.
8. A. Andújar, J. Anguera and Y. Cobo, "Distributed Systems Robust to Hand Loading based on Non-Resonant Elements," *Microwave and Optical Technology Letters*, Vol. 55, No. 10, pp. 2307-2317, October 2013.
9. CTIA Test Plan for Wireless Device Over-the-Air Performance, Version 3.6, June 2016.

# 5G Is Coming: How T&M Manufacturers Can Prepare For and Benefit From 5G

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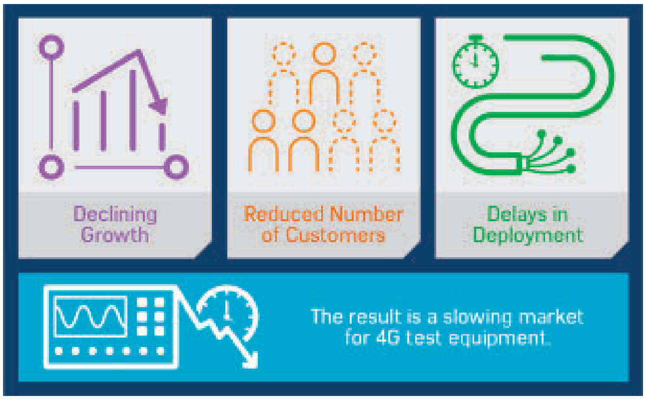
For many, that headline is both a beacon of hope and a source of trepidation. This is especially true for test equipment manufacturers. While 5G offers the opportunity for healthy growth, there are several factors that will make reaping benefits from this generation of wireless broadband technology more challenging than it was for its predecessors.

Let's start with the current situation for electronic test and measurement (ETM) manufacturers. What generates growth in the wireless ETM business is the combination of new handset models, an increasing volume of annual handset shipments and wireless technology advancements that drive new infrastructure equipment. We have seen a reduction in the growth rate of handset shipments as annual shipment volumes have started to exceed one billion units. At the same time, mergers and acquisitions in the wireless infrastructure industry have reduced the number of customers in that segment. Finally, ETM manufacturers have also been coping with delays in the deployment of LTE-Advanced carrier aggregation in major markets. The result is a slowing market for LTE R&D and production test equipment as the industry awaits the technology shift to 5G (see ***Figure 1***).

## 5G IS COMING—WITH CHALLENGES

As wireless broadband technology has evolved from generation to generation—especially from feature to feature—ETM manufacturers have often been able to rely on software upgrades to adapt to changes. The move to 5G, however, is seen as a giant stride forward that will require new and far more complex solutions.

Behind the faster speed, reduced latency, increased capacity and improved reliability of 5G are new and less familiar technologies, such as mmWave, massive MIMO and adaptive beamforming—all of which will demand significantly more advanced base stations and customer devices. The most substantial change to the 5G physical layer is the option for mmWave transmission coupled with adaptive beamforming, requiring a large number of antenna elements. While mmWave transmission is a familiar technology for point-to-point line-of-sight wireless backhaul, using those frequencies in a cellular topology, where each cell serves hundreds or thousands of mobile users and where many antennas will be integrated into advanced device packaging, is challenging and uncharted territory. It is clear that to research, develop and test the new technologies behind 5G, ETM equipment will have to deliver




▲ **Fig. 1** **A slowing market for LTE test equipment has manufacturers eagerly awaiting the acceleration of 5G.**


▲ **Fig. 2** **An African proverb that applies to ETM manufacturers.**

far more advanced capabilities than previous generations. The ETM challenge is made more difficult by the fact that the 5G standards have not yet been finalized. And, like previous generations of wireless technology, there is the very strong desire by operators to be first with deployed networks, intensifying the need for ETM equipment early in the technology lifecycle.

Normally, this list of challenges would excite and energize an R&D group. However, the slackening growth in LTE ETM equipment has left some manufacturers with far fewer resources to devote to 5G innovation and development.

## A PEEK BEHIND THE CURTAIN

While 5G introduces significant hurdles, they are not insurmountable, especially if you subscribe to the wisdom of the African proverb shown in ***Figure 2***. New levels of cooperation can be seen throughout the wireless industry. Instrumentation, wireless infrastructure, semiconductors and software organizations are working together with standards bodies, research organizations and government regulators worldwide to ensure that 5G is a unified standard addressing the many challenging performance goals, including unprecedented speed, connection density and ubiquity. Association with important wireless industry organizations such as ITU and 3GPP, and collaboration with any of the multitude of important research organizations such as NIST and any of the numerous 5G research alliances, is a first step toward greater understanding of the 5G technology trajectory. In addition, ETM manufacturers appear to be gaining a better foothold in the 5G market by forming partnerships and alliances with suppliers.

Moving supplier relationships from highly transactional to being more collaborative can bring greater effectiveness to ETM manufacturers. Knowledge sharing and close collaboration with private companies, including operators and suppliers, is essential to timely delivery of new test products with features that are best aligned with early market needs. Nondisclosure agreements and other proprietary arrangements are giving manufacturers early access to new ideas and emerging technologies, further enabling the technological breakthroughs required to deliver 5G test capabilities.

Component suppliers are providing information to optimize the performance of existing products beyond published data or are going a step further, such as creating part derivatives to meet specific needs. The right partnerships can bolster an ETM organization's strengths with early access to advanced technology. Further, by transferring design work to experienced suppliers, an ETM manufacturer can free up scarce engineering resources, allowing them to focus on their strength of delivering value-added product features.

Combined, the partnering activities outlined above are helping ETM manufacturers get the solutions they need, accelerating their own schedules and, thereby, helping them and their customers succeed.

## THE CHALLENGES

With the desire to reduce time-to-market and meet the demands of 5G, ETM manufacturers need to develop equipment prior to standards being finalized. Because 5G standards will remain in flux for the foreseeable future, working with the right supplier is giving manufacturers access to high performance solutions across the entire signal chain, from mmWave to bits. In that way, even as the 5G standard changes, there will be no need to scrap the original hardware design.

ETM manufacturers will face increased demands for greater capabilities and lower costs. As a result, test products for 5G will be far more complex than those of generations before. Looking beyond individual components to chipsets and system solutions is helping manufacturers squeeze more performance out of limited space and lower cost targets—something especially demanded of modular instrumentation. At the same time, this high level of integration, as well as the increased signal chain count required for MIMO and beamforming, is putting even greater demands on power. By working with suppliers, especially those with the broadest portfolio of products, it is becoming possible to better engineer components into complete signal chain solutions to meet the demanding performance, power, space and time-to-market requirements of tomorrow's instrumentation.

## READY OR NOT

5G is an evolutionary leap rather than a simple generational step-up. While questions still remain about what 5G will be when it arrives, there is no doubt that it is on the way. Whether 5G becomes an opportunity for ETM manufacturers will depend heavily on whether they are ready when this new technology arrives. Embracing partnerships and alliances with key suppliers will significantly help ETM manufacturers thrive in the coming 5G market. ■

## Mobile Force Protection Aims to Thwart Adversaries' Small Unmanned Aircraft

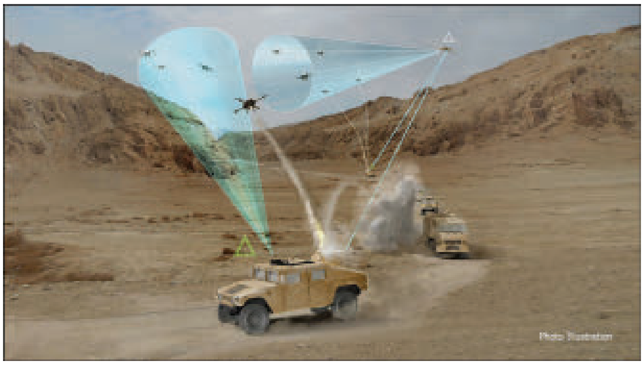
DARPA's Mobile Force Protection (MFP) program focuses on a challenge of increasing concern to the U.S. military: countering the proliferation of small, unmanned aircraft systems (sUAS). These systems—which include fixed- or rotary-wing aircraft with numerous advantages such as portability, low cost, commercial availability and easy upgradeability—pose a fast-evolving array of dangers for U.S. ground and maritime convoys.

Countering these threats in real-time requires a range of technology advances to enable rapid detection, identification, tracking and neutralization of adversary sUASs—all while mitigating collateral damage. MFP aims to achieve these goals by developing scalable, modular and affordable approaches that could be deployed within the next three to four years and nimbly evolve with advances in threats, tactics and technology.

The Agency recently awarded Phase 1 agreements for MFP to three teams, led by Dynetics Inc., Saab Defense and Security USA LLC and SRC Inc.

"The three teams have innovative ideas for a versatile, layered defense system that could protect convoys on the move from multiple sUASs in real-time," said Jean-Charles Ledé, a program manager in DARPA's Tactical Technology Office (TTO). "Each team will now work to integrate novel ideas for advanced sensors and neutralization approaches into a common framework emphasizing safety for civilian bystanders, ease of operation and low SWaP and cost. Our goal is a technology demonstration system that could fit onto currently deployed tactical ground vehicles and maritime vessels—getting advanced and upgradeable capabilities quickly to the warfighters who need them."

DARPA has selected the U.S. Army's Maneuver Aviation and Fires Integration Application (MAFIA) service-oriented architecture as the common framework for the data-fusion engine, decision-aid algorithms and user interface, as well as the backbone for the teams' command and control (C2) software. Already fielded by several DoD programs of record, MAFIA supports multiple operating systems and provides services, libraries, common applications and a software development kit for performer integration. These features will facilitate creation of MFP's envisioned plug-and-play system capable of integrating new sensors and emerging technologies. In addition, DARPA is working closely on MFP with the Department of Homeland Security's Science & Technology Directorate and the U.S. Coast Guard.



*Mobile Force Protection (DARPA Image)*

The MFP program is aiming for three phases punctuated by open-air demonstrations involving increasingly sophisticated threats and scenarios. The goal is for the technology demonstration system to show initial functionality at the end of Phase 1 and progressively improve, culminating in a full-capability demonstration on a moving vehicle or vessel by the end of Phase 3.

At the conclusion of each open-air demonstration, DARPA plans to offer the services and other U.S. Government agencies the opportunity to fund extended field evaluations of the current technology demonstration system. DARPA's goal is to develop the interim versions and the final prototype system to meet the needs of a broad number of potential U.S. government and commercial users.

## General Dynamics Awarded $105M CAC2S Full-Rate Production Contract

U.S. Marine Corps awarded General Dynamics Mission Systems a full-rate production contract worth approximately $105 million over four years for the Common Aviation Command and Control System (CAC2S) program. CAC2S integrates information from various aerial and ground-based radar systems and sensors to enable a common, real-time air picture. Used by the Marine Air-Ground Task Force, CAC2S visually combines ground and aviation data for greater situational awareness and faster decision-making.

"Mission Systems will provide the Marine air command and control team and aviators with an integrated air-ground picture that allows them to adapt quickly in any size operation," said Bill Weiss, Ground Systems vice president and general manager at General Dynamics Mission Systems. "CAC2S will help Marines at any echelon to plan and execute their missions faster and more effectively."

Fielding of CAC2S to operational units began in May 2017 at the Marine Corps Air Station at Cherry Point, N.C. The Marine Air Control Squadron-2 (MACS-2) is the first Marine Corps unit to receive CAC2S.

CAC2S consolidates the existing functionality of the seven Marine Air Command and Control Systems into one system. Developed using an open architecture approach, technology insertion and capability enhancements are easy to implement and intuitive to use.

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## Air & Missile Defense Radar Stacks Up Second Ballistic Missile Test Success

Raytheon Company's AN/SPY-6(V) Air and Missile Defense Radar successfully searched for, acquired and tracked a ballistic missile test target during its second live-target flight test at the U.S. Navy's Pacific Missile Range Facility in Kauai, Hawaii.

This test event featured a more complex, threat-representative ballistic missile target than prior tests, intended to challenge the detection and tracking capabilities of the new radar. AN/SPY-6 acquired and maintained the long-range missile target track, from launch through flight.

"We are continuing to stress this radar by increasing the range and complexity of the targets and demonstrating the radar is meeting its performance requirements," said Navy Capt. Seiko Okano, major program manager for Above Water Sensors, Program Executive Office (PEO) Integrated Warfare Systems (IWS). "AN/SPY-6 is the nation's most advanced radar and will be the cornerstone of the U.S. Navy's surface combatants for many decades."

This result is the most recent in a series of successes for AN/SPY-6, following the tracking of the first ballistic missile target in March 2017. Building up to that milestone, the radar was tested against targets of increasing complexity, including integrated air and missile defense targets of opportunity, satellites and aircraft.

Having achieved Milestone C ahead of schedule, the program remains on track for delivery to the first DDG 51 Flight III destroyer. AN/SPY-6(V) transitioned to Low Rate Initial Production with the May 1 contract award for the first three ship sets.

AN/SPY-6(V) provides greater capability—in range, sensitivity and discrimination accuracy—than currently deployed radars, increasing battlespace, situational awareness and reaction time to effectively counter current and future threats. It is the first scalable radar, built with Radar Modular Assemblies (RMA)—radar building blocks. Each RMA, roughly 2 ft x 2 ft x 2 ft in size, is a standalone radar that can be grouped to build any size radar aperture, from a single RMA to configurations larger than currently fielded radars.

The U.S. Navy's new Enterprise Air Surveillance Radar leverages the highly-scalable design and mature technologies of AN/SPY-6 in a scaled nine-RMA configuration to meet the mission requirements of carriers and amphibious ships. The commonality—in both hardware and software—with AN/SPY-6 offers a host of advantages, including maintenance; training; logistics; and lifecycle support.

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## Nokia Drives 5G MoNArch European Research Project

Nokia has launched the 5G Mobile Network Architecture (5G MoNArch) research project. Supported and financed as part of Phase II of the 5G Infrastructure Public Private Partnership (5G-PPP) under the auspices of the European Union's Horizon 2020 Framework Programme, the project will put fifth-generation mobile network architecture into practice.

Scheduled to run for two years with a total budget of €7.7 million, 5G MoNArch involves 14 key mobile network players from six European countries, bringing together the complementary background and technical know-how required to turn the project's vision into reality, focusing on the implementation of a set of 5G use cases in real-world test beds.

5G MoNArch's specific goal is to use network slicing, which capitalizes on the capabilities of software-defined networking (SDN), network functions virtualization (NFV), orchestration and analytics, to support a variety of use cases in vertical industries. Network slicing is a technique where the network is logically (not physically) sectorised, so that separate services are supported by each "separate" logical network. As 5G networks need to simultaneously support various services with different requirements, network slicing will be a crucial aspect of the network architecture, providing flexible and adaptive networks which fulfil the 5G requirements.

Peter Merz, head of End-to-End Mobile Networks Solutions at Nokia Bell Labs, said: "5G PPP brings together a range of stakeholders from the communications technology sector and other industries. We follow a shared architecture of what the next-generation communications infrastructure needs to look like to enable and meet the network demands of the next decade. 5G communication needs both private and public entities to invest in the infrastructure and ensure Europe remains competitive. Nokia is fully committed to the 5G PPP: we have delivered know-how and innovative technologies since its launch in 2015 in order to strengthen the European 5G footprint."

## Leti Launches Emulator Service for European Chipmakers

Leti, a technology research institute of CEA Tech, and Mentor®, a Siemens business, announced that Leti will provide access to the Mentor Veloce® emulator to SMEs and start-ups and introduce emulation technology to global companies. The Veloce emulator is a high-capacity, high-speed, multi-application tool for emulation of system-on chip (SoC) designs that was installed at Leti in 2013.

The Leti offer, which targets European chipmakers, includes the institute's expert support, such as taking control of device design, optimized implementation within the emulator, debug and analysis of results. It will also provide access and support to additional specific tools available in its Grenoble, France facility as needed.

Emulation is a vital process for more efficient development of complex digital circuits that includes debugging the design at early stages and validating the upstream, onboard software operation. The Veloce emulator accelerates block and full SoC register-transfer level (RTL) simulations during all phases of the design process, ending the long delay between starting simulations and getting results. It enables pre-silicon testing and debug, can use real-world data while both hardware and software designs are still fluid.

"Veloce dramatically speeds up the design cycle, because it is 1000x faster than traditional RTL simulation tools," said Thierry Colette, head of Leti's Architecture, IC Design and Embedded Software division. "It is now possible to verify multi-processor circuits that have several billion transistors—a real competitive advantage that improves return on investment and speeds time to market. But because this powerful tool represents a major investment for microelectronics manufacturers or design houses, Leti is launching this special emulation service to provide our partners direct access to this technology and the benefits it offers."

## Leonardo's U.K.-based Space Business Provides Support to ESA

Leonardo has signed a contract worth €11 million per year for up to five years with the European Space Agency (ESA) under which the company's Telespazio VEGA U.K. subsidiary, based in Luton, will provide subject matter experts to the ESA in support of their programmes and missions. The Luton facility also supports the first U.K. ground station for the Italian Space Agency's COSMO-SkyMed satellite radar constellation, based in Harwell, U.K.

The ESA's satellite programmes demand world class expertise and need to be innovative, robust, secure and work first time, every time. Telespazio VEGA U.K. is able to draw on the pan-European presence of the Telespazio Group to provide high quality staff, with a wide variety of engineering skill sets, to all of the ESA's locations in Europe. Such skill sets include satellite communications/navigation, remote sensing, integrated applications, software and control systems, automation, optics, electromagnetics, power/radiofrequency systems, science operations and training support for astronauts.

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Leonardo is strongly committed to its space business in the U.K. This is in line with the ambitions of the U.K. government, which has identified the space industry as a key sector for economic growth and is a major investor in British space technology and research.

## UN Report Identifies Broadband's Important Role in Development

Broadband technologies are driving substantial transformation in many development-related sectors including health, education, financial inclusion and food security, making them a key accelerator towards achievement of the United Nations' Sustainable Development Goals (SDG), says *The State of Broadband 2017: Broadband Catalyzing Sustainable Development* report released by the UN Broadband Commission for Sustainable Development.

Issued annually, the report is a global snapshot of broadband network access and affordability. It also examines global trends in broadband connectivity and technologies, reflects on policy and regulatory developments, as well as the applications of broadband for sustainable development and presents several policy recommendations.

The report identified growing digital inequality; while 48 percent of the global population is now online, some 3.9 billion people still do not have access to the Internet—with the digital gap growing between developed and developing countries. According to estimates, Internet penetration in the developing world is projected to reach 41.3 percent by the end of 2017, while Internet user penetration is projected to reach only 17.5 percent in Least Developed Countries (LDC) in 2017. Also, only 76 percent of the world's population lives within access of a 3G signal, and only 43 percent of people within access of a 4G connection. Unless people have the opportunity to migrate from 2G to at least 3G to 4G and beyond, they will remain under-connected.

Fixed and mobile broadband services are becoming progressively more affordable in a large number of countries. However, there are many challenges to making Internet access affordable for developing countries, in part due to the high costs of satellite access and fibre-optic cables. Also, over the last year there has been impressive growth in the number of new Internet Exchange Points (IXP), an important form of support infrastructure that can potentially help reduce latency and cut transit costs. The growth of IXPs in Africa over the last year is significant.


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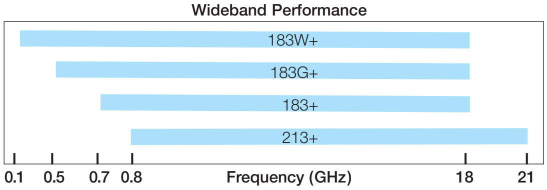
183W+
183G+
183+
213+
0.1
0.5
0.7
0.8
Frequency (GHz)
18
21

## CommercialMarket

Cliff Drubin, Associate Technical Editor

## Mobile Players Leverage Smart Home Integration, Support Long-Term Strategy

The smart home is battleground for a range of established players and new entrants each seeking to gain a major foothold in the emerging market. In a bid to leverage their global user bases, mobile device and operating system vendors are increasingly integrating their offerings into smart home platforms and controllers.

A recent ABI Research report studied the growing role of mobile devices in the home and how the global mobile user-base surpassing 7.5 billion connections offers some of the most valuable, global IT companies—like Amazon, Apple, Google and Samsung—ways to leverage the smart home to extend their core businesses and user bases into the home.

"There are a number of drivers pushing mobile integration into the smart home, but the value of end user data is prominent," says Jonathan Collins, research director at ABI Research. "Any mobile player that can push to provide smart home management can leverage that data to extend their core services, as well as be the data gatekeeper for a range of partners across multiple industries."

> Mobile players that provide smart home management can leverage user data to extend core services.

Key market players are already preparing for the benefits of mobile integration in the smart home. Apple's HomeKit initiative provides the ability to better understand its customer base and sell additional devices and services into consumers' homes. Google gains additional insight into its consumers' behaviors that will support its core advertising revenue stream. Even Amazon, a much smaller mobile market player, already set its sights on smart home services to help understand and target its customer relationships.

Tighter integration between the mobile and smart home environments will ultimately provide the infrastructure for a wide range of applications and integrations, further personalizing consumer and citizen interaction with the world around them. The emerging, more advanced smart home solutions will have a long-term effect on the broader IoT and enterprise markets.

"Telcos, cable companies, utilities, security providers and retailers are already working to expand their smart home footprints," concludes Collins. "How they compete or align with the mobile industry over the next five years will determine which players reap the greatest benefit from widespread smart home adoption."

## Los Angeles, New York and Chicago are the Smartest Cities in North America

Cities were evaluated across various metrics such as deployment of LED streetlights, smart meters, renewable energy, electric mobility, smart parking, mobility-as-a-service (MaaS), vehicle-to-everything (V2X) technologies, smart waste and first responder communications.

"New York is the leading city with the highest deployment of LED streetlights in the U.S., followed closely by Los Angeles," says Raquel Artes, industry analyst at ABI Research. Chicago will have the highest upgrade of current legacy streetlights, as the local government is targeting to replace 270,000 legacy streetlights with energy-efficient LED lights by 2021. SilverSpring Networks, Telensa, Philips and GE are the key stakeholders in this space.

> Most U.S. states are embracing the digital transformation.

Additionally, Florida, New York, Miami and Michigan are the leading sites that would likely have the highest deployment of V2X technologies due to government initiatives to boost road safety and accelerate the development of autonomous vehicles. Meanwhile, New York leads in the replacement of existing legacy payphones with state-of-the-art kiosks called Links. Chicago and Kansas City have recently trial-launched smart Wi-Fi kiosks, and smart sanitation bins are gaining traction in Los Angeles, New York, Chicago, Tampa City, Philadelphia, San Diego, San Francisco and Texas.

While larger cities are focusing on large-scale deployment of smart city projects and experimental technologies, their smaller counterparts tend to prioritize projects based on more immediate tangible benefits such as cost savings, reduction of carbon footprint and the overall improvement of quality of life.

Top smart city projects that aim to reduce carbon emissions and air pollution are:

- ***Electric Mobility.*** Overall, Los Angeles, San Francisco and New York have the highest deployment of electric vehicles (EV) and EV charging stations in the U.S. Among medium-sized states, Oregon ranked first, followed by Colorado and Maryland. Among small area population states, Hawaii ranked first, followed by Vermont and New Hampshire. This is driven by government mandates such as zero emission vehicle (ZEV) programs and Clean Energy Acts.
- ***Solar PV.*** Los Angeles ranked first, followed by San Diego and Phoenix with the highest deployments of solar PV technologies. Among mid-sized cities, Honolulu ranked first, followed by Albuquerque and New Orleans. Among smaller cities, Newark ranked first, followed by Cincinnati.

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- ***Smart Meter.*** Among large states, California, Texas and Florida were the leading states with the highest deployments of smart meters in the U.S. in 2016. Among medium-sized states, Maryland ranked first, followed by Alabama and Oklahoma. Among smaller states, Maine ranked first, followed by Idaho and Delaware.

## VR Expected to Reach Over a Quarter of a Billion Users Worldwide by 2022

Virtual reality (VR) technology looks set to gain widespread adoption over the next five years, reaching an installed base of 256 million users worldwide and generating revenues of over $60 billion in 2022. While the consumer market is expected to account for most of the market's revenue, the commercial and enterprise space will expand its share reaching over 40 percent of the market by 2022, up from 26 percent in 2015.

"Content availability remains an issue, but healthy strides were made in the past year, particularly in Asia-Pacific and China, with location based VR. Further trials and launches will accelerate the adoption of immersive content across the market and expand the use of VR as a tool for training, design, preparatory work and planning," says Michael Inouye, principal analyst at ABI Research. "While the consumer space often garners the largest share of attention the market potential is much wider and we've already seen very promising interest in verticals like retail, healthcare, automotive, education and real estate/architecture/engineering/construction."

VR experiences still range quite widely from more basic seated/standing mobile HMD configurations to dedicated location based VR installations and VR arcades that allow for 6DOF or room-scale experiences. The rise of wireless HMDs, standalone VR and 6DOF mobile VR will help narrow the gaps between these different classes of experiences. Additionally, further technology advancements/introductions are on the horizon like eye tracking, foveated rendering and increasingly higher resolution screens.

Sam Rosen, managing director and VP at ABI Research, concluded, "We continue to view VR as a long-term market proposition, a technology that will really start to show its true transformative capabilities five plus years from now. In addition, while we currently see clear delineations between AR and VR today and into the near future. We expect these lines of demarcation to begin fading as the technologies increasingly reach maturity and saturation, perhaps then becoming better suited to the mixed and merged reality monikers that some use today."


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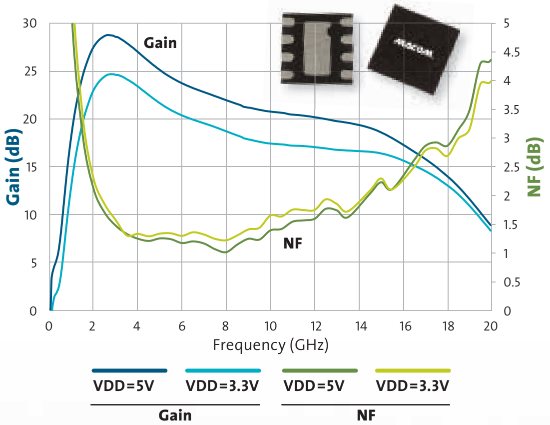


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# Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

## MERGERS & ACQUISITIONS

Aerospace supplier **United Technologies Corp. (UTC)** has struck a $30 billion agreement to buy avionics and interiors maker, **Rockwell Collins Inc.**, in a deal that bulks up UTC's power with plane makers by creating one of the world's largest makers of civilian and defense aircraft components. Farmington, Conn.-based UTC will pay $140 per share for Rockwell Collins, split between $93.33 per in cash and $46.67 in stock, according to the companies. The price represents a 17.6 percent premium to Rockwell's $119 share price before news of the talks emerged on August 4.

**Integra Technologies LLC** announced that it has acquired **CORWIL Technology Corp.** CORWIL provides high quality and responsive semiconductor die prep, assembly and test services focusing on Hi-Rel, fast-turn and wafer processing markets. Founded in 1990 and based in Milpitas, Calif., CORWIL is the premier U.S. provider of full back-end assembly services. The combination of the two companies will provide a single point of contact for an extremely broad array of semiconductor die prep, assembly, test and evaluation services supporting military, avionics, space, medical, automotive and fabless semiconductor markets.

## COLLABORATIONS

**Keysight Technologies Inc.** announced an agreement with **Sequans Communications** whereby Keysight will use Sequans' Monarch LTE for IoT chip platform to provide support for NB-IoT and LTE-M customers using Keysight's E7515A UXM wireless test set. The integration assures customers that they have their test needs covered for IoT deployments and are in compliance with 3GPP standards. Keysight and Sequans are developing products and solutions that are tailored for the IoT ecosystem, and the companies are now working closely together to accelerate the deployment of IoT technologies in the industry.

**Microsemi Corp.** announced its collaboration with **Mellanox Technologies Ltd.** to develop a unique reference architecture for NVM express over Fabrics (NVMe-oF) applications as part of Microsemi's Accelerate Ecosystem Program. Microsemi's Accelerate Ecosystem speeds development efforts for customers and collaborators through technology alignment, joint marketing and sales acceleration. Collaborating with Microsemi allows companies like Mellanox and Celestica to leverage Microsemi's peer-to-peer memory architecture, which is supported by its Switchtec™ PCIe switches in combination with its Flashtec™ NVRAM cards and NVMe controllers to enable large data streams to transfer between NVMe-oF applications without the central processing unit in the data plane.

**Bosch, Geo++**, **Mitsubishi Electric** and **u-blox** have announced the creation of **Sapcorda Services GmbH**, a joint venture that will bring high precision GNSS positioning services to mass market applications. The four companies recognized that existing solutions for GNSS positioning services do not meet the needs of emerging high precision GNSS mass markets. As a result of which, they have decided to join forces to facilitate the establishment of a worldwide available and affordable solution for system integrators, OEMs and receiver manufacturers. Each partner brings its unique expertise to the joint venture Sapcorda Services.

**Qualcomm Technologies** has collaborated on 5G NR-enabled small cell technologies with **Industrial Technology Research Institute (ITRI)**. The effort is expected to accelerate delivery and global commercialization of 5G NR small cell products and infrastructure by Taiwanese original equipment manufacturers (OEM) and original design manufacturers (ODM). Small cells will be a key component of 5G networks, delivering enhanced performance utilizing both mmWave and sub-6 GHz spectrum. This new collaboration will provide ITRI early access to Qualcomm's key 5G small cell technology, including the creation of industry-grade quality assurance capability for communication protocol product and a live network test bed to enable product testing and performance verification under real world environment prior to product launch field trials.

## NEW STARTS

Preliminary construction is underway on a new $350 million **Lockheed Martin** facility that will produce next-generation satellites. The new facility, located on the company's Waterton Canyon campus near Denver, is the latest step in an ongoing transformation infused with innovation, to provide future missions at reduced cost and cycle time. The new Gateway Center, slated for completion in 2020, includes a state-of-the-art high bay clean room capable of simultaneously building a spectrum of satellites from micro to macro. The facility's paperless, digitally-enabled production environment incorporates rapidly-reconfigurable production lines and advanced test capability.

## ACHIEVEMENTS

**Raytheon** announced their active electronically scanned array (AESA) radars for fighter aircraft have accumulated more than 1 million flight hours, aggregating the hours from two U.S. services and four international customers. Raytheon delivered its 1,000th production AESA in May, and says it was the first company to produce AESA radars for tactical aircraft. Raytheon's AESA radars have been the primary targeting sensor on the F-15 Eagle, F/A-18 Super Hornet and E/A-18 GROWLER, serving in every major U.S. air combat operation since the mid-2000s: Operation Enduring Freedom, Operation Iraqi Freedom, Operation Odyssey Dawn, Operation Unified Protection and Operation Inherent Resolve.

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# Around the **Circuit**

**The Italian Ministry of Defense**'s OPTSAT-3000 satellite has been successfully launched by **Arianespace** from the Kourou European spaceport in the French Guyana, with a VEGA European launcher, produced by **AVIO**. The whole system is supplied by **Leonardo** through **Telespazio** (Leonardo 67 percent, Thales 33 percent). As prime contractor, Telespazio leads an international group of companies including, among others, Israel Aerospace Industries (IAI), which built the satellite within an international co-operation agreement between Italy and Israel as well as OHB Italia, responsible for the launch services.

A **Boeing**-led team, including **U.S. Air Force** and **Naval Air Systems Command** representatives, recently completed KC-46 tanker electromagnetic testing. This testing evaluates the aircraft's ability to safely operate through electromagnetic fields produced by radars, radio towers and other systems under mission conditions. Testing was conducted on the Naval Air Station Patuxent River, Md., electromagnetic pulse (EMP) and Naval Electromagnetic Radiation Facility pads, as well as in the Benefield Anechoic Facility at Edwards Air Force Base in Calif. During tests on the EMP pad at Patuxent River, the program's second low-rate initial production KC-46 received pulses from a large coil/transformer situated above the aircraft. The outdoor simulation was designed to test and evaluate the KC-46's EMP protection while in flight.

**7layers** has extended its scope of LoRa certification services with new LoRa RF antenna performance requirements. LoRaWAN, a low-power wireless network protocol for IoT devices and services, is based on an open industry standard called LoRa, which is managed and controlled by the LoRa Alliance. Generally speaking, IoT services depend heavily on reliable connectivity, since the loss of a radio connection can lead to the interruption of an IoT service and disappointed users. Eventually it may even put the whole business case of an IoT services provider at risk. Therefore, it is very important that all wireless components in an IoT service system meet the expected performance criteria and secure the dependable transmission of data.

**ip.access** announced that it has shipped the two millionth license for its 3G small cell software platform. The milestone highlights the industry leading network performance of ip.access' residential small cell software. The platform is used in the Cisco 3G Microcell, one of the world's earliest and largest residential small cell deployments with AT&T in the U.S. Having been deployed, hardened, enhanced and maintained continuously over the last eight years, ip.access' software platform guarantees performance at the highest quality of service standards while still being delivered independently.

Based on its recent analysis of the universal serial bus (USB) vector network analyzer (VNA) industry, **Frost & Sullivan** recognized **Copper Mountain Technologies (CMT)** with the 2017 Global Frost & Sullivan Award for Product Leadership. The imminent move of many IoT technologies from research to commercialization is expected to drive the demand for lower cost instrumentation over the next 5 to 10 years. CMT is well positioned to make the most of this opportunity with a strong and established USB VNA offering that is coupled with superior customer support spanning customer service, software development and customization.

**Aeroflex Wichita Inc.** announced their ISO 9001 standard certification from ISO 9001:2008 to the newly revised standard ISO 9001:2015. ISO 9001 is the world's most widely recognized quality management standard and help organizations to meet the expectations and needs of their customers. As an ISO 9001:2008 certified organization, Aeroflex Wichita has successfully completed the transition to the 2015 standard. By achieving this level of certification, they continue to demonstrate their ability and desire to effectively and efficiently provide a quality management system, while continuously improving their products and services as well as their internal process.

## CONTRACTS

**Vencore Inc.** announced that as a partner of the **QWK Integrated Solutions LLC** joint venture, it has won a position on the **U.S. Army Space and Missile Defense Command** and **Army Forces Strategic Command, Design, Development, Demonstration and Integration** (D3I) program Domain 1 contract. The indefinite delivery/indefinite quantity (IDIQ) multi-award contract is valued at more than $3 billion and has a five-year base period of performance, with two consecutive two-year options. The D3I program will provide the Army with rapid design, development, demonstration and integration of technology to support the mission of SMDC/ARSTRAT and the warfighter.

**VSE Corp.** was awarded several delivery orders in July and August 2017 by the **Naval Sea Systems Command International Fleet Support Program Office** to provide support under its Foreign Military Sales (FMS) contract. VSE will provide maritime program support including logistics, planning, repair and maintenance management, procurement, technical assistance, training and engineering support to 11 client countries. The periods of performance for these delivery orders range between 9 and 20 months, and the delivery orders have a combined funded value of $57.4 million.

**OSI Systems** announced that its Security division received a delivery order valued at approximately $21 million from **U.S. Customs and Border Protection (CBP)** to provide Z Portal® cargo and vehicle screening systems. The order was issued under the indefinite delivery/indefinite quantity (IDIQ) contract received in October 2016 from CBP. The company has now received approximately $56 million in orders under this IDIQ contract since its inception. The Z Portal® system is the only drive-through cargo and vehicle inspection system that uses multiple detection technologies to provide up to six views of the vehicle under inspection.

# Around the **Circuit**

**Antenna Systems Solutions S.L. (Celestia Technologies Group)**, a provider of antenna measurement solutions for the defence, government and wireless industries, announced that it has won a contract to supply an Automotive Antenna Measurement Test Range to **Aalborg University** in Denmark. The system will be designed to measure full-size vehicles up to 110 GHz and 5G testing.

## PEOPLE

▲ *Dan Goodwin*

**Aethercomm** hired **Dan Goodwin** as vice president of Business Development after serving as the vice president of Technical Marketing and Government Affairs for renewable fuel startup American Power Group Inc. Dan Goodwin is a retired U.S. Marine who flew F/A-18 Hornets in combat for the Marines and commanded a Marine Corps Fighter-Attack squadron during his time on active duty. He has also served at the highest levels in the Department of Defense, working at U.S. Marine Corps Headquarters inside the Pentagon. With his decades of operational experience using high-technology military radar, communications and EW systems, he brings a user perspective to Aethercomm's business development and marketing efforts.

▲ *Gerald T. Garland*

**RF Industries Ltd.** has appointed **Gerald T. Garland** to its Board of Directors. Over his 18 years in the wireless telecommunications industry, Garland has been an accomplished senior executive with extensive experience in product management, sales management, solutions development and finance. RF Industries now intends to leverage his skills and financial expertise to improve sales and profitability, as well as expand product offerings in Distributed Antenna Systems, wireless and data center markets.

▲ *Megan LeBaron*

**Southwest Antennas** announced the promotion of **Megan LeBaron** to Supply Chain manager. After managing both inside sales and purchasing for many years, LeBaron has received a much-deserved promotion to Supply Chain manager in order to focus her skills on the company's vendor management and procurement activities. With a keen interest in this field, LeBaron has received her certification from the Supply Chain Management program at UCSD.

## REP APPOINTMENTS

**Anokiwave Inc.** announced they have signed an agreement with **Cain-Forlaw Co.** for sales representation in the central U.S. The agreement aligns with


## Around the **Circuit**

Anokiwave's goal to support new customers and opportunities in the central U.S. with a highly-technical sales and applications team. Cain-Forlaw has been a technical manufacturers' representative for over 45 years and is the largest geographical RF and microwave representative in the country. Cain-Forlaw is focused on providing world class sales and customer service to the electronics industry.

**Modelithics** announced their newest MVP (Modelithics Vendor Partner), **Guerrilla RF**, and the availability of S-parameter and noise parameter models for five packaged broadband ultra-low noise amplifiers. Guerrilla RF is now a valued Supportive Modelithics Vendor Partner and through this program, the two companies have collaborated to characterize five ultra-low noise broadband amplifiers from Guerrilla RF, including four LNAs from the GRF207x series and the GRF2501DSR LNA. The MVP program enhances the collaboration and communication during vendor device characterization and modeling, and expands the promotion of devices for which new data and/or models are available.

**Precision Connector Inc. (PCI)** has announced that **T&E Repco** is their new exclusive sales representative for the state of Florida. T&E Repco is an established and recognized RF and microwave manufacturers representative that will strengthen and enhance PCI's presence in the region.

**RFMW Ltd.** has joined the **Electronics Representatives Association (ERA)** as a global distributor member. ERA is the international trade organization for professional field sales companies in the global electronics industries; manufacturers who go to market through representative firms and global distributors. RFMW is an ISO 9001:2008 certified, specialized technical distributor of RF and microwave products providing consultative component selection, value add and design solutions through a focused technical sales and marketing organization.

**Southwest Microwave** announced the appointment of **Scientific Devices Inc.** as manufacturer's representative agency for southern New Jersey and Pennsylvania. Established in 1969, Scientific Devices offers RF and microwave components for diverse applications in the commercial, military, medical, space and telecom markets. The company is staffed by experienced design engineers and technologists, who have also worked extensively in sales and marketing.

# Noise Analysis, Then and Today

Dr. Ulrich L. Rohde
*Universität der Bundeswehr München, Munich, Germany*

Noise analysis of oscillators, also known as autonomous circuits, was a dream for many years. The first and linear approach must be credited to David Leeson, who took a linear lowpass equivalent circuit and derived his frequently quoted linear formula.[1] This formula requires data which can only be gained after a post prior analysis. The values of the output power, the loaded Q, the large-signal noise factor—frequently confused with noise figure (NF), which is 10log(noise factor)—and the flicker noise contribution are not known a priori, although they may be computed.[2] The introduction of nodal noise analysis in a proper way was published by Hillbrand and Russer.[3] The Lee-Hajimiri noise analysis is interesting but not very practical; while often quoted in the literature, its use is not practically shown.[2,4-6] If we combine the Leeson formula with the tuning diode contribution, the following equation allows us to completely calculate the noise of the oscillator.[2] The VCO term was added by Rohde,[2] and the flicker term was added by Scherer.[7]

$$L(f_m) = 10\log\left\{\left[\left(1+\frac{f_0^2}{(2f_mQ_L)^2}\right)\left(1+\frac{f_c}{f_m}\right)\frac{FkT}{2P_{sav}}+\frac{2kTRK_0^2}{f_m^2}\right]\right\} \quad (1)$$

where

$L(f_m)$ = ratio of sideband power in a 1 Hz bandwidth at $f_m$ to total power, in dB

$f_m$ = frequency offset

$f_0$ = center frequency

$f_c$ = flicker frequency

$Q_L$ = loaded Q of the tuned circuit

F = noise factor

$kT = 4.1 \times 10^{-21}$ at $300K_0$ (room temperature)

$P_{sav}$ = average output power of the oscillator

R = equivalent noise resistance of the tuning diode (typically 50 to 10 kΩ)

$K_o$ = oscillator voltage gain

Kaertner's paper[8] used a nice time domain approach and includes, probably for the first time, the noise correlation in oscillator design. At that time, the now available harmonic balance method had not been invented. A very good description is found in the works by Rizzoli.[9-11] While not easy to read and highly mathematical, Kaertner's calculation produced real results.

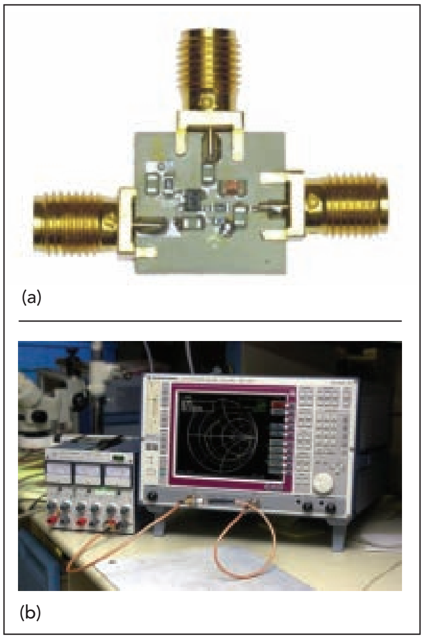
## LARGE-SIGNAL NOISE ANALYSIS

The introduction of the piecewise linear harmonic balance (HB) method, developed by Vittorio Rizzoli and his team, was the

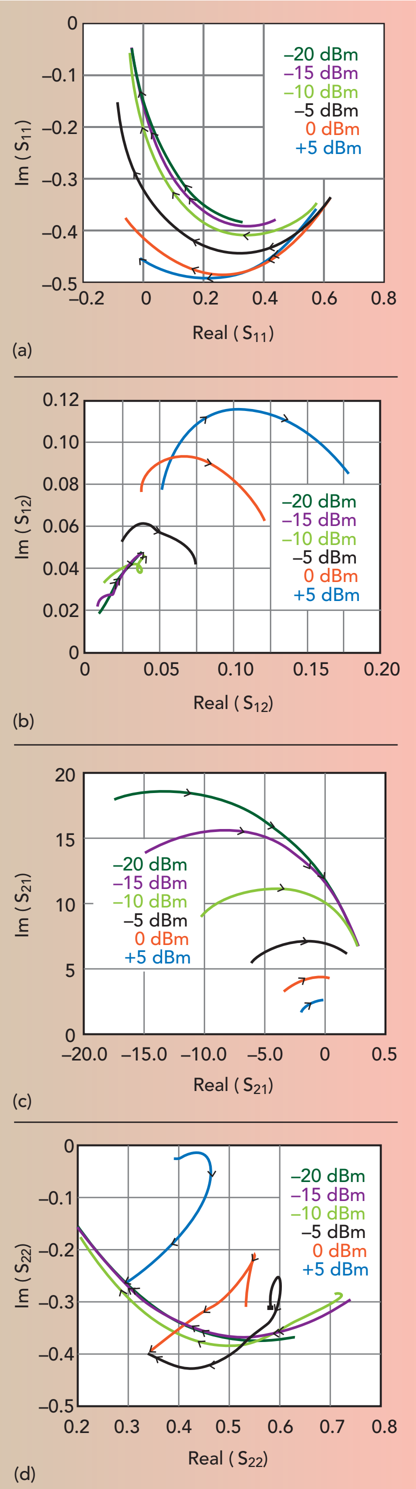
perfect body to include the noise correlation method. The famous nonlinear time domain circuit analysis program SPICE lacks a rigorous noise correlation analysis, and the HB programs are a hybrid of linear (frequency) and nonlinear (time domain) computations.[12,13] Both publications by Rizzoli and Gilmore were leading on the topic. Rowan Gilmore worked with me during our Compact Software time.

My team at Compact Software and the Rizzoli team were struggling to validate the results, and it was complicated to get reliable measured data and maintain accuracy and speed. The Compact Software approach and the Rizzoli team were always fighting about this topic. I remember telling users that short cuts used in some programs were getting them faster to the wrong answer. At the end, developing a very fast, double precision, multidimensional matrix inversion program was the solution, and using FORTRAN gave the most stable results. This HB approach is also able to deal with hysteresis.

The first and most challenging circuit analysis of a low noise amplifier, developed by Raytheon, was published[14] for the first time, in cooperation with Robert Pucell of Raytheon and Tony Pavio of Texas Instruments. We demonstrated very accurate results using SPICE type data for GaAs FETs. They were hard to come by; we ended up using a modified Materka model.[15-19] The




▲ **Fig. 1** Test fixture (a) and network analyzer (b) used to measure large signal S-parameters.

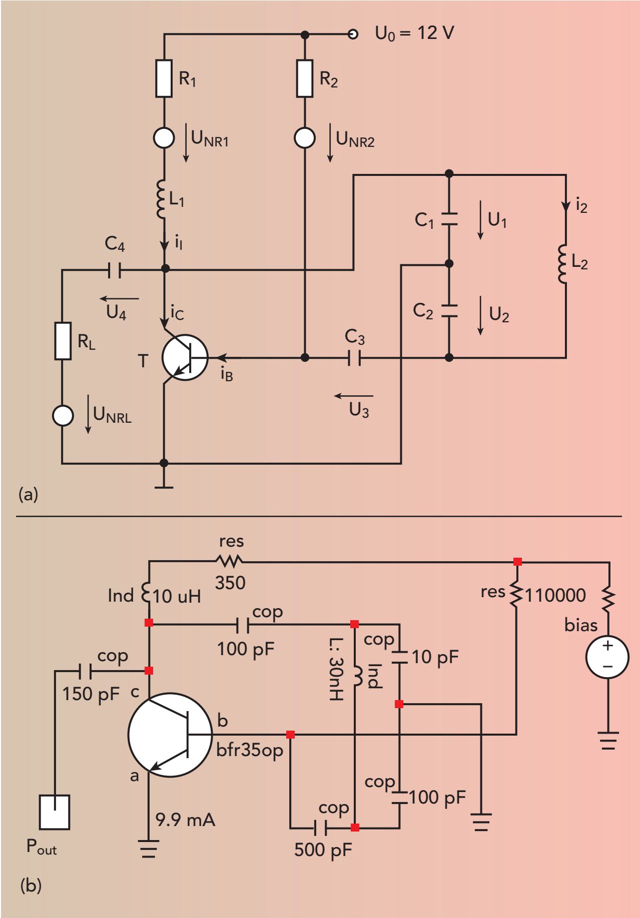



▲ **Fig. 2** Measured large-signal S-parameters of the Infineon BFP520 bipolar transistor from 600 MHz to 3 GHz in 50 MHz steps: $S_{11}$ (a), $S_{12}$ (b), $S_{21}$ (c) and $S_{22}$ (d).

actual circuit was published in *Microwave Journal*.[20] So far, I have demonstrated that the noise analysis can be done solely using available and accurate SPICE parameters of GaAs FETs and its family members.

But the really needed large-signal circuit analysis was the oscillator. To implement the proper FET[15-19] and BJT[20-22] models and its derivatives was quite a task. The internal noise modeling was based on the noise correlation matrix[2] and the results were published by W. Anzill, F. X. Kaertner and P. Russer in 1992.[23] In 1987, the Microwave Harmonica program by Compact Software was proven to be reliable.[20] The next step was to match the measured results of practical circuits. Hewlett Packard had the first, reliable phase noise system; Dieter Scherer was the lead engineer who educated us all. Today, the leading phase noise analyzer is the Rohde and Schwarz FSWP/8/26/50.

For a systematic approach, even without a simulator, it is useful to have large-signal S-parameters.[2,24] The large-signal parameters of bipolar transistors, which had not been derived at the time of Kaertner's work, are best obtained from measurements.[24] The proper de-embedding procedure[19] translates the external measurements to the actual chip (see ***Figure 1a***), and a network analyzer with variable output power is needed for the measurement (see ***Figure 1b***). With large-signal operation, the BJT behaves differently than for low noise applications,[18-22] as shown in ***Figure 2***.[25]




▲ **Fig. 3 Colpitts oscillator analyzed by Kaertner (a) and circuit schematic in Compact Software (b).**

## KAERTNER COLPITTS OSCILLATOR

With this background, I would like to analyze the circuit used by Kaertner as the basis of his brilliant paper.[8,23] The component values in the schematic of ***Figure 3a*** are taken from his publication: $R_1$ = 350 Ω, $R_2$ = 110 kΩ, $R_L$ = 500 Ω, $L_1$ = 10 μH, $L_2$ = 30 nH, $C_1$ = 10 pF, $C_2$ = 940 pF, $C_3$ = 2.7 nF, $C_4$ = 1.5 nF and T = BFR35A.

Kaertner made one simplification that in circuit theory is deadly: $L_2$ was assumed to have infinite Q. For his approach, as the circuit will actually load the unloaded Q, this is permissible. With an infinite Q and with $C_2$ = 940 pF, it will oscillate. Once a real Q, like $Q_L$ =100, is used, the value of $C_2$ must be reduced to 100 pF; then all works well. The feedback has to be increased, and it is advisable to reduce $C_4$ to 100 pF, as it is not possible to make a capacitor without parasitic inductance. The same applies to the 10 μH inductor,

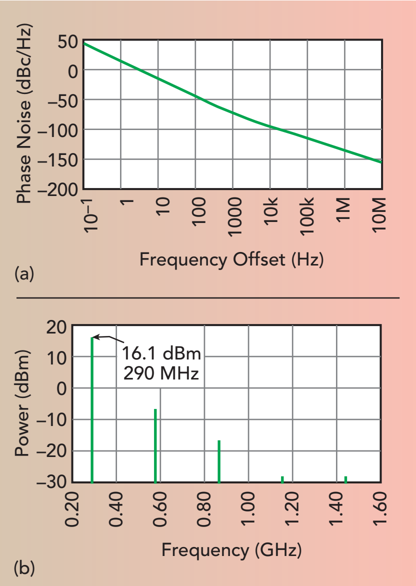



**Fig. 4** Simulated phase noise (a) and output power vs. frequency (b) of the Kaertner oscillator.

which is probably resonant at the operating frequency; 1 μH seems to be a better choice. Kaertner published the calculated phase noise of his oscillator,[4] pointing out correctly that the flicker contribution was not included.

***Figure 3b*** shows Kaertner's oscillator circuit when modeled with Compact Software Microwave Harmonia, to use the HB technique. The simulation includes the flicker noise exponent (AF) and the flicker noise constant (KF) and the simulation provides results tracking Kaertner's publication (see ***Figure 4a***). The influences of AF and KF are clearly seen at 1 kHz. The simulation also predicts the output power and harmonic content (see ***Figure 4b***). The output power is approximately 16 dBm with about 20 dB harmonic suppression. This indicates a good operating Q of the resonant circuit. The analysis tracks the performance very well.

## SUMMARY

This brief history provides insight into the struggle to develop and validate a general purpose, nonlinear computer-aided design (CAD) tool that correctly predicts large-signal noise in amplifiers, frequency doublers and mixers. There are many more examples.[2,14]

There were many excellent contributors. Vittorio Rizzoli probably contributed the most, and my team's effort to test and validate the Serenade Harmonica program should not be underestimated. Later, a CAD independent mathematical time domain calculation was developed, which, without immediately resorting to an expensive tool, can predict the noise performance of oscillators.[2,23-24]■

## References

1. D. B. Leeson, "A Simple Model of Feedback Oscillator Noise Spectrum," *Proceedings of the IEEE*, Vol. 54, No. 2, February 1966, pp. 329–330.
2. U. L. Rohde, A. K. Poddar and G. Böck, The Design of Modern Microwave Oscillators for Wireless Applications: Theory and Optimization, pp. 131–137.
3. H. Hillbrand and P. Russer, "An Efficient Method for Computer Aided Noise Analysis of Linear Amplifier Networks," *IEEE Transactions on Circuits and Systems*, Vol. 23, No. 4, April 1976.
4. L. A. Hajimiri, "Linearity, Time Variation, and Oscillator Phase Noise," *RF and Microwave Oscillator Design*, Artech House, 2002.
5. A. Hajimiri and T. Lee, "A General Theory of Phase Noise in Electrical Oscillators," *IEEE Journal of Solid-State Circuits*, Vol. 33, No. 2, February 1998, pp. 179–194.
6. D. Ham and A. Hajimiri, "Concepts and Methods in Optimization of Integrated LC VCOs," *IEEE Journal of Solid-State Circuits*, June 2001.
7. D. Scherer, "Design Principles and Test Methods for Low Phase Noise RF and Microwave Sources," *RF and Microwave Measurement Symposium and Exhibition*, Hewlett Packard, 1983.
8. F. X. Kaertner, "Determination of the Correlation Spectrum of Oscillators with Low Noise," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 37, No. 1, January 1989.
9. V. Rizzoli, F. Mastri and C. Cecchefti, "Computer-Aided Noise Analysis of MESFET and HEMT Mixers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 37, September 1989, pp. 1401–1410.
10. V. Rizzoli and A. Lippadni, "Computer-Aided Noise Analysis of Linear Multiport Networks of Arbitrary Topology," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 33, December 1985, pp. 1507–1512.
11. V. Rizzoli, F. Mastri and D. Masotti, "General-Purpose Noise Analysis of Forced Nonlinear Microwave Circuits," *Military Microwave*, 1992.
12. R. J. Gilmore and M. B. Steer, "Nonlinear Circuit Analysis Using the Method of Harmonic Balance—A Review of the Art. Part I. Introductory Concepts," *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 1, No. 1, January 1991, pp. 22–37.
13. R. J. Gilmore and M. B. Steer, "Nonlinear Circuit Analysis Using the Method of Harmonic Balance—A Review of the Art. Part II. Advanced Concepts," *International Journal of 367T*.
14. U. L. Rohde and D. P. Newkirk, "RF/Microwave Circuit Design for Wireless Application," *Wiley*, 2000.
15. R. A. Pucel, H. A. Haus and H. Statz, "Signal and Noise Properties of Gallium Arsenide Microwave Field-Effect Transistors," Advances in Electronics and Electron Physics, *Academic Press*, Vol. 38, 1975.
16. U. L. Rohde, "New Nonlinear Noise Model for MESFETs Including MM-Wave Application," *First International Workshop of the West German IEEE MTT/AP Joint Chapter on Integrated Nonlinear Microwave and Millimeterwave Circuits (INMMC'90) Digest*, Duisburg University, October 3–5, 1990.
17. U. L. Rohde, "Improved Noise Modeling of GaAs FETs: Using an Enhanced Equivalent Circuit Technique," *Microwave Journal*, November 1991, pp. 87–101; December 1991, pp. 87–95.
18. M. Rudolph, R. Doerner, K. Beilenhoff and P. Heymann, "Scalable GaIn/GaAs HBT Large-Signal Model," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 48, December 1990, pp. 2370–2376.
19. R. A. Pucel, W. Struble, R. Hallgren, and U. L. Rohde, "A General Noise De-embedding Procedure for Packaged Two-Port Linear Active Devices," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 11, November 1992, pp. 2013–2024.
20. U. L. Rohde, A. M. Pavio and R. A. Pucel, "Accurate Noise Simulation of Microwave Amplifiers Using CAD," *Microwave Journal*, Vol. 31, No. 12, December 1988, pp. 130-141.
21. R. A. Pucel and U. L. Rohde, "An Exact Expression for the Noise Resistance Rn of a Bipolar Transistor for Use with the Hawkins Noise Model," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No. 2, February 1993, pp. 35–37.
22. C. C. McAndrew, J. A. Seitchik, D. F. Bowers, M. Dunn, M. Foisy, I. Getreu, M. McSwain, S. Moinian, J. Parker, D. J. Roulston, M. Schroeter, P. van Wijnen and L. F. Wagner, "VBIC95, The Vertical Bipolar Inter-Company Model," *IEEE Journal of Solid-State Circuits*, Vol. 31, No. 10, October 1996, pp. 1476–1483.
23. W. Anzill, F. X. Kaertner and P. Russer, "Simulation of the Single-Sideband Phase Noise of Oscillators," *Second International Workshop of Integrated Nonlinear Microwave and Millimeterwave Circuits*, 1992.
24. U. L. Rohde and A. Apte, "Everything You Always Wanted to Know about Colpitts Oscillators," *IEEE Microwave Magazine*, Vol. 17, No. 8, August 2016, pp. 59–76.
25. U. L. Rohde, "Parameter Extraction for Large Signal Noise Models and Simulation of Noise in Large Signal Circuits Like Mixers and Oscillators," *23rd European Microwave Conference*, Madrid, September 6–9, 1993.

INVITED PAPER

# Measurement-Based Optimization of Aperture Tunable Antennas

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In the quest for larger bandwidths and throughput in mobile communication, operators are looking for an ever-increasing number of frequency bands, using multiple bands simultaneously with carrier aggregation techniques and adopting multi-antenna technologies. For mobile portable devices, the evolution of the industrial design toward large displays, large batteries and thin profiles has pushed antenna design requirements to the limit. Antenna tuning techniques have, therefore, become increasingly important, as it is difficult to cover all required mobile frequency bands with a fixed antenna resonator and fixed impedance matching circuit.

Besides allowing the mobile device to set the antenna to operate optimally at the desired frequency band (open loop tuning), tunable antennas also enable the implementation of "adaptive tuning," also known as closed loop tuning. The mobile device will, in this case, continuously try to adapt the antenna to the changing environment—for example, loading by the user's hand. As the name suggests, this technique also requires actively measuring one or more performance parameters, which the controller can use as guidance for setting the tuner control.

Frequency tunable antennas can be implemented in two basic methods. In impedance tuning, the matching circuit connected to the antenna feed will contain a tunable element, such as a tunable capacitor or a switch. A more sophisticated technique is aperture tuning, where a tuning network is attached to the antenna resonator using a dedicated connection located a given distance from the feed port. The latter technology has recently gained the most interest in the industry thanks to the higher potential performance benefits. However, it can be very sensitive to the losses in the tuning element, which must be able to sustain higher currents and voltages.[1]

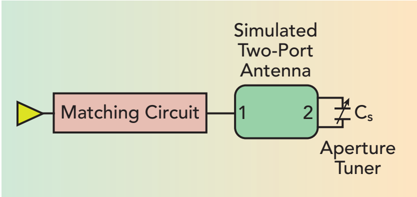
Several technologies are currently available for implementing reconfigurable networks to be used as antenna tuners. Solid-state switches can be used in single-pole multi-throw configurations, which allows for the connection and disconnection of external passive components such as inductors and capacitors. Different technology variants, such as high resistivity silicon on insulator (HR-SOI)[2] and silicon on sapphire,[3] are continuously evolving to achieve the best figure of merit for the switch, indicated by the product of on resistance and off capacitance ($R_{on}C_{off}$ in ps). Microelectromechani-

cal systems (MEMS) technology can potentially surpass solid-state technology in this figure of merit, but the commercial availability of MEMS switches for the RF market is still limited. Besides using a switch, a variable capacitor available as a single component can provide a more compact alternative. Digitally variable capacitors (DVC) are commercially available and largely deployed in antenna tuners in phones on the market, implemented either in solid-state or MEMS technologies.[4]

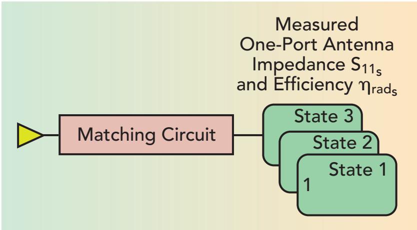
This article aims to show how to design an aperture tunable antenna for frequency band selection. A variable capacitor is used to implement the aperture tuner while a fixed matching circuit at the antenna feed is co-designed for best performance across all required frequency bands. It will be demonstrated how the co-design of the aperture tuned antenna and the fixed matching network are key for achieving optimum performance, since the operation of the aperture tuner greatly affects the impedance presented at the antenna feed port. The design flow also presents opportunities for designing antennas for carrier aggregation combinations: a given tuner configuration is set to cover a combination of bands instead of a single one. However, this significantly complicates the design effort and falls beyond the scope of this work.

## DESIGN METHODOLOGY

The design goal for the aperture tuned antenna and fixed impedance matching network is to maximize the total radiation efficiency over each frequency band. This is more relevant than getting the lowest possible return loss at the feed, since any losses in the matching components or the tuner will improve the feed match, but at the expense of radiated power.[5] At least as an initial design candidate, the aperture tunable antenna can be designed using simulated antenna, tuner and matching component data. As shown in ***Figure 1***, the antenna system is a two-port system with port 1 being the feeding port and port 2 the aperture port. The design task is to design a matching circuit for port 1 and find the best possible values for the aperture tuner at port 2 to cover all the frequency bands.




**▲ Fig. 1 The aperture tuned antenna system consists of a matching circuit, simulated two-port antenna and aperture tuner.**




**▲ Fig. 2 An alternative, measurement-based design approach for an aperture tuned antenna.**

To describe the problem in a mathematical sense, assume that a tuner component has been attached to the aperture port 2, with value $C_s$ for state s. Assume that the frequencies have been separated to n frequency sets $F_k$, with $k = 1,\dots,n$, where each set contains one of multiple frequency bands, which need to be covered with one tuner state. The total efficiency is denoted by $\eta(f, S, \eta_{rad}, P, C_{s(k)})$, which depends on the frequency f, the two-port antenna scattering parameters S, radiation efficiency $\eta_{rad}$ of antenna port 1, fixed component values P of the matching circuit at port 1 and tunable component values $C_{s(k)}$ in the aperture port, where s(k) is the chosen tuner state for frequency set k. The optimization task can be written as follows:

$$\max_{P,s(1),\dots,s(n)} \ \min_{k=1,\dots,n} \ \min_{f\in F_k} \eta\left(f,S,\eta_{rad},P,C_{s(k)}\right)$$

The search is for the values of the fixed matching components and the tuner states which maximize the minimum efficiency over all the frequencies in all the frequency sets, where the tuner can assume a different state for each frequency set. Note that this formula describes the

optimization when the matching circuit topology is known. Instead of manually trying out different matching topologies, circuit synthesis algorithms can be used to produce multiple optimized matching circuit topologies, dramatically speeding up the design process of tunable matching circuits.

In many cases, the accurate design of the tunable system is not possible using simulations; in an actual mobile device, many small details may affect antenna performance. The electric and dielectric properties are unknown, making accurate electromagnetic simulation impossible. The radiation efficiency of the feed port will depend on the value of the aperture tuner, and this interaction is difficult to capture accurately when using circuit simulators or matching circuit optimization tools. When carrying out measurements, it is often difficult or impossible to measure the aperture port impedance accurately, due to the proximity of the feed port.

In contrast, the following single-port design flow based on a prototype, which contains the aperture tuner, is proposed (see ***Figure 2***). The radiation efficiency ($\eta_{rad_s}$) and input impedance ($S_{11s}$) of the antenna prototype is measured or simulated for each tuner state (s). This information is used in the matching circuit optimization to find the best tuner state, which varies with frequency band, and a fixed matching circuit.

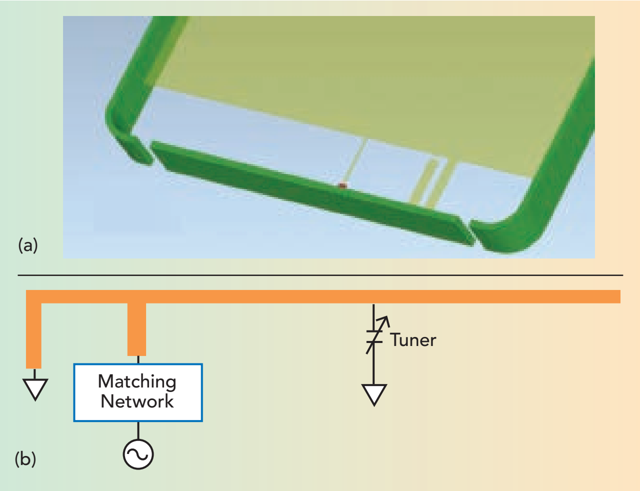


**Fig. 3** 3D model (a) and schematic (b) of an aperture tuned antenna.

When s(k) is the chosen tuner state for frequency set k, the optimization task (for a fixed matching circuit topology) can be written as:

$$\max_{P,s(1),\dots,s(n)} \ \min_{k=1,\dots,n} \ \min_{f\in F_k} \eta\left(f, S11_{s(k)}, \eta_{rad_{s(k)}}, P\right)$$

What needs to be ascertained are the values of the fixed matching components and the tuner states (the tuner is embedded in the measured/simulated one-port data) that maximize the minimum efficiency over all the frequencies in all the frequency sets, where the tuner can assume a different state for each frequency set. The optimization algorithm is searching an optimal impedance and efficiency data set (implicitly the best tuner state) for each of the frequency sets, while optimizing the fixed matching circuit

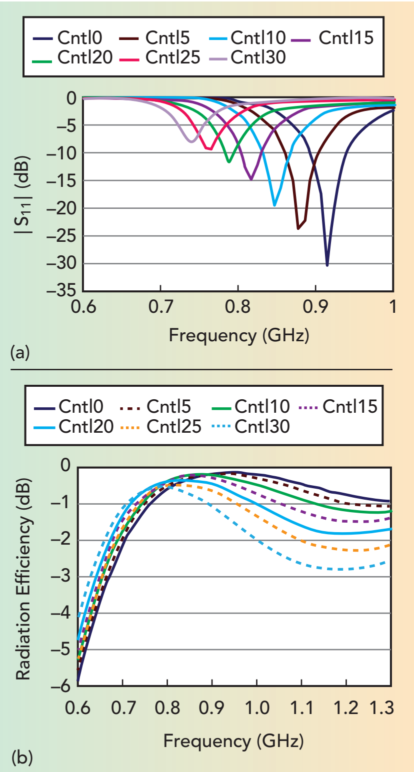
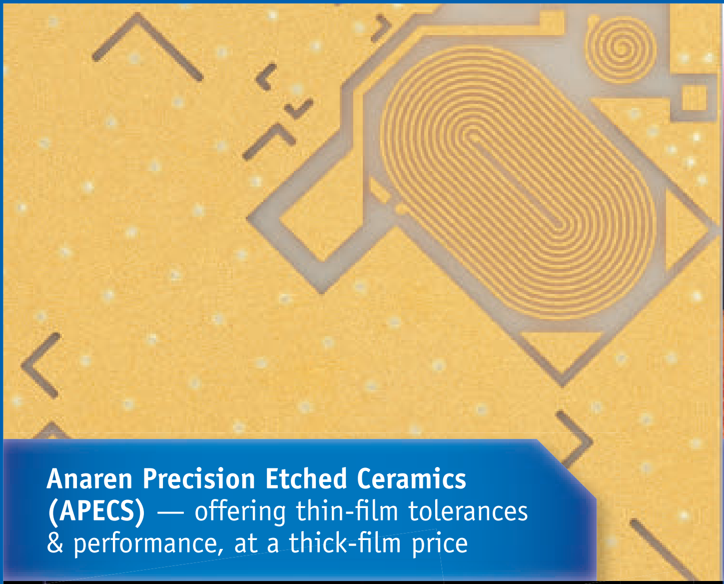


**Fig. 4** Simulated $|S_{11}|$ (a) and radiation efficiency (b) vs. tuning state.



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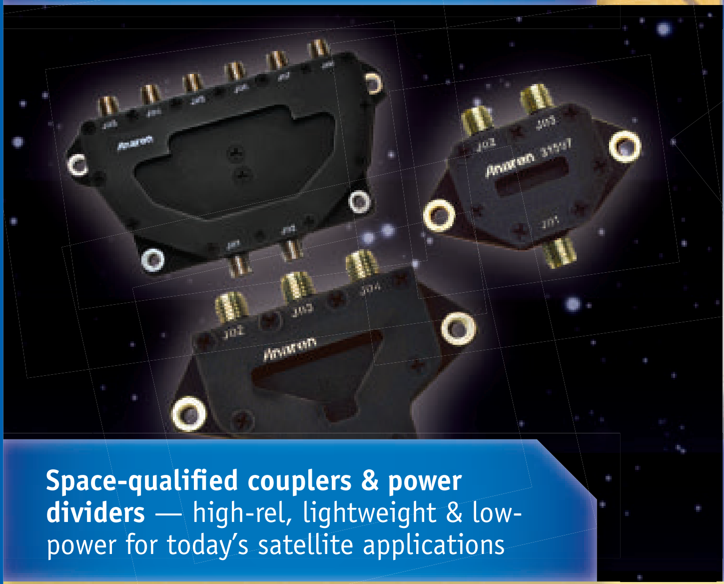

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values for best global performance. Both the matching circuit topology and component values can be optimized if the design tool supports topology synthesis in this context.

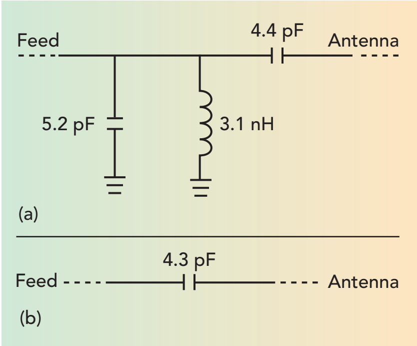
## DESIGN EXAMPLES

This section presents an aperture tuned antenna design based on the methodology presented in the previous section. ***Figure 3*** shows a 3D model for a metal frame phone antenna based on a planar inverted-F antenna (PIFA) and the schematic of the design concept, extended with an aperture tuning connection point (i.e., tuner). To tune the antenna across all desired low frequency bands (700 to 960 MHz), a MEMS-based DVC is connected to the antenna resonator 10 mm from the feed. The variable capacitor is digitally controlled with 5 bit resolution, with a total of 32 control states (Cntl 0 to Cntl 31). ***Figure 4*** shows the $|S_{11}|$ of the antenna for a selection of tuning states, based on the antenna impedance $S_{11s}$ at the reference plane of the antenna feed.

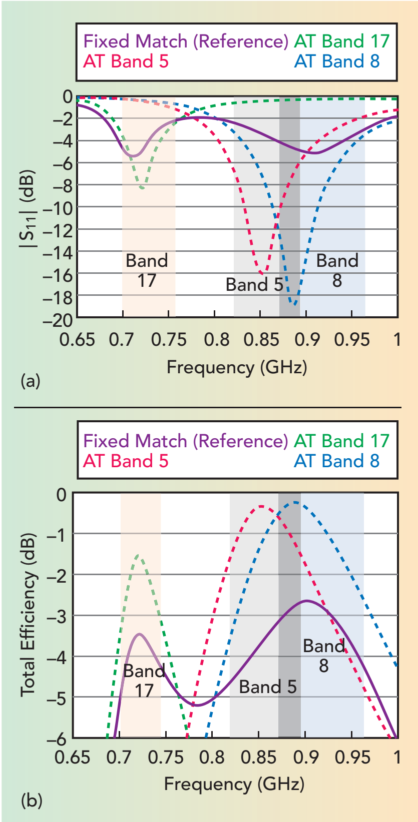
The steps to design the aperture tuning circuit are:

- Simulate/measure the return loss and efficiency of the antenna for each state of the tuner
- Import the S-parameters and efficiency data into the matching circuit design software
- Calculate the proper tuning state and fixed matching network






▲ **Fig. 5 Matching networks for the fixed (a) and aperture tuned (b) antenna designs covering bands 5, 8 and 17.**




▲ **Fig. 6 Simulated $|S_{11}|$ (a) and total efficiency (b) comparisons of the aperture tuned and fixed matching circuit designs covering bands 5, 8 and 17.**

**TABLE 1**

**FIXED MATCHING vs. APERTURE TUNING COMPARISON, BAND 5/8/17 DESIGN**

| Design Approach | Band 5 Efficiency Minimum/ Average (dB) | Band 8 Efficiency Minimum/ Average (dB) | Band 17 Efficiency Minimum/ Average (dB) |
|---|---|---|---|
| 3-Section Fixed Matching Network | -4.5/-3.5 | -4.1/-3.1 | -4.5/-4 |
| 1-Section Matching & Aperture Tuning | -1.4/-0.8 (Tuner in State 7) | -2.5/-1 (Tuner in State 0) | -3/-2.2 (Tuner in State 21) |



to cover the desired frequency bands.

The $S_{11}$ and efficiency results for individual tuning states are calculated in EMPIRE XPU 3D EM simulation software.[6] The co-simulation of the matching network and aperture tuned antenna calculation uses matching circuit optimization software.[7] The tuner used in this design is a MEMS-based DVC.[8] It has an ultra-low resistance together with high voltage handling, which is suitable for efficient antenna tuning.[1,4] Realistic models of the inductors and capacitors, including component losses and parasitic reactances, were used in the example.

To show the effectiveness of the presented design methodology, two examples are presented. In both, the aperture tuned antenna will be compared to a more traditional fixed antenna, where both antenna options include an optimized fixed matching network at the feed.

### Covering Bands 5, 8 and 17

The results presented here represent a typical design requirement for portable mobile devices, which includes the following frequency bands: LTE band 17, LTE band 5 (GSM850) and LTE band 8 (GSM900). This band configuration is typically quite challenging for small handset antennas. The matching network is limited to one component for the tuned antenna, while three components are required for the fixed antenna (see ***Figure 5***). The aperture tuned antenna, while requiring an extra contact point for the tuner, requires considerably less space in feeding area due to the lower number of matching elements. ***Figure 6*** compares the $|S_{11}|$ and the total efficiency for the proposed aperture tuned antenna design technique versus a fixed reference antenna for all required frequency bands, and ***Table 1*** summarizes the efficiency results of the two solutions. The aperture tuned antenna improves the total efficiency by more than 3 dB in band 5 and more than 1.5 dB in bands 8 and 17.

### Covering Bands 5, 8 and 28

A more challenging design is covering LTE band 28 with LTE band 5 (GSM850) and LTE band 8

(GSM900). The very large bandwidth of band 28 makes this band configuration extra challenging compared to the previous example. ***Figure 7*** shows the schematic of the fixed matching network for both solutions. In this case, due to the large bandwidth requirement of band 28, the aperture tuned antenna required two matching components, while the fixed antenna matching network required three elements, as before. ***Figure 8*** compares the $|S_{11}|$ and total efficiency of the two solutions, and ***Table 2*** summarizes the total efficiency versus frequency band for each solution. The aperture tuned antenna improves the efficiency by more than 1 dB in all the desired frequency bands; in band 28, the average total efficiency is improved by 1 dB without trading off efficiency in the other two bands.

## CONCLUSION

Tunable antenna solutions are increasingly being used to enhance the radio performance of mobile handheld devices. The design and implementation of tunable antennas is challenging as it involves the co-design of the tuner states and the fixed matching circuitry to obtain optimal total efficiency. This article presents a novel measurement-based design flow for aperture tunable antennas, using the measured impedances and radiation efficien-

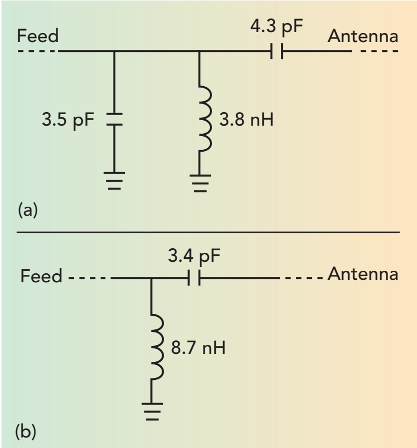



**Fig. 7** Matching networks for the fixed (a) and aperture tuned (b) antenna designs covering bands 5, 8 and 28.

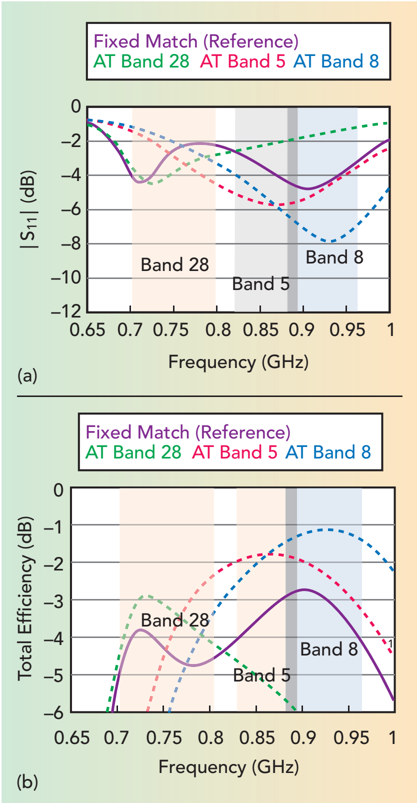
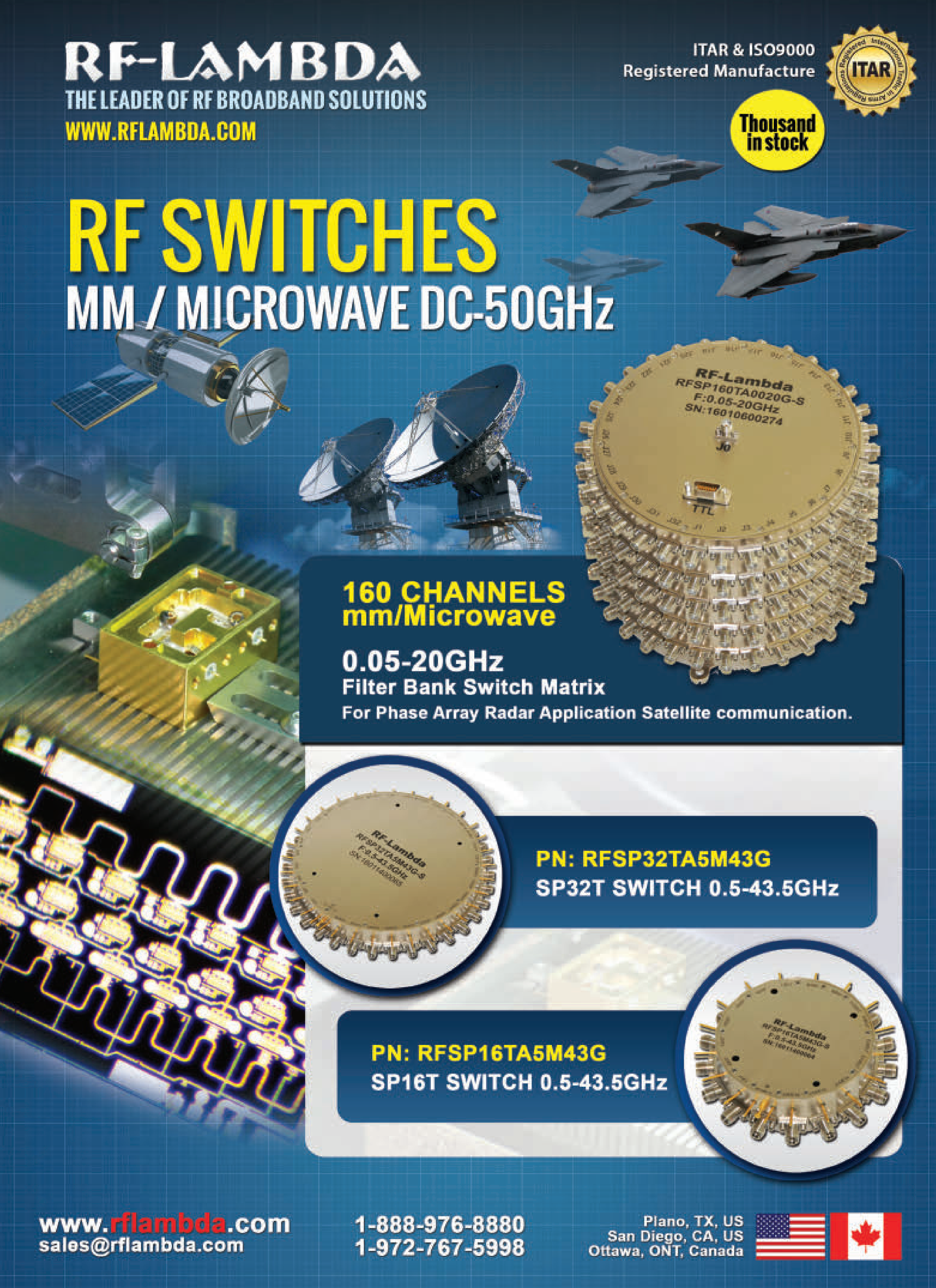



**Fig. 8** Simulated $|S_{11}|$ (a) and total efficiency (b) comparisons of the aperture tuned and fixed matching circuit designs covering bands 5, 8 and 28.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cies of the antenna system for each state of the digitally controlled aperture tuner capacitor. This collection of data is used to synthesize an optimal fixed matching circuit topology at the antenna input, to optimize the discrete component values and to select the optimal tuner states.

The benefit of this approach is that the measurement setup of the antenna impedance and radiation efficiency is greatly simplified and provides more reliable data. In contrast, an accurate two-port measurement involving both the feed and the aperture tuning ports is difficult due to the proximity of the ports, influence of the aperture port measurement cable to the antenna performance and the presence of other components. Proper incorporation of the radiation efficiencies would be complicated in a two-port approach.

While electromagnetic simulation can alleviate the measurement setup problems at early design phases, the radiation efficiency problem still persists, and the approach presented generalizes to simulated data as well. The design examples demonstrate that the aperture tuning approach with ultra-low loss tuner components provides a significant improvement over the reference case utilizing just a fixed matching circuit at the antenna input—even when using fewer matching components than in the reference case.■

**TABLE 2**

**FIXED MATCHING vs. APERTURE TUNING COMPARISON, BAND 5/8/28 DESIGN**

| Design Approach | Band 5 Efficiency Minimum/ Average (dB) | Band 8 Efficiency Minimum/ Average (dB) | Band 28 Efficiency Minimum/ Average (dB) |
|---|---|---|---|
| 3-Section Matching | -4.2 /-3.3 | -3.9/-3.1 | -4.7/-4.4 |
| 2-Section Matching & Aperture Tuning | -2/-1.8 (Tuner in State 9) | -1.5/-1.2 (Tuner in State 0) | -4.2/-3.5 (Tuner in State 23) |



## References


1. P. A. Tornatta, R. Gaddi, "Aperture Tuned Antennas for 3G-4G Applications Using MEMS Digital Variable Capacitor," *Microwave Symposium Digest (IMS)*, 2013 IEEE MTT-S International, June 2-7, 2013.
2. A. Botula et al., "A Thin-Film SOI 180 nm CMOS RF Switch Technology," *Silicon Monolithic Integrated Circuits in RF Systems*, 2009 (SiRF '09), January 19-21, 2009.
3. R. Novak, "UltraCMOS® Technology for High-Performance Switch Paths and Tunable Components," *2013 International Symposium on VLSI Technology, Systems, and Applications (VLSI-TSA)*, April 22-24, 2013.
4. V. Joshi et al., "MEMS Solutions in RF Applications," *IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference (S3S)*, October 7-10, 2013.
5. J. Rahola, "Optimization of Matching Circuits for Antennas," *Proceedings of the EuCAP 2011 Conference*, Rome, April 11-15, 2011.
6. Empire XPU, IMST GmbH, www.empire.de/main/Empire/en/home.php.
7. Optenni Lab Matching Circuit Optimization Software, www.optenni.com.
8. Cavendish Kinetics, www.cavendish-kinetics.com.

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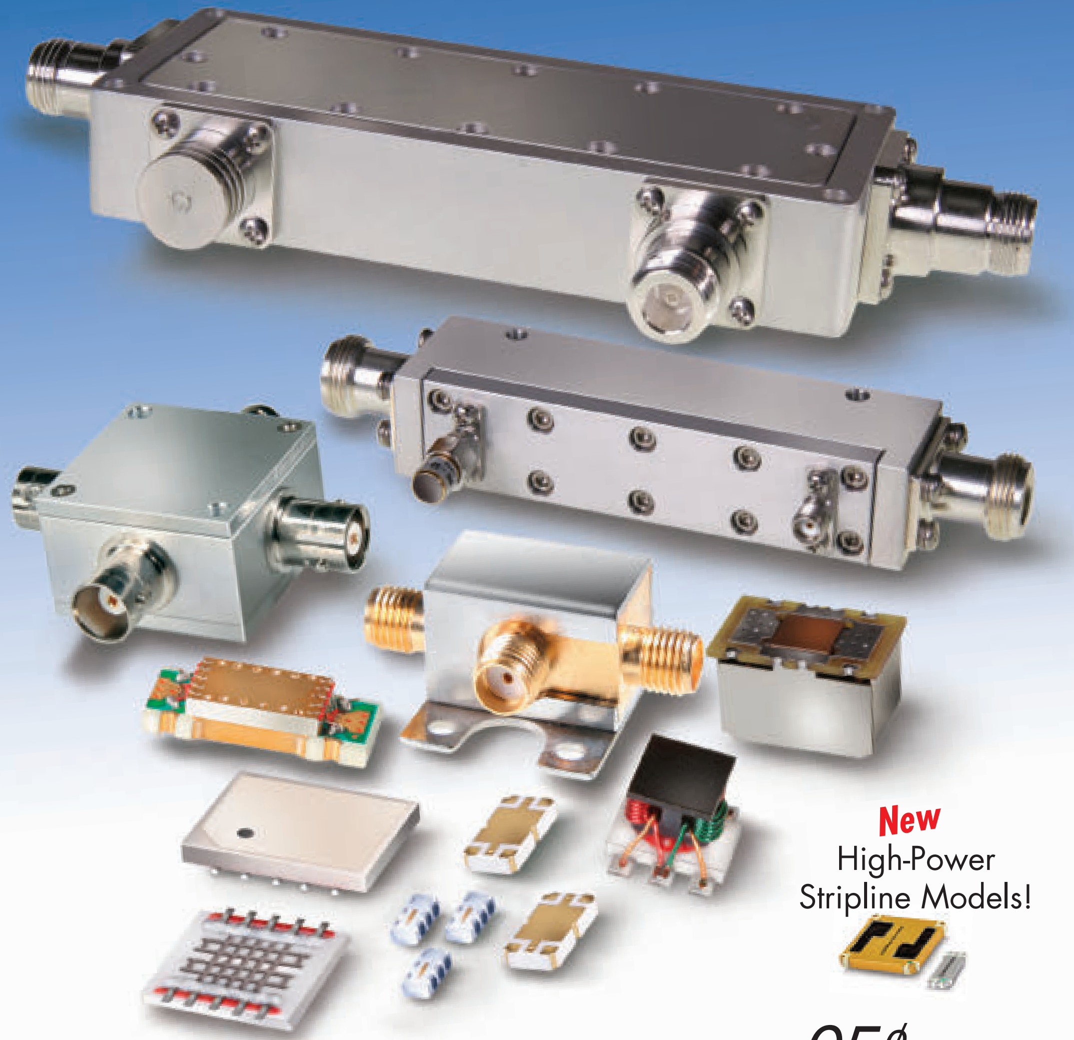

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# Modeling 3-Port Center-Tapped Spiral Inductors for K-Band VCO

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*School of Physics and Technology, Wuhan University, Wuhan, China*

*Three-port center-tapped spiral inductors are designed to achieve high performance with symmetrically octagonal twin shapes for a K-Band voltage-controlled oscillator (VCO) in 0.13 μm SiGe BiCMOS technology. The modeling of on-chip inductors includes a 3D physical model for actual chip fabrication and a double π equivalent circuit model for precise parameter extraction. Simulation results for the physical and circuit models agree closely. The total inductance is 300 pH with a high Q of 18 at the desired operating frequency of 20 GHz. A 20 GHz VCO for K-Band applications using 0.13 μm SiGe BiCMOS technology with a chip area of 0.22 mm$^2$ was built to verify the accuracy of the inductor modeling. The tuning range of the VCO was 2.21 GHz, from 19.9 to 22.11 GHz. At 20.89 GHz, the measured phase noise at 100 kHz and 1 MHz offset frequencies was -52.26 and -92.07 dBc/Hz, respectively. VCO power dissipation was 27 mW with a 1.5 V supply.*

On-chip spiral inductors are needed to meet the increasing demand for wireless products with high performance, low-power, low-cost and high levels of integration. They are widely used in radio frequency integrated circuits (RFIC) to provide appropriate inductance values with high quality factors (Q) and high self-resonances.[1]

Due to the lack of an accurate high frequency model for on-chip inductors in 0.13 μm SiGe BiCMOS technology, modeling of on-chip spiral inductors for the design of RFICs should be carefully considered.[2] A 3D physical model was accurately designed to be a compact octagon shape for ease of implementation, and an equivalent circuit model was established to be a double π schematic for precise parameter extraction and circuit optimization.[3,4]

Three-port symmetric spiral inductors with center taps are often employed for differential RFICs such as VCOs, low-noise amplifiers (LNA) and mixers. The center tap is connected to the center node of a symmetric inductor. The symmetric inductor is constructed with underpasses independent of the number of turns, to minimize the chip area; however, the underpasses and interlayer vias increase parasitic resistance and capacitance, which inevitably degrades inductor Q, especially for high frequency applications.[5] Compared with a symmetric inductor, a single-ended inductor usually has only one underpass. Therefore, to improve Q by reducing the number of underpasses, two single-ended spiral inductors can be used to realize a symmetric structure. The penalty is increased chip area. In this work, a three-port symmetric inductor with center tap is accurately modeled with two single-ended spiral inductors for use in a 0.13 μm SiGe BiCMOS K-Band VCO.

## PHYSICAL INDUCTOR MODEL

The process cross section for a 0.13 μm SiGe BiCMOS passive circuit is illustrated in ***Figure 1a***. From bottom to top, the process includes one polymer layer, five thin metal layers (M1 through M5) and two thick metal layers (TM1 and TM2), with a top via between TM1 and TM2. For a Si substrate, the

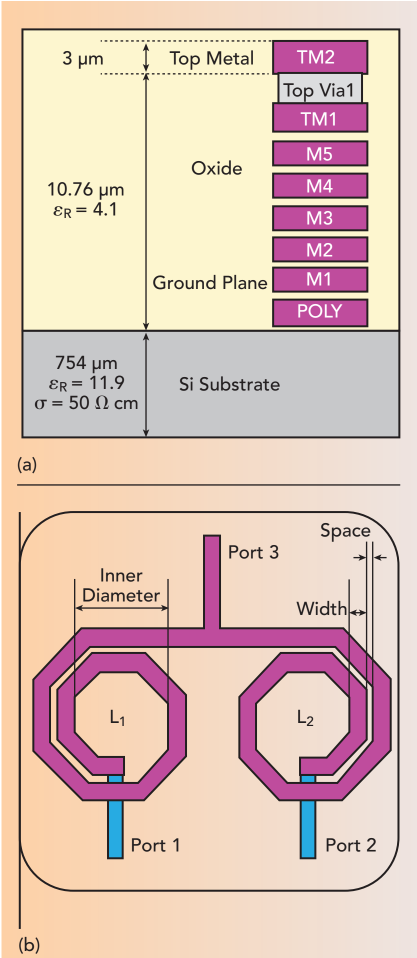
thickness, dielectric constant and resistivity are 754 µm, 11.9 and 50 Ω-cm, respectively. The dielectric constant of oxide is 4.1. The top metal layer (TM2) is 3 µm thick and 10.76 µm above the Si substrate.

The difficulty in physical modeling stems from the complexity of the high frequency phenomena, i.e., eddy currents in the interconnects and the substrate losses in the silicon. The key to accurate physical modeling is the ability to identify relevant parasitics and their effects.[6] Generally, inductors must be high Q. Inductor Q is enhanced by reducing the transmission losses caused by parasitic series resistance, which is frequency dependent due to the skin effect, and the parasitic shunt capacitance to the substrate. Transmission loss becomes more serious at high frequencies.

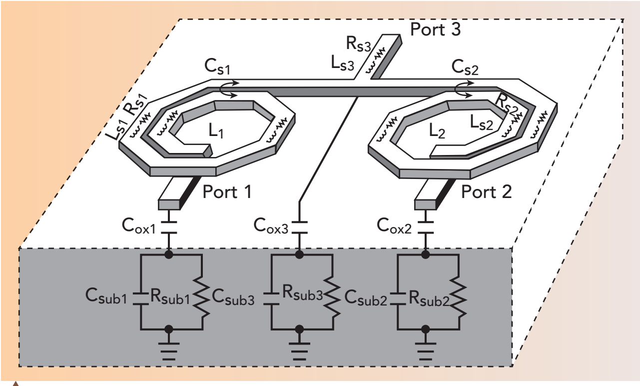
To achieve high Q, the design addressed the following considerations (see ***Figure 1b***): The inductor is in the shape of a spiral octagon with three ports. For differential RFICs, a symmetric structure is built with two single-ended inductors, $L_1$ and $L_2$, having the common port connected to the center tap (port 3). This two, single-ended symmetric structure is implemented mainly by the top metal layer (TM2), with only two underpasses realized by metal layer TM1 and inner-layer vias between TM1 and TM2. This minimizes parasitic resistance and capacitance, to decrease transmission loss and improve Q. Physical parameters (width, space, inner diameter and number of turns) are adjusted to optimize performance.

Another consideration for reducing transmission loss is to place a ground plane above the Si substrate to prevent currents from parasitically coupling into it. As the distance of the ground plane to the inductor decreases, however, its parasitic capacitance increases, causing






▲ **Fig. 1 Cross section of 0.13 µm SiGe BiCMOS process (a) and layout of the three-port symmetric spiral inductor (b).**




**▲ Fig. 2 Physical structure of the symmetric inductor showing parasitic elements.**

the performance to degrade from self resonance. An approach to solve this is to utilize the bottom metal layer (M1) as the ground plane, which is far away from the inductor layers.

## EQUIVALENT CIRCUIT MODEL

Equivalent circuit models of spiral inductors utilizing lumped RLC elements, together with other design components, can be used effectively to evaluate electrical performance. Compared with the physical model simulated by an electromagnetic field solver, a lumped equivalent circuit model significantly decreases simulation time, for more rapid optimization.

To illustrate the equivalent circuit model, a 3D view of the symmetric inductor is shown in ***Figure 2***. $L_{s1}$, $R_{s1}$, $C_{s1}$ and $L_{s2}$, $R_{s2}$, $C_{s2}$ represent the inductances, resistances and line-to-line capacitances of the spiral wires of inductors $L_1$ and $L_2$, respectively.[4,5] $L_{s3}$ and $R_{s3}$ denote the inductance and resistance of the center tap line. $C_{ox1,2,3}$ represent oxide capacitances between the inductor line and the substrate. $C_{sub1,2,3}$ and $R_{sub1,2,3}$ depict the capacitances and resistances in the Si substrate. $C_{ox1,2,3}$, $C_{sub1,2,3}$ and $R_{sub1,2,3}$ form the RC network to model ohmic loss in the substrate. The total $C_{ox}$, $C_{sub}$ and $R_{sub}$ can be calculated as follows:

$$F(w,t)=\frac{1}{2\pi}\left(\frac{8t_{sub}}{w}+\frac{w}{4t_{sub}}\right) \quad \text{for } \frac{t_{sub}}{w}>1 \qquad (1)$$

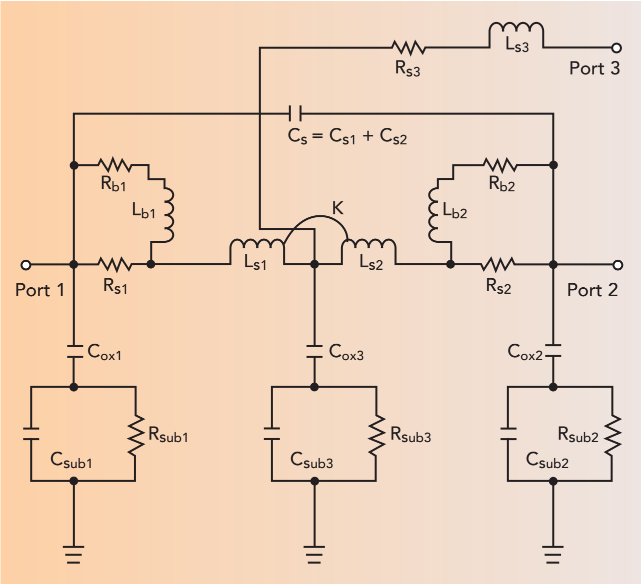
$$\frac{1}{\frac{w}{t_{sub}}+2.42-\frac{0.44t_{sub}}{w}+\left(1-\frac{t_{sub}}{w}\right)^{6}} \quad \text{for } \frac{t_{sub}}{w}<1 \qquad (2)$$

$$C_{ox}=\frac{\varepsilon_0\varepsilon_{ox}(l_{wire})}{2F(w,t_{ox})} \qquad (3)$$

$$C_{sub}=\frac{\varepsilon_0\varepsilon_{ox}(l_{wire})}{2F(w,t_{sub})} \qquad (4)$$

$$R_{sub}=\frac{2F(w,t_{sub})}{\sigma_{sub}\left[1+\left(1+\frac{10t_{sub}}{2}\right)^{-0.5}\right](l_{wire})} \qquad (5)$$

where $l_{wire}$ is the total physical length of the symmetric inductor, $t_{sub}$ and




▲ **Fig. 3 Double π equivalent circuit model of the symmetric inductor.**

$t_{ox}$ represent the thickness of the substrate and the height of the metal layer and w is the inductor width.

Double π equivalent circuit models of inductors are extensively used to achieve wideband modeling accuracy,[7] which significantly ensures circuit stability beyond the operating frequency range of the RFIC. Additionally, double π equivalent circuit models are built by frequency-independent RLC elements to achieve geometric scalability.[3,4] The double π equivalent circuit model corresponding to the physical structure in Figure 2 is shown in ***Figure 3***. $L_{b1}$, $R_{b1}$ and $L_{b2}$, $R_{b2}$ are added to model skin and proximity effects of the inductors at high frequency. In this case, the coupling coefficient k can be regarded as minimal, because the distance between $L_1$ and $L_2$ is relatively large.

Focusing on differential RFICs operating in K-Band, the physical and equivalent circuit models are optimized to verify uniformity through electromagnetic and circuit simulations, respectively. For the physical model, the width, space, inner diameter and turns of the inductor (see Figure 1) are optimized to be 7, 3, 50 and 1.5 μm, respectively. For the double π equivalent circuit model, a numerical approach is adopted to accurately calculate the lumped elements for the ladder circuit.[2] Using this approach, calculation complexity is dramatically reduced. Parameters used for calculation are extracted and shown in ***Table 1***.

L and Q are calculated using Equations 6 and 7

$$L = \frac{2\text{imag}(Z_{DD})}{2\pi f} \quad (6)$$

$$Q = \frac{\text{imag}(Z_{DD})}{\text{real}(Z_{DD})} \quad (7)$$

$$\varepsilon = \left| \frac{X - m}{X} x100\% \right| \quad (8)$$

where $Z_{DD}$ is equal to $(Z_{11} + Z_{12} + Z_{21} + Z_{22}) * 0.5$

Results of both models are compared in ***Figure 4*** and agree well. The simulated total inductance of $L_1$ and $L_2$ is approximately 300 pH (150 pH each) and the Q is approximately 18 at the operating frequency of 20 GHz.

## K-BAND VCO DESIGN

To evaluate the performance of the symmetric inductor, a 20 GHz VCO was designed for K-Band applications. ***Figure 5*** shows the schematic of the 20 GHz VCO core and buffers.[8] The differential LC VCO core is constructed with cross-coupled nMOS transistors $M_1$ and $M_2$, which provide the negative conductance to compensate the loss of the LC tank. Transistor $M_3$ is used as the tail current source to set the current of the VCO. The LC tank is built using spiral inductors $L_1$ and $L_2$ together with MOS varactors $C_1$ and $C_2$. The MOS varactors are realized with a polysilicon-to-n-well structure, which has good linearity, high Q and a wide tuning ratio. The tuning ratio $C_{max}/C_{min}$ is approximately 3 at 20 GHz, when the gate width, length and fingers of each varactor are selected to be 40 μm, 3 μm and 4, respectively. The output buffer of the VCO is a single-stage source

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| | |
|---|---|
| Frequency | 0.01 to 18.0 GHz |
| Gain | 40 dB Typ - Measured 43.03 dB / 38.89 dB Max / Min |
| Gain Flatness | ±2.0 dB Typ - Measured ±2.03 dB |
| Noise Figure | 3.0 dB Typ - Measured 5.35 dB @ < 0.5 GHz 3.62 dB @ > 0.5 GHz |
| OP1dB | +27 dBm Typ, +24 dBm Min - Measured 25.46 dBm |
| VSWR | 2.0:1 Typ - Measured 1.95:1 |

**Package Size:** 3.00" x 3.00" x 1.75"
**AC Voltage:** 120 VAC
**RF Connectors:** Type N Female

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| | |
|---|---|
| Frequency | 1.0 to 20.0 GHz |
| Gain | +60 dB Typ - Measured 64.5 dB |
| Gain Flatness | ±3.0 dB Typ - Measured ±1.29 dB |
| Noise Figure | 5.0 dB Typ - Measured 4.6 dB |
| OP1dB | +10 dBm Min - Measured +10.7 dBm |
| VSWR In/Out | 2.0:1 Typ - Measured 1.54:1 / 1.81:1 |

**Package Size:** 4.92" x 4.92" x 2.10"
**AC Voltage:** 120 VAC
**RF Connectors:** SMA Female

### Model: PTB-42-1G40G-12-292FF-DC12-220VAC

http://www.pmi-rf.com/Products/amplifiers/PTB-42-1G40G-12-292FF-DC12-220VAC.htm

| | |
|---|---|
| Frequency | 1.0 to 40.0 GHz |
| Gain | +40 dB Typ - Measured 38.1 dB |
| Gain Flatness | ±2.5 dB Typ - Measured ±1.85 dB |
| Noise Figure | 5.0 dB Typ - Measured 4.64 dB |
| OP1dB | +22 dBm Typ (1.0 to 18.0 GHz) +18 dBm Typ (18.0 to 40.0 GHz) |
| VSWR In/Out | 2.0:1 Typ - Measured 1.82:1 / 1.53:1 |

**Package Size:** 4.92" x 4.92" x 2.10"
**AC Voltage:** 220 to 230 VAC
**RF Connectors:** 2.92mm Female

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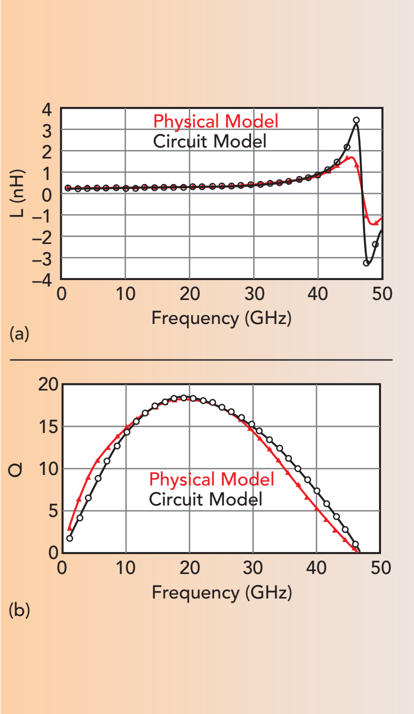
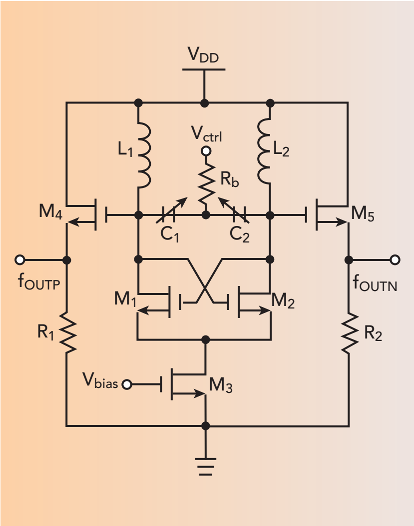
**TABLE 1**

**EXTRACTED CIRCUIT MODEL PARAMETERS**

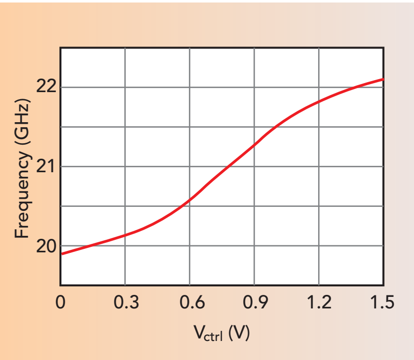
| Port 1 | Port 2 | Port 3 | Other |
|---|---|---|---|
| $L_{s1}$ = 120.076 pH | $L_{s2}$ = 120.076 pH | $R_{s3}$ = 0.2 Ω | $C_s$ = 0.044 pF |
| $R_{s1}$ = 2.2 Ω | $R_{s2}$ = 2.2 Ω | $L_{s3}$ = 0.8 pH | |
| $R_{b1}$ = 0.55 Ω | $R_{b2}$ = 0.55 Ω | $C_{ox3}$ = 0.004 pF | |
| $L_{b1}$ = 8.5 pH | $L_{b2}$ = 8.5 pH | $R_{sub3}$ = 1650 Ω | |
| $C_{ox1}$ = 0.002 pF | $C_{ox2}$ = 0.002 pF | $C_{sub3}$ = 0.009 pF | |
| $R_{sub1}$ = 2900 Ω | $R_{sub2}$ = 2900 Ω | | |
| $C_{sub1}$ = 0.0045 pF | $C_{sub2}$ = 0.0045 pF | | |




▲ Fig. 4 Comparison of the physical and circuit models: L (a) and Q (b).




▲ Fig. 5 20 GHz VCO core and buffers.




▲ Fig. 6 VCO frequency vs. tuning voltage.

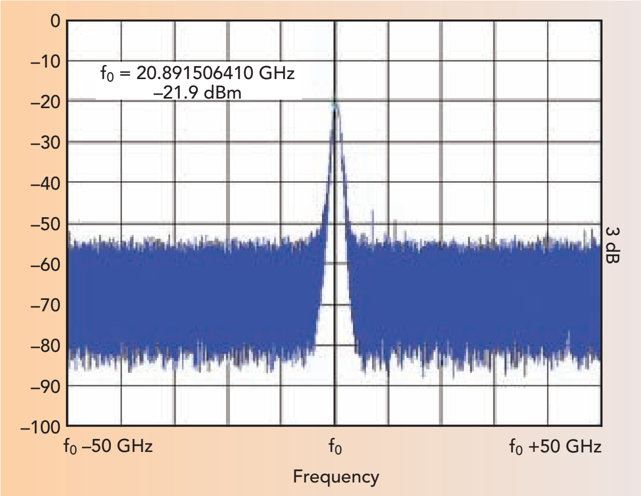



Fig. 7 Measured output spectrum.

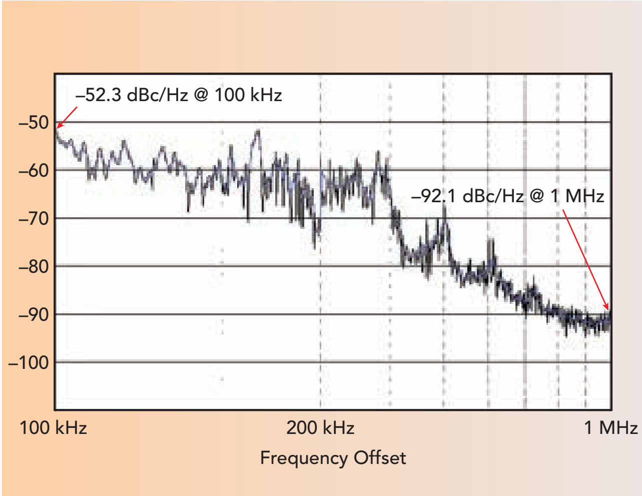



Fig. 8 Measured phase noise.

follower amplifier, which has high input impedance to minimize loading of the VCO core and low output impedance to facilitate matching to a 50 Ω output.

The VCO design was fabricated on a 0.13 μm SiGe BiCMOS process having seven metal backends. The nMOS transistors used for low-power wireless applications achieve a cut-off frequency, $f_T$, around 100 GHz and a maximum oscillation frequency, $f_{MAX}$, around 130 GHz. The entire chip area, including testing pads, is 0.47 × 0.47 $mm^2$. One of differential outputs is terminated internally with an on-chip 50 Ω resistor, for measurement purposes.

On-wafer measurements were performed using a probe station with Cascade 100 μm G-S-G probes. ***Figure 6*** shows the measured tuning characteristic of the VCO. The tuning range is 2.21 GHz, approximately 10.5 percent, from 19.9 to 22.11 GHz when $V_{ctrl}$ changes from 0 to 1.5 V. The linear range is 0.96 GHz, from 20.56 to 21.52 GHz, when $V_{ctrl}$ varies from 0.6 to 1 V. From this, the linear gain of the VCO is calculated to be 2.4 GHz/V.

The measured output spectrum over a 100 MHz span is shown in ***Figure 7***. The output frequency was 20.89 GHz, with an output power of -21.9 dBm. Phase noise at 20.89 GHz is shown in ***Figure 8***. At 100 kHz and 1 MHz offset frequencies from the carrier, the phase noise was -52.3 and -92.1 dBc/Hz, respectively. Using a 1.5 V supply voltage, the tail current of the VCO core was set at 4 mA, and the output buffers drew around 14 mA; hence, the total power dissipation of the VCO was 27 mW.

***Table 2*** compares the measured performance with simulation. The discrepancies between the simulated and measured results are attributed to losses from the probe, coaxial cable and SMA connector that reduce the output power and the parasitic effects of wire interconnects and signal pads that reduce the oscillating frequency, $f_0$, and tuning range and increase the phase noise. Hence, the interconnects for the VCO must be designed to be as short as possible, and the parasitic capacitance of the signal pads must be minimized.

## CONCLUSION

Physical and circuit models were developed for a three-port symmetric spiral inductor with center tap.

| TABLE 2<br>VCO SIMULATED VS. MEASURED RESULTS | | |
|---|---|---|
| **Performance** | **Simulated** | **Measured** |
| $f_0$ (GHz) | 22.5 | 20.89 |
| Output Power (dBm) | –14.6 | –21.88 |
| Tuning Range (GHz) | 20.53 to 24.41 | 19.9 to 22.11 |
| Phase Noise (dBc/Hz) | –59.3 @ 100 kHz<br>–99.2 @ 1 MHz | –52.26 @ 100 kHz<br>–92.07 @ 1 MHz |

The performance of the two models agreed well and were designed and verified by fabricating a 20 GHz VCO, using a 0.13 µm SiGe BiCMOS process. The results show that the modeling approach described in this work provides a good estimate of L and Q for the highly integrated, differential RFIC designs.■

## ACKNOWLEDGMENT

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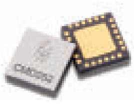
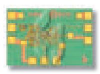
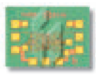
## References


1. H. H. Chen, H. W. Zhan, S. J. Chung, J. T. Kuo and T. C. Wu, "Accurate Systematic Model-Parameter Extraction for On-Chip Spiral Inductors," *IEEE Transactions on Electron Devices*, Vol. 55, No. 11, November 2008, pp. 3267–3273.
2. Y. G. Ahn, S. K. Kim, J. H. Chun and B. S. Kim, "Efficient Scalable Modeling of Double-π Equivalent Circuit for On-Chip Spiral Inductors," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 10, October 2009, pp. 2289–2300.
3. Y. Cao, R. A. Groves, X. Huang, N. D. Zamdmer, J. O. Plouchart, R. A. Wachnik, T. J. King and C. Hu, "Frequency-Independent Equivalent-Circuit Model for On-Chip Spiral Inductors," *IEEE Journal of Solid-State Circuits*, Vol. 38, No. 3, March 2003, pp. 419–426.
4. W. Y. Lim, M. A. Arasu and M. K. Raja, "Modeling of Two Port Center-Tapped to Ground and Three Port Scalable Symmetrical Inductor," *14th International Symposium on Integrated Circuits*, December 2014, pp. 540–543.
5. J. Chen and J. J. Liou, "Improved and Physics-Based Model for Symmetrical Spiral Inductors," *IEEE Transactions on Electron Devices*, Vol. 53, No. 6, June 2006, pp. 1300–1309.
6. C. P. Yue and S. S. Wong, "Physical Modeling of Spiral Inductors on Silicon," *IEEE Transactions on Electron Devices*, Vol. 47, No. 3, March 2000, pp. 560–568.
7. W. Gao and Z. Yu, "Scalable Compact Circuit Model and Synthesis for RF CMOS Spiral Inductors," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 3, March 2006, pp. 1055–1064.
8. J. He, J. Li, D. Hou, Y. Z. Xiong, D. L. Yan, M. A. Arasu and M. Je, "A 20 GHz VCO for PLL synthesizer in 0.13-µm BiCMOS," *IEEE International Symposium on Radio-Frequency Integration Technology*, November 2012, pp. 231–233.











# Planar Four-Way Power Divider with Stopband Rejection and Good Output Isolation

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*A planar four-way wideband power divider with compact size, good isolation and output port impedance matching uses quarter-wavelength coupled lines, instead of the quarter-wavelength transmission lines used in a conventional Wilkinson power divider, to implement stopband rejection and the four-way power dividing function. Even and odd mode equivalent circuits are presented and design equations are derived. A compact planar four-way power divider is designed, optimized, fabricated and measured. Measured results show good agreement with simulation.*

Power dividers play an important role in power-combining amplifiers and antenna arrays. Current development is focused on wide bandwidth,[1-4] multi-band response,[5-7] miniaturization,[8,9] high isolation[10,11] and harmonic suppression,[12,13] as well as small size, low cost and ease of integration.[14-19] Xu[16] reported on a four-way power divider interconnecting power dividers with several output ports, but it was large. Xu et al.[18] used composite right/left-handed transmission lines to construct parallel three-way and four-way power dividers;[18] however, since no isolation elements were used, isolation and match at the output ports were poor. They mentioned that reasonable isolation, good output match and compact size are difficult to realize in multi-way planar power dividers.

Filters are needed in RF systems to reject unwanted signals. Power dividers and filters are often connected together to achieve low insertion loss, miniaturization and low cost. At present, power dividers with filtering are normally constructed in two types: Type I power dividers with harmonic suppression[20,21] and Type II power dividers with bandpass filter responses.[22-29] Power dividers with single and dual bandpass responses have been developed;[30,31] however, planar multi-way power dividers with bandpass response or stopband rejection, good output isolation and good output impedance matching are very few.

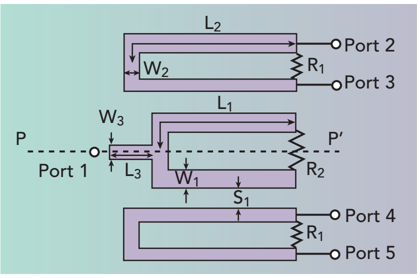


**Fig. 1** **Planar four-way power divider with stopband rejection.**

In this article, we describe a compact, planar, four-way power divider with stopband rejection, good isolation and impedance matching at its output ports. The power divider is constructed using coupled lines. Its frequency response is similar to a coupled line filter. Coupled lines are utilized instead of the quarter-wavelength line in a conventional Wilkinson power divider to reduce the size. Measured results show that this planar four-way power divider with stopband rejection has several advantages: excellent input impedance matching, low insertion loss, a good balance of amplitude and phase at the output ports, good filter response and good isolation within the passband.

## DESIGN

The coupled line four-way power divider (see ***Figure 1***) can be described as equivalent to a combination of a coupled line filter and a Wilkinson power divider. Stopband rejection is realized with the same λ/4 microstrip lines of the Wilkinson power divider.


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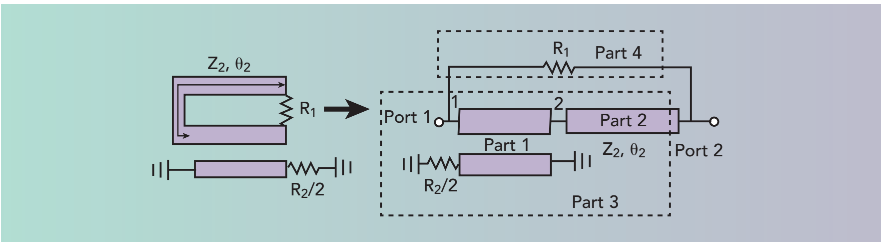



▲ Fig. 2 Odd mode equivalent circuit.

The length ($L_1$) of the coupled line is about $\lambda_g/4$, where $\lambda_g$ is the guided wavelength of the microstrip line at the center frequency. Output ports 2 and 3 are located at the two ends of the upper folded microstrip line, while output ports 4 and 5 are located at the two ends of the lower folded microstrip line.

The operating bandwidth is determined by the coupling gap, $S_1$, between the transmission lines, which can be obtained by simulation. Isolation resistors ($R_1$ in Figure 1) are located between ports 2 and 3 and ports 4 and 5. Another isolation resistor, $R_2$, is located between the two central coupled lines. Since the power divider is symmetric, the even/odd mode method can be used for analysis.

## EQUIVALENT CIRCUIT ANALYSIS

Under odd mode excitation, the symmetrical plane PP' shown in Figure 1 is an electrical wall (see ***Figure 2***). Part 1 in Figure 2 is a coupled line, which can be viewed as a four-port network. One of the four ports is a short circuit and another connects to the resistance $R_2$. According to microwave network theory, part 1 can also be viewed as a two-port network. The two ports are designated 1 and 2, respectively. The impedance matrix elements of the two-port network are obtained as follows:

$$[Z_1]=\begin{bmatrix} Z'_{11}, & Z'_{12} \\ Z'_{21}, & Z'_{22} \end{bmatrix} \quad (1)$$

where

$$Z'_{11}=\frac{Z_{11}Z_{12}-Z_{13}Z_{14}}{Z_{12}}+\left(Z_{14}-\frac{Z_{11}Z_{13}}{Z_{12}}\right)\cdot\left(\frac{Z_{12}Z_{13}-Z_{11}Z_{14}-R_2Z_{14}}{Z_{11}^2-Z_{12}^2+R_2Z_{11}}\right)$$

$$Z'_{12}=\frac{Z_{12}^2-Z_{13}^2}{Z_{12}}+\left(Z_{14}-\frac{Z_{11}Z_{13}}{Z_{12}}\right)\cdot\left(\frac{Z_{12}Z_{14}-Z_{11}Z_{13}-R_2Z_{13}}{Z_{11}^2-Z_{12}^2+R_2Z_{11}}\right)$$

$$Z'_{21}=\frac{Z_{12}^2-Z_{14}^2}{Z_{12}}+\left(Z_{13}-\frac{Z_{11}Z_{14}}{Z_{12}}\right)\cdot\left(\frac{Z_{12}Z_{13}-Z_{11}Z_{14}-R_2Z_{14}}{Z_{11}^2-Z_{12}^2+R_2Z_{11}}\right)$$

$$Z'_{22}=\frac{Z_{11}Z_{12}-Z_{13}Z_{14}}{Z_{12}}+\left(Z_{13}-\frac{Z_{11}Z_{14}}{Z_{12}}\right)\cdot\left(\frac{Z_{12}Z_{14}-Z_{11}Z_{13}-R_2Z_{13}}{Z_{11}^2-Z_{12}^2+R_2Z_{11}}\right)$$

$Z_{11}$, $Z_{12}$, $Z_{13}$, $Z_{14}$, $Z_{21}$ and $Z_{22}$ are the impedance matrix elements of the four-port network. The transmission matrix $[A_1]$ of part 1 is obtained by the relationship between the impedance matrix and the transmission matrix. In addition, the transmission matrix $[A_2]$ of part 2 is obtained as follows:

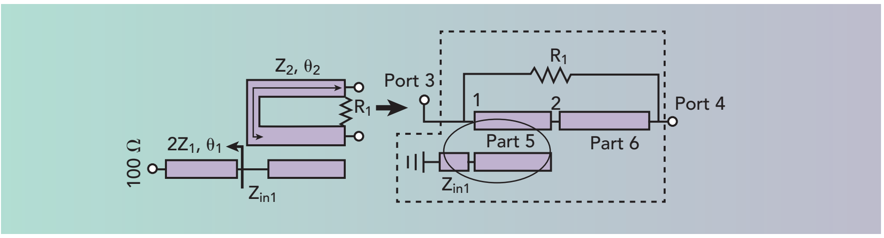
$$[A_2]=\begin{bmatrix} \cos\theta & j\sin\theta \\ j\sin\theta & \cos\theta \end{bmatrix}= \quad (2)$$

where $\theta$ is the electrical length of part 3. The transmission matrix $[A_3]$ of part 3 is obtained by combining Equations 1 and 2.

$$[A_3]=[A_1]*[A_2] \quad (3)$$

Meanwhile, the admittance matrix $[Y_3]$ of part 3 is also obtained by using the relationship between the transmission matrix and the admittance matrix. The admittance matrix $[Y_4]$ is as follows:

$$[Y_4]=\begin{bmatrix} 1/R_1 & -1/R_1 \\ -1/R_1 & 1/R_1 \end{bmatrix} \quad (4)$$




▲ **Fig. 3** Even mode equivalent circuit.

The admittance matrix $[Y_{w1}]$ or transmission matrix $[A_{w1}]$ of the entire network can be obtained by

$$[Y_{w1}] = [Y_3] + [Y_4] \quad (5)$$

When port 1 and port 2 are simultaneously matched, the following condition must be satisfied:

$$Z_0 = \frac{(A_{w1}Z_0 + B_{w1})}{(C_{w1}Z_0 + D_{w1})} \quad (6)$$

where $A_{w1}$, $B_{w1}$, $C_{w1}$ and $D_{w1}$ are the elements of the transmission matrix $[A_{w1}]$.

Under even mode excitation, the symmetrical plane PP' is a magnetic wall, as shown in ***Figure 3***. The analysis method is similar to the odd mode. According to transmission line theory, the input impedance $Z_{in1}$ is determined by

$$Z_{in1} = \frac{2Z_1(100 + j2Z_1 \tan\theta_1)}{(2Z_1 + j100\tan\theta_1)} \quad (7)$$

Based on microwave network theory, the impedance matrix $[Z_2]$ of part 5 is

$$[Z_2] = \begin{bmatrix} Z_{11\_1}', & Z_{12\_1}' \\ Z_{21\_1}', & Z_{22\_2}' \end{bmatrix} \quad (8)$$

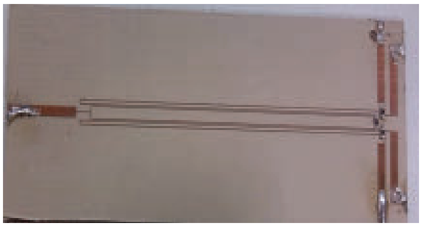
where

$$Z_{11\_1}' = Z_{11} - \frac{Z_{13}^2}{Z_{11} + Z_{in1}}$$

$$Z_{12\_1}' = Z_{21\_1}' = Z_{12} - \frac{Z_{13}Z_{14}}{Z_{11} + Z_{in1}}$$

$$Z_{22\_1}' = Z_{11} - \frac{Z_{14}^2}{Z_{11} + Z_{in1}}$$

The transmission matrix $[A_{w2}]$ of the entire network is determined in a manner similar to that for the odd mode analysis. When ports 3 and 4 are simultaneously matched, the condition that must be satisfied is



▲ **Fig. 4** Fabricated planar four-way power divider.

$$Z_0 = \frac{(A_{w2}Z_0 + B_{w2})}{(C_{w2}Z_0 + D_{w2})} \quad (9)$$

where $A_{w2}$, $B_{w2}$, $C_{w2}$ and $D_{w2}$ are the elements of $[A_{w2}]$. The isolation resistances $R_1$ and $R_2$ can be calculated by combining Equations 1 to 9 after the other parameters are confirmed.

## SIMULATION AND MEASUREMENT

To verify and demonstrate the design method and circuit performance, a four-way planar power divider was built on an RF-35 substrate with relative permittivity of 3.5, thickness of 0.508 mm and loss tangent of 0.0018. The circuit model was constructed in HFSS. After simulation and optimization, the dimensions of the fabricated planar four-way power divider were chosen to be $L_1$ = 43.2 mm, $L_2$ = 45.65 mm, $L_3$ = 2 mm, $W_1$ = 0.1 mm, $W_2$ = 0.1 mm, $W_3$ = 0.1 mm, $S_1$ = 0.1 mm, $R_1$ = 100 Ω and $R_2$ = 100 Ω. A photograph of the fabricated planar four-way power divider is shown in ***Figure 4***. The circuit size is just 0.014 × 0.26 λg.

Measured versus simulated results are shown in ***Figures 5*** and ***6***. The measured input return loss is greater than 15 dB, while the simulated input return loss is greater than 20 dB over the operating frequency range, as shown in ***Figure 5a***. The center frequency is about 1.05 GHz, and the 10 dB input return

loss bandwidth is about 28 percent. Insertion loss is about 0.4 dB within the passband, and the 1 dB insertion loss bandwidth is about 45 percent. A maximum amplitude imbalance of ±0.15 dB is observed over the operating passband. Lower stopband rejection is greater than 15 dB from 0 to 0.45 GHz, while upper stopband rejection is greater than 15 dB from 1.75 to above 2.75 GHz.

Measured return loss for the four output ports is greater than than 13.5 dB at the center frequency, as shown in ***Figure 5b***. Since ports 2 and 3 are symmetric with ports 4 and 5, the curves of $S_{22}$ and $S_{33}$ are similar to the curves of $S_{55}$ and $S_{44}$, respectively. Because port 2 is not symmetric with port 3, the curve of $S_{22}$ is not similar to the curve of $S_{33}$. Likewise, the curve of $S_{44}$ does not match the curve of $S_{55}$.

The measured insertion phase of port 2 is similar with that of ports 3, 4 and 5 (see ***Figure 6a***) with a maximum phase imbalance of ±2 degrees from 0.5 to 1.4 GHz. Amplitude and phase imbalance is likely due to fabrication and assembly tolerances. ***Figure 6b*** shows the isolation between output ports, which is greater than 15 dB over the passband.

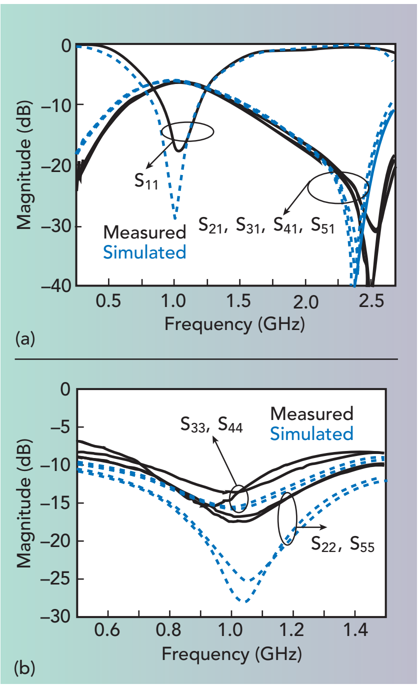



**Fig. 5** Simulated vs. measured insertion loss and $|S_{11}|$ (a) and $|S_{22}|$, $|S_{33}|$, $|S_{44}|$ and $|S_{55}|$ (b).

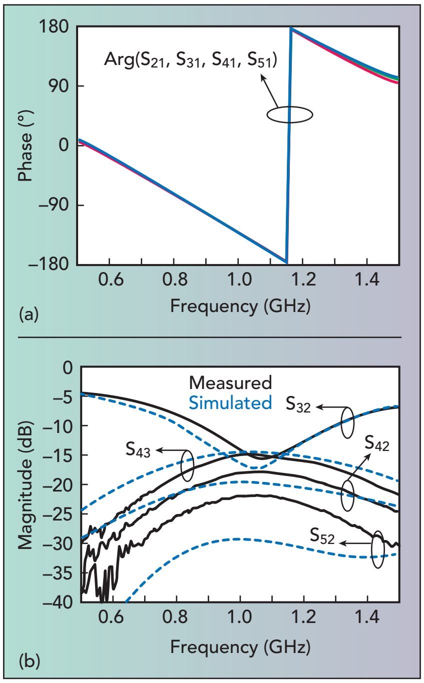



**Fig. 6** Insertion phase (a) and simulated vs. measured $|S_{32}|$, $|S_{42}|$, $|S_{43}|$ and $|S_{52}|$ (b).

## CONCLUSION

A compact planar four-way wideband power divider with stopband rejection uses coupled line technology not only provides a four-way power dividing function but also a bandpass response. Even and odd mode equivalent circuits are presented and design equations are derived. Measurement is in good agreement with simulation, verifying the theoretical analysis. This structure has excellent input and output impedance matching, low insertion loss, good balance of amplitude and phase at the four output ports, a filter response and good isolation within the passband.■

## ACKNOWLEDGMENT

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## References


1. S. W. Wong and L. Zhu, "Ultra-Wideband Power Divider With Good In-Band Splitting and Isolation Performances," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 8, August 2008, pp. 518–520.
2. M. E. Bialkowski and A. M. Abbosh, "Design of a Compact UWB Out-of-Phase Power Divider," *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 4, April 2007, pp. 289–291.
3. K. Song, Y. Mo, Q. Xue and Y. Fan, "Wideband Four-Way Out-of-Phase Slotline Power Dividers," *IEEE Transactions on Industrial Electronics*, Vol. 61, No. 7, July 2014, pp. 3598–3606.
4. K. Song and Y. Fan, "Broadband Travelling-Wave Power Divider Based on Substrate Integrated Rectangular Waveguide," *Electronics Letters*, Vol. 45, No. 12, June 2009, pp. 4631–632.
5. Y. Wu, Y. Liu, Y. Zhang, J. Gao and H. Zhou, "A Dual Band Unequal Wilkinson Power Divider Without Reactive Components," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 1, January 2009, pp. 216–222.
6. K. K. M. Cheng and C. Law, "A Novel Approach to the Design and Implementation of Dual-Band Power Divider," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 56, No. 2, February 2008, pp. 487–492.
7. A. S. S. Mohra, "Compact Dual Band Wilkinson Power Divider," *IEEE Microwave Optical Tech. Lett.*, Vol. 50, No. 6, June 2008, pp. 1678–1682.
8. P. K. Singh, S. Basu and Y. H. Wang, "Coupled Line Power Divider With Compact Size and Bandpass Response," *Electronics Letters*, Vol. 45, No. 17, August 2009, pp. 892–893.
9. X. Ren, K. Song, B. Hu and Q. Chen, "Compact Filtering Power Divider With Good Frequency Selectivity," *IEEE Microwave and Optical Technology Letters*, Vol. 56, No. 9, September 2014, pp. 2122–2125.
10. J. C. Kao, Z. M. Tsai, K. Y. Lin and H. Wang, "A Modified Wilkinson Power Divider With Isolation Bandwidth Improvement," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 9, September 2012, pp. 2768–2780.
11. L. Chiu and Q. Xue, "A Parallel-Strip Ring Power Divider With High Isolation and Arbitrary Power-Dividing Ratio," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 11, November 2007, pp. 2419–2426.
12. K. H. Yi and B. Kang, "Modified Wilkinson Power Divider for nth Harmonic Suppression," *IEEE Microwave and Wireless Components Letters*, Vol. 13, No. 5, May 2003, pp. 178–180.

13. D. J. Woo and T. K. Lee, "Suppression of Harmonics in Wilkinson Power Divider Using Dual-Band Rejection by Asymmetric DGS," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 6, June 2005, pp. 2139–2144.
14. Y. Wu, Y. Liu, Q. Xue, S. Li and C. Yu, "Analytical Design Method of Multiway Dual-Band Planar Power Dividers With Arbitrary Power Division," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, No. 12, December 2010, pp. 2832–2841.
15. K. Song, Y. Fan and Y. Zhang, "Eight-Way Substrate Integrated Waveguide Power Divider With Low Insertion Loss," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 56, No. 6, June 2008, pp. 1473–1477.
16. Y. Xu and R. G. Bosisio, "Design of Multiway Power Divider by Using Stepped-Impedance Transformers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 9, September 2012, pp. 2781–2790.





17. K. Song and Q. Xue, "Ultra-Wideband Ring-Cavity Multiple-Way Parallel Power Divider," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 10, October 2013, pp. 4737-4744.
18. H. X. Xu, G. M. Wang, C. X. Zhang, Z. W. Yu and X. Chen, "Composite Right/Left-Handed Transmission Line Based on Complementary Single-Split Ring Resonator Pair and Compact Power Dividers Application Using Fractal Geometry," *IET Microwaves, Antennas & Propagation*, Vol. 6, No. 9, June 2012, pp. 1017–1025.
19. K. Song, F. Zhang, S.Y. Hu and Y. Fan, "Ku-Band 200-W Pulsed Power Amplifier Based on Waveguide Spatially Power-Combining Technique for Industrial Applications," *IEEE Transactions on Industrial Electronics*, Vol. 61, No. 8, August 2014, pp. 4274–4280.
20. M. G. Choi, H. M. Lee, Y. H. Cho, X. G. Wang and S. W. Yun, "Design of Wilkinson Power Divider With Embedded Low-Pass Filter and Cross-Stub for Improved Stop-Band Characteristics," *IEEE MTT-S International Microwave Symposium Digest*, June 2011, pp. 1–4.
21. K. K. M. Cheng and W. C. Ip, "A Novel Power Divider Design With Enhanced Spurious Suppression and Simple Structure," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, No. 12, December 2010, pp. 3903–3908.
22. K. Song and Q. Xue, "Novel Ultra-Wideband (UWB) Multilayer Slotline Power Divider with Bandpass Response," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 1, January 2010, pp. 13–15.
23. K. Song and Q. Xue, "Ultra-Wideband Out-of-Phase Power Divider Using Multilayer Microstrip-Slotline Coupling Structure," *IEEE Microwave and Optical Technology Letters*, Vol. 52, No. 7, July 2010, pp. 1591–1594.
24. T. H. Duong and I. S. Kim, "Single Section Wilkinson Type UWB Power Divider With Bandpass Filter and DC Block Characteristics in LTCC Technology," *IEEE MTT-S International Microwave Symposium Digest*, May 2010, pp. 117–120.
25. C. Zhuge, K. Song and Y. Fan, "UWB Power Divider Based on Signal Interference Techniques," *IEEE Microwave and Optical Technology Letters*, Vol. 54, No. 4, April 2012, pp. 1028–1030.
26. K. Song, S. Hu, Y. Mo, Y. Fan and C. Zhong, "Novel Bandpass-Response Power Divider With High Frequency Selectivity Using Centrally Stub-Loaded Resonators," *Microwave and Optical Technology Letters*, Vol. 55, No. 7, July 2013, pp. 1560–1562.

27. P. Cheong, K. I. Lai and K. W. Tam, "Compact Wilkinson Power Divider With Simultaneous Bandpass Response and Harmonic Suppression," *IEEE MTT-S International Microwave Symposium Digest*, May 2010, pp.1588–1591.
28. K. Song, Y. Mo, C. Zhuge and Y. Fan, "Ultra-Wideband (UWB) Power Divider With Filtering Response Using Shorted-End Coupled Lines and Open/Short-Circuit Slotlines," *AEU-International Journal of Electronics and Communications*, Vol. 67, No. 6, June 2013, pp. 536–539.
29. K. Song, X. Ren, F. Chen and Y. Fan, "Compact In-Phase Power Divider Integrated Filtering Response Using Spiral Resonator," *IET Microwaves, Antennas & Propagation*, Vol. 8, No. 4, March 2014, pp. 228–234.
30. Z. Zhang, Y. C. Jiao and Z. B. Weng, "Design of 2.4 GHz Power Divider With Harmonic Suppression," *Electronics Letters*, Vol. 48, No. 12, June 2012, pp. 705–707.
31. Y. C. Li, Q. Xue and X. Y. Zhang, "Single- and Dual-Band Power Dividers Integrated with Bandpass Filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 61, No. 1, January 2013, pp. 69–76.



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# Enhanced 3D, EM and Electro-Thermal Simulation for Wireless Design

Keysight Technologies
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Modern wireless communications systems are based on an ever-expanding array of standards and boast new and sophisticated functionality. This serves to complicate an already challenging design and test process. Keysight Technologies' Advanced Design System (ADS) software has been used by RF and microwave designers to solve the most demanding problems. Its latest release, ADS 2017, introduces pioneering solutions, a host of new 3D capabilities and enhanced performance in circuit, electromagnetic (EM) and electro-thermal simulation to help designers meet the stringent requirements of modern wireless communications design.

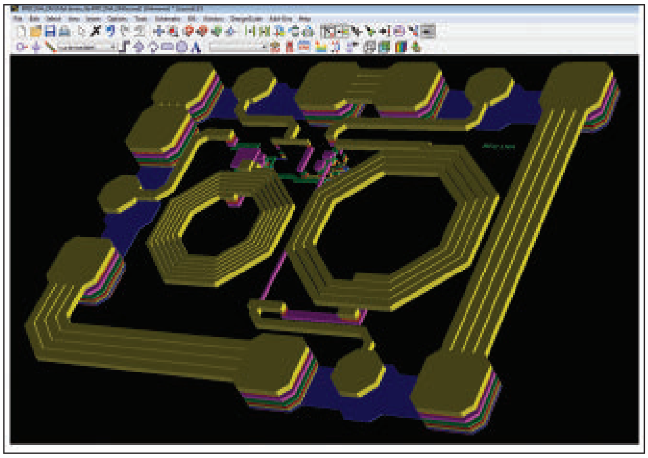


Fig. 1 Editable 3D layout of an LNA.

**Optimized 3D Design**—The increased complexity of today's wireless designs demands improved solutions for viewing and editing. With the new 3D capabilities in ADS2017, it is now possible to visualize and edit a printed circuit board (PCB) or MMIC/RFIC layout in three dimensions (see ***Figure 1***). This provides a powerful tool for verifying that designs meet requirements and helping to find mistakes. ADS 2017's new 3D capabilities also simplify stitching with vias in a multi-layered design, routing in dense areas and making complex structure selections while preparing for EM simulation.

**Enhanced 3D Electro-Thermal Simulation**—To avoid costly circuit revisions with

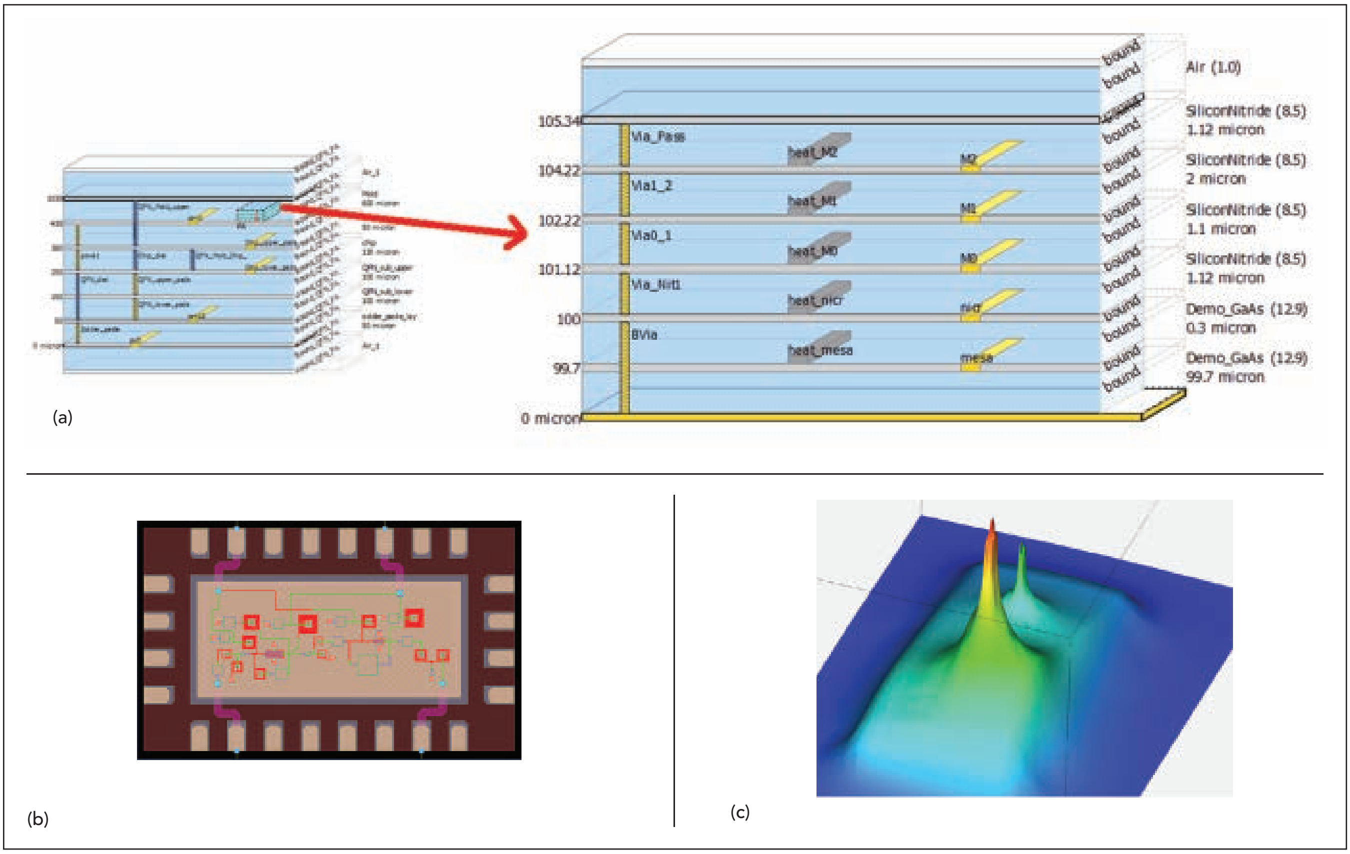



Fig. 2 Multi-technology electro-thermal simulation for a flip-chipped and packaged PA, showing the package cross-section (a), PA die (b) and 3D thermal profile (c).

power amplifier (PA) modules requiring high density layouts or employing advanced processes (e.g., GaN and GaAs), designers must assess the thermal performance of the circuit prior to tape out. The ADS electro-thermal simulator provides designers with a full 3D thermal solver tightly integrated with the ADS layout environment and circuit simulators. It computes the full system or chip temperature profile and annotates this information in the circuit simulator for temperature-accurate circuit analysis. ADS 2017 takes these capabilities one step further by allowing multiple technologies to be thermally simulated together.

As an example, consider a PA design flip-chipped and encapsulated in a QFN package. The design includes the die, laminate, copper bumps and packaging, which creates a highly variable thermal resistance profile that is difficult to analyze. ***Figure 2*** shows the multi-technology substrate setup inside ADS 2017 and the thermal analysis of the entire 3D chip, with excellent resolution and accuracy. With this information, designers can make necessary edits and tape out with a high degree of confidence.

**Simplified 3D Data Visualization**—ADS 2017 offers designers a simple way to process ADS simulation results using Python. The capability unleashes new functionality to analyze, manipulate and visualize ADS results and is available to expert Python users, as well as those with no previous experience. For non-programmers, Keysight provides workspaces containing Python scripts. One example application with downloadable code is the creation of 3D Smith charts, a graphical aid that helps visualize large amounts of information using a single plot. For instance, a 3D Smith Chart can plot how impedance changes versus frequency, voltage or other variables, so designers can make informed decisions on tradeoffs among these parameters (see ***Figure 3***).

**Powerful 3D EM Simulation**—The 3D finite element method (FEM) engine in ADS is a full-wave EM simulator that is used to analyze 3D EM effects in the frequency do-

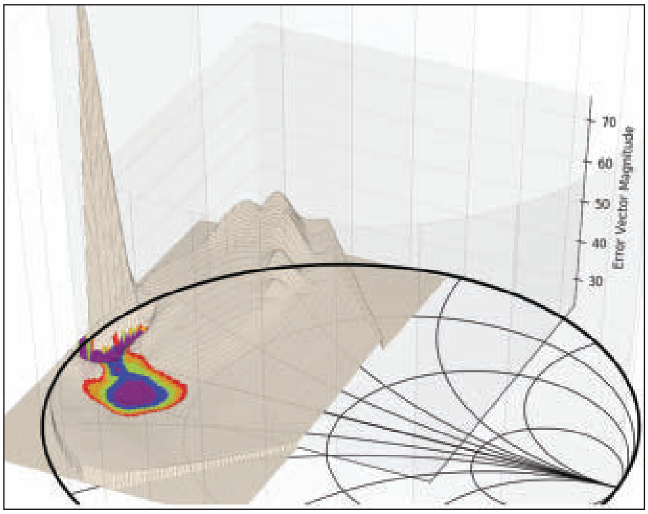
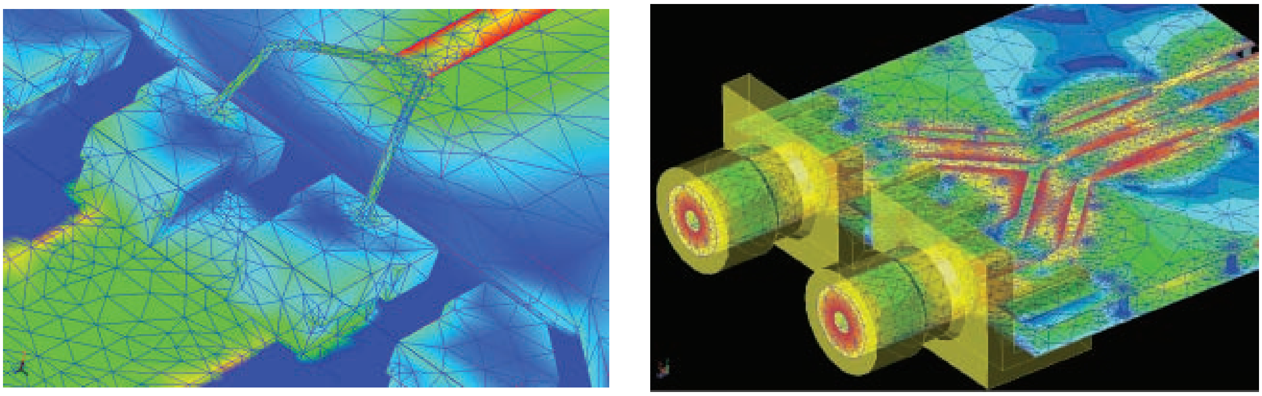



Fig. 3 3D Smith chart showing EVM surface versus the load impedance for a PA.



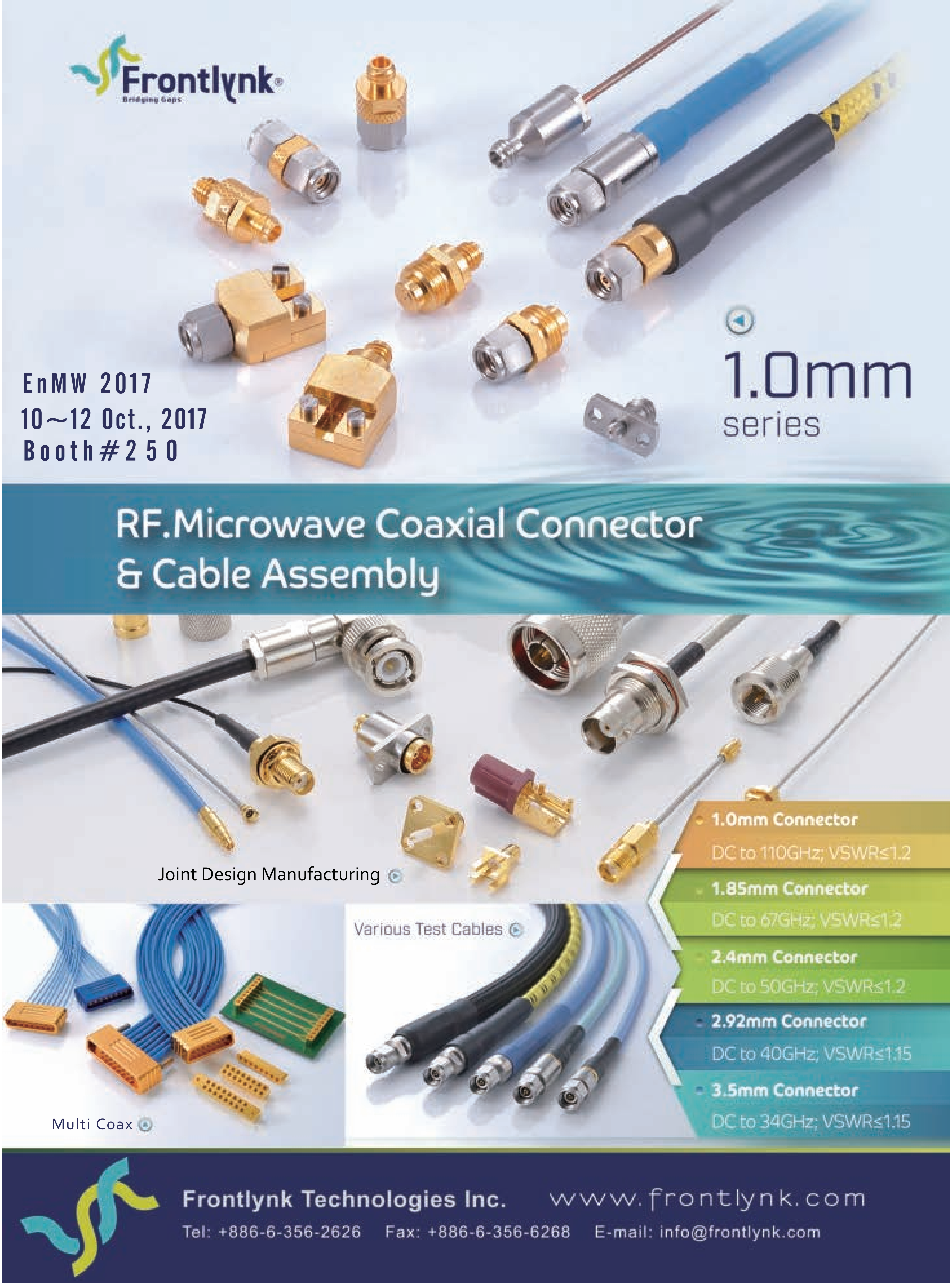
(a) (b)

▲ **Fig. 4** FEM-generated EM waves for a chip package and bond wires (a) and PCB with board interconnects (b).

main. It is especially useful simulating the EM effects of components, such as high speed and RFIC packages, bond wires, antennas, on- and off-chip embedded passives and PCB interconnects. The FEM engine is fully integrated inside both ADS and Keysight's 3D modeling and simulation environment, EMPro. Exporting and importing designs to and from the engine is automated to save time and minimize errors, compared to manually exporting and importing.

With the release of ADS 2017 and EMPro 2017, the FEM engine is more powerful (see ***Figure 4***). A smarter mesh creator, adaptive meshing algorithm, use of mixed-order functions and parallel frequency point solving allow the FEM in ADS 2017 to run an average of 1.5 to 2x faster than its predecessor. Also, disk space usage is reduced by approximately 50 percent. This makes the FEM engine more accessible to RF and microwave designers.

**3D Via Designer**—Via models that are accurate at high frequencies is a crucial problem when simulating



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DC to 110GHz; VSWR≤1.2
1.85mm Connector
DC to 67GHz; VSWR≤1.2
2.4mm Connector
DC to 50GHz; VSWR≤1.2
2.92mm Connector
DC to 40GHz; VSWR≤1.15
3.5mm Connector
DC to 34GHz; VSWR≤1.15
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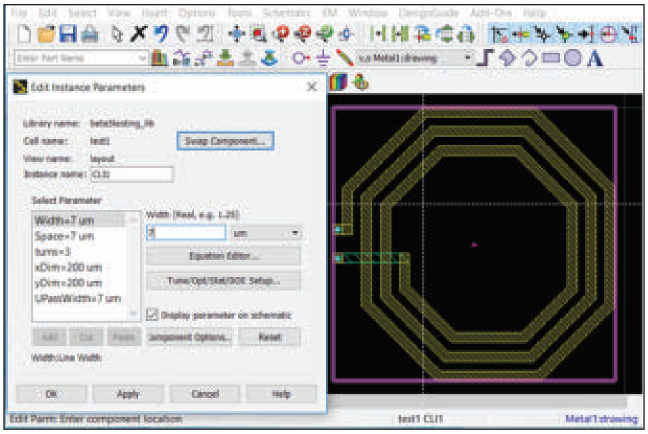


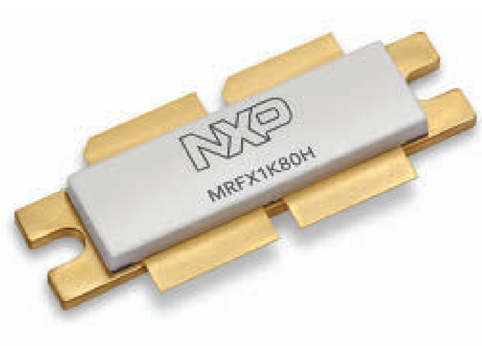
Fig. 5 CoilSys automates PCell construction so RFIC designers can create DRC-clean PCells.

high speed signal interconnects. To solve this, ADS 2017 introduces Via Designer, a tool for creating and modeling single-ended or differential PCB vias, giving the designer full control over the via's parameters. Via Designer uses FEM to fully characterize the EM effects of the model, ensuring high frequency accuracy. It supports parametrized sweeps, enabling fine tuning of the circuit during full-channel simulation. With this new tool, the uncertainty associated with via design is eliminated.

**Automated PCell Construction**—Abundant and capable simulation options and integration with Keysight's GoldenGate software, the "gold standard" in RFIC simulation, make ADS an excellent platform for starting and completing silicon RFIC designs. ADS 2017 further complements this functionality with the addition of CoilSys, an add-on utility that automates PCell construction for spiral inductors (single-ended or differential), transformers, baluns, solenoids and transmission lines (see ***Figure 5***). The resulting PCells are design rule checking (DRC) clean and ready to utilize in an RFIC design. CoilSys eliminates the manual creation of layout cells, often a laborious task and not an efficient use of the RFIC designer's time. The layouts created with CoilSys are EM simulated and can be parametrized for component synthesis, as well as design optimization.

**Stronger and More Comprehensive Simulation**—In the wireless communications system design environment, where the slightest edge can mean the difference between design success or failure, the powerful and comprehensive new features in ADS 2017 may be just the tool today's designers need to get ahead.

**Keysight Technologies Inc.**
**Santa Rosa, Calif.**
**www.keysight.com**




# 65 V LDMOS Enables 1800 W Transistor

NXP Semiconductors
*Chandler, Ariz.*

Industrial, scientific and medical applications are migrating from using vacuum tubes to solid-state, requiring RF systems to reach increasingly higher power levels. This move multiplies the number of RF power transistors per system, resulting in combining losses, increased size of power amplifiers and more complex power supply management. As a result, there is an ever-increasing need for higher output power per RF transistor.

Silicon laterally diffused metal oxide semiconductor (LDMOS) is the dominant technology for high-power RF designs. Ten years ago, the industry moved to 50 V drain voltage to achieve 1 kW of output power per transistor. Over time, the 50 V LDMOS technologies improved in ruggedness and power density, last year delivering 1500 W from a single device. That level of CW output power constitutes the upper limit of what can be achieved at 50 V without compromising usability.

This makes a higher voltage technology desirable. Here's why: There are four ways to boost the output power of an RF transistor. Two involve simply adding more LDMOS periphery on the chip, either by increasing the die size or by increasing the density (i.e., total gate width) of the active silicon on the die. However, both solutions augment the parasitic output capacitance ($C_{ds}$) of the transistor, making it difficult to match to 50 Ω. The third way is to optimize existing 50 V LDMOS technology further, to increase the power density of LDMOS (i.e., W/mm). This method does not address the fundamental RF transistor design trade-offs. As described in Motorola's 1991 application note, AN1526, the output resistance is a function of the drain voltage and the output power, shown by the formula

$$R_L = \frac{V^2}{2P}$$

Increasing the output power, P, lowers the output resistance $R_L$. This makes the transistor difficult to match to 50 Ω. The fourth way to increase the output power is to raise the drain voltage, V, with two-fold benefits: Increasing the voltage increases the power density and enables higher output power without having to expand the LDMOS periphery; this keeps the output capacitance $C_{ds}$ at a desirable level. More importantly, per the above formula, raising the drain voltage, V, helps maintain the existing output resistance $R_L$ when P increases.

As an example, an 1800 W, 50 V push-pull transistor has an output impedance of

$$R_L = \frac{50^2}{2 \times 900} \times 2\ \text{sides} = 2.8\,\Omega$$

at low frequencies, requiring a transformation ratio of 18:1 to match it to 50 Ω. An 1800 W, 65 V push-pull transistor has a "friendlier" output impedance of 4.7 Ω and requires a lower 10:1 transformation ratio, making it possible to use the device at higher frequencies and in wideband applications. The example illustrates that raising the drain voltage allows higher power levels without compromising ease of use, by keeping both output $R_L$ and $C_{ds}$ at reasonable levels.

Developing a higher drain voltage device requires a multi-year silicon technology research and development effort, to find the right balance between the on-state resis-

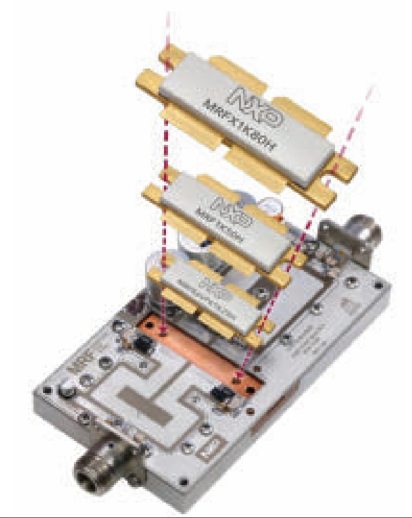
**TABLE 1**
**MRFX1K80H TYPICAL PERFORMANCE**

| Frequency (MHz) | Voltage (V) | Output Power (W) | Gain (dB) | Drain Efficiency (%) |
|---|---|---|---|---|
| 27 | 60 | 1800 CW | 27.8 | 75.6 |
| 64 | 65 | 1800 Pulse | 27.1 | 69.5 |
| 81.36 | 63 | 1700 CW | 24.5 | 76.3 |
| 87.5 to 108 | 60 | 1600 CW | 23.6 | 82.5 |
| 123/128 | 65 | 1800 Pulse | 25.9 | 67.0 |
| 144 | 65 | 1800 CW | 23.5 | 78.0 |
| 230 | 65 | 1800 Pulse | 25.1 | 75.1 |
| 325 | 63 | 1700 Pulse | 22.8 | 64.9 |

tance, ruggedness and reliability. Earlier this year, NXP qualified a new 65 V LDMOS technology, enabling a new generation of RF power transistors: the MRFX series. The technology is designed for 1.8 to 400 MHz industrial, scientific and medical applications, such as laser or plasma generation, particle accelerators, industrial heating, MRI and diathermy, as well as FM and VHF TV broadcast transmitters and HF/VHF aerospace and defense applications.

The first device of the MRFX series was released in August 2017. The MRFX1K80H delivers 1800 W of CW output power and can be used with drain voltages from 30 to 65 V. It has a low thermal resistance of 0.09°C/W and withstands a reflected energy of 65:1 VSWR in all phase angles with no degradation. The typical RF performance at various frequencies is shown in ***Table 1***.

This new transistor demonstrates that raising the drain voltage from 50 to 65 V brings five benefits to RF power amplifier designers. The 65 V drain bias increases the power to 1800 W while retaining a reasonable output impedance. This latter advantage enables a third benefit: the MRFX1K80H was designed to be pin-compatible with existing 50 V LDMOS solutions on the market. As this 1800 W, 65 V transistor has an output impedance close to that of a 1250 W, 50 V transistor, the same PCB can be used (see ***Figure 1***). Little to no retuning is needed, depending on the frequency and the bandwidth, which reduces the development cycle time for faster time-to-market. The fourth benefit is that a higher voltage decreases the current in the system, limiting magnetic radiation and lowering the stress on power supplies and components. Lastly, the new 65 V LDMOS technology exhibits a typical breakdown voltage of 193 V. This higher safety margin improves ruggedness and reliability and enables higher efficiency classes of operation.



**▲ Fig. 1 The MRFX1K80H is pin-compatible with existing 50 V LDMOS devices, enabling higher power using the same PCB with little or no retuning.**

NXP warrants production availability of the MRFX1K80H for 15 years. The data sheet, simulation models and other tools may be downloaded from NXP's website. Reference circuits at various frequencies are available through NXP's approved distributors.

**NXP Semiconductors**
**Chandler, Ariz.**
**www.nxp.com/RF**

# Handheld Spectrum Analyzer Covers 56 to 67 GHz

SAF Tehnika
*Riga, Latvia*

Rising demand for bandwidth is driving the growth in deployment of point-to-point radios in the 60 GHz band (V-Band). V-Band is unlicensed in the U.S. and serves as a complement to the unlicensed 5.8 GHz band. The unique characteristics of the signal allow for dense deployments using small cell or picocell technology. However, deployment in V-Band presents some challenges. Because signals in that frequency are susceptible to both atmospheric and rain attenuation, link distances are limited to 500 to 700 m (1600 to 2200 ft). With only a 5 mm wavelength, meeting link budgets requires unobstructed line of sight, careful link planning and proper antenna alignment. Until now, there have been no convenient tools to perform these tasks; reference solutions available on the market are large, complex and quite expensive.

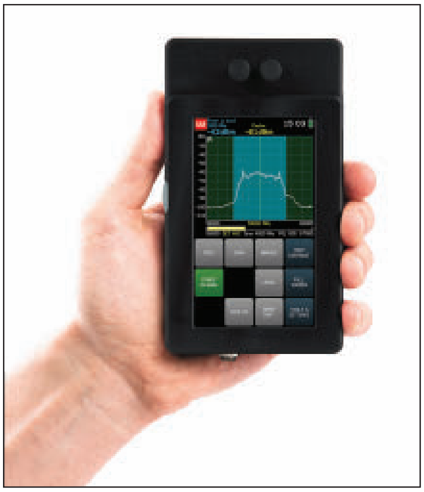
In addition to data backhaul, the Wi-Fi Alliance has begun certifying devices for 60 GHz Wi-Fi, or WiGig. While the Alliance established a well-tried interoperability test bed for device certification, a portable solution for physical layer testing in deployed environments, one able to provide real-time information, has, so far, been unavailable.

Options have been limited to bringing large lab standards into the environment or using a portable spectrum analyzer that does not have a screen, then analyzing all the data in a post-measurement environment. SAF Tehnika has addressed these issues with the introduction of the J0SSAP60 Spectrum Compact spectrum analyzer. With a frequency range of 56 to 67 GHz, this is the latest addition to the Spectrum Compact family that already covers 2 to 40 GHz and 70 to 87 GHz.

## CHARACTERISTICS

As the first handheld spectrum analyzer on the market covering 56 to 67 GHz, the J0SSAP60 enables microwave engineers to observe what is going on in real-time. It does not use an external down-converter, working directly at V-Band frequencies. The analyzer has a fixed 10 MHz resolution bandwidth (RBW) and a guaranteed noise floor of -90 dBm. It comes with a wide-beam sniffer antenna that can be attached to the WR15 waveguide flange located on the back panel of the analyzer.

With a scan speed of 0.5 s at a 1 GHz span and the level of system gain, this spectrum analyzer is suitable for interference detection, free channel investigation, tower



▲ **Fig. 1** **The J0SSAP60 Spectrum Compact is a true handheld spectrum analyzer.**

inspections from the ground and environmental mapping for indoor environments. The instrument can be used by mobile operators and private network owners in the planning stage to avoid interference that would adversely affect the performance of a link. For regulatory authorities, it is an asset for gaining insight into traffic levels and potential interference challenges in the band. The receiver's high sensitivity allows users to perform tower inspections from the ground. For Wi-Fi engineers deploying WiGig, the Spectrum Compact can fully map the space, using the unit's 4 GB of memory to save an almost unlimited number of spectrum traces for later analysis and reporting.

Once a V-Band system is deployed, a report of the signal density and propagation can be generated using the included Spectrum Manager software. In established environments, interference or signal loss caused by rogue RF or unwanted absorption can be investigated and remedied. Like the entire Spectrum Compact range, the J0SSAP60 is designed to be used comfortably for extended periods of time in a variety of challenging environments.

Battery powered, the instrument is useful for microwave radio engineers performing equipment installation, link troubleshooting or gathering data for planning. A key feature of the spectrum analyzer is its form factor: its dimensions are similar to those of a cell phone, as can be seen in ***Figure 1***.

▲ **Fig. 2** **The standard kit includes the spectrum analyzer and a small wide angle horn antenna.**

## FIELD OPERATION

Instead of features that would only be useful in a laboratory environment, the Spectrum Compact has the qualities and functionality needed by microwave field engineers to efficiently perform their daily tasks: radio parameter verification, antenna alignment, interference and multipath detection, in-band power measurements, link troubleshooting and saving the spectrum traces for reports and later analysis. The analyzer utilizes a resistive touch screen, allowing operation while wearing gloves. The unit's high sensitivity and low noise floor enable field engineers to detect exceptionally weak signals, making it possible to do multiple measurements from the ground and carry out link troubleshooting without site traffic interruptions.

A standard kit includes the spectrum analyzer and a small wide angle horn antenna, as shown in ***Figure 2***. The V-Band antenna can be attached to a WR15 waveguide flange at the back of the analyzer, enabling detection and visualization of the incoming signal just by pointing at the transmitting radio. The J0SSAP60 is housed in a rugged dust and splash resistant IP54 rated enclosure. A weatherproof, dedicated DC charging socket enables fast charging; a fully charged unit has up to three hours of battery life.

**SAF Tehnika**
**Riga, Latvia**
**www.saftehnika.com**

# Broadband, 75 Ω Transformer for DOCSIS 3.1

Designed for DOCSIS 3.1, MiniRF's next generation broadband transformer covers 45 to 1218 MHz without sacrificing performance. The MRFXF0035 is a 75 Ω, 1:1 transformer with 0.6 dB typical insertion loss and 25 dB input return loss. Amplitude and phase balance between the two outputs are typically 0.2 dB and 3 degrees, respectively. The transmission line design transforms an unbalanced input to a balanced output, and the low insertion loss, high return loss and good balance provide the maximum drive for push-pull amplifiers, while minimizing imbalance and channel distortion.

The MRFXF0035 design is RoHS compliant, constructed using a ceramic substrate and weld bonds to yield a rugged, reliable product; MiniRF's mature manufacturing process ensures repeatability. The small, surface-mount package fits the industry standard, four-pad, 0.15 in x 0.15 in footprint, which makes it drop-in compatible with transformers from multiple manufacturers. With a low coefficient of thermal expansion (CTE) package, the MRFXF0035 is guaranteed to operate from −40°C to + 100°C.

Samples may be ordered from RFMW Ltd. or through MiniRF's sales representatives, and production quantities are available in tape-and-reel format.

MiniRF is a new name for a passive component company with more than 20 years design and manufacturing experience. The company was formed by Premier Devices Inc. (PDI) in the early 1990s, acquired by Sirenza Microdevices in 2006, which was subsequently acquired by RFMD. MiniRF has returned to its roots: developing and manufacturing only passive components.

VENDORVIEW

**MiniRF**
**Fremont, Calif.**
**www.minirf.com**

# 10 MHz Ultra-Stable, Low Noise DOCXO

Expanding its family of Xstal-Clear™ oven controlled crystal oscillators (OCXO), Morion has introduced the MV336M double oven controlled crystal oscillator (DOCXO). The MV336M's combined temperature stability, Allan deviation (ADEV) and phase noise performance makes it ideal for atomic clocks, precision frequency measurement and time-based synchronization maintenance.

The MV336M achieves an ADEV of 1.5 x $10^{-13}$ (1 s), phase noise below −120 dBc/Hz at 1 Hz and temperature stability of 4 x $10^{-11}$ over the −10°C to +70°C range. As frequency stability versus temperature may influence ADEV for longer than 3 s intervals, the MV336M's stability facilitates precise and reliable measurements of ADEV from 10 to 100 s. The MV336M improves the phase noise at 0.1 Hz, now specified at −92 dBc/Hz.

The crystal blank's special surface treatment enables higher yield for superior phase noise and ADEV. The design also reflects studies of crystal surface state and optimum power dissipation and their influence on close-in phase noise. A precise DOCXO requires minimizing the influence of temperature on the oscillator. Frequency stability is determined by the temperature dependence of each element, i.e., the ovens, capacitors, inductances and transistors. Thermal modeling of the oscillator design enables circuit and design solutions to be optimized, significantly improving frequency stability.

The MV336M has analog frequency control; digital frequency tuning with the step size of 1~3 x $10^{-14}$ will soon be available. The DOCXO is housed in a 92 mm x 80 mm x 50 mm package and biased with 12 V. A smaller DOCXO (51 mm x 51 mm x 25 mm) with the same performance is being developed.

Morion, based in Saint Petersburg, has been developing quartz devices, from blanks to precision OCXOs, since 1930. Morion-US is an independent California corporation serving the American market.

**Morion-US**
**San Jose, Calif.**
**www.morion-us.com**

# CatalogUpdate

## 256 Element Reconfigurable Phased Array Innovator Kit

VENDORVIEW

Anokiwave is expanding its 5G Active Antenna family with the introduction of the AWA-0134-IK, a 256 element reconfigurable active antenna array. The AWA-0134 can act as a single beam 256 element array or as a four beam 64 element array that enables 4 x 4 MIMO. With over 60 dBmi of EIRP in the single beam mode and full flexibility for the user in the choice of waveform stimulus and timing-control, the array is another enabling product for the evaluation and development of 5G networks.

**Anokiwave Inc.**
**www.anokiwave.com**

## Precision RF & Microwave Components Catalog

VENDORVIEW


Anritsu Co. is a global leader in the design and production of precision RF and microwave test and measurement equipment for laboratories and field applications. Anritsu's RF and microwave components offer high return loss connectors and cables, instrumentation grade adapters, precision terminations, measurement components and accessories. View the catalog on their website for detailed information about these precision components.

**Anritsu Co.**
**www.anritsu.com**

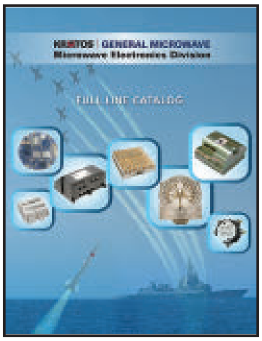
## New 2nd Half 2017 Catalog

VENDORVIEW


AR's latest catalog for 2017 features the new low cost Universal series amplifiers with the widest bandwidth in the industry, covering the 10 kHz to 1000 MHz frequency range and up to 25 W CW. Applications for these amplifiers include lab use, R&D, EMC testing, antenna testing and watt meter calibration. Additional catalog highlights include new RF Solid State CW Amplifiers, Pulsed Amplifiers, TWTAs, details on HIRF systems components and reference to a new product demo video on the 6 to 18 GHz amplifier series.

**AR/RF Microwave Instrumentation**
**www.arworld.us/html/catalogRequest.asp**

## Full Line Catalog




Since 1960, General Microwave Corp. has been an industry leader in design and production of state-of-the art PIN Diode RF/microwave control components. Today, its product line has expanded to RF/microwave signal sources, including fast (1 usec) indirect synthesizers with FM capability and high-power X- and Ku-Band solid state amplifiers. All of these, and more, can be designed into custom integrated microwave assemblies for demanding military or commercial applications. See General Microwave's Full Line Catalog.

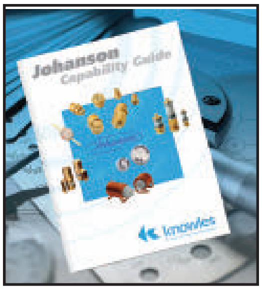
**Kratos | General Microwave**
**www.kratosmed.com**

## Product Catalog


K&L designs and manufactures a full line of RF and microwave filters, duplexers and subassemblies, including ceramic, lumped element, cavity, waveguide and tunable filters. K&L supplies many of today's most significant military and homeland security electronics programs. Applications include space flight, radar, communications, guidance systems and mobile radio base stations, as well as air traffic communication and control. Visit their website to download the complete catalog or sections of interest.

**K&L Microwave**
**www.klmicrowave.com**

## Capability Guide




The shortform guide covers the variable capacitors available from Johanson MFG for RF and microwave applications, including Giga-Trim capacitors, miniature capacitors designed for high resolution tuning of RF power circuits. Giga-Trim caps have a working voltage of 500 VDC, operate at a temperature range of -65°C to +125°C and offer an insulation resistance greater than 106 MΩ. The guide also outlines Air Capacitors incorporating a one piece, self-locking, constant torque mechanism and Ceramic Trimmer Capacitors available in surface mount, strip-line and through hole lead styles.

**Knowles Capacitors**
**www.knowlescapacitors.com**

## Kuhne Electronic Goes Digital


Catalogs are no longer necessary—you can download a PDF data sheet from all products on the website in a comfortable and easy way. This gives you the most important information 24/7: technical specifications, features, applications and much more. Even whole product categories like Power Amplifiers or Signal Generators can be easily generated with a single click. Not enough? For many of the company's products, you can also download the manual with detailed information like connections, commands, software, etc.

**Kuhne Electronic**
**www.kuhne-electronic.de**

## Updated PIN Diode Control Product Literature

L3 Narda-MITEQ has updated its PIN Diode Control Product literature. It is a 23-page application note and short-form catalog covering their PIN Diode switches, attenuators, limiters and IMAs. A 1.8 MB PDF version is available for download on their website. Simply click the literature download button on the left side of the homepage and navigate to PIN Diode Applications and click download PDF.

**L3 Narda-MITEQ**
**www.nardamiteq.com**

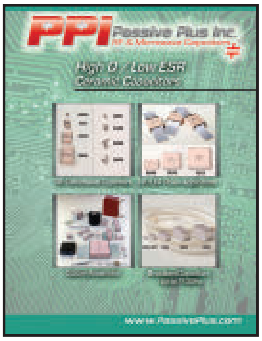
## Coolest New Products

VENDORVIEW


This new 20 page product guide provides a complete survey of Mini-Circuits' latest product releases from the first quarter of 2017. Highlights include everything from cavity filters, ultra-wideband MMIC LNAs and multi-channel programmable attenuators to solid state switches, high-power stripline couplers, 40 GHz coaxial products and more. The company is continuously innovating new products to meet your needs, and this informative product line update will help you stay up to date with their latest, coolest new model releases.

**Mini-Circuits**
**www.minicircuits.com**

## New Catalog Release




PPI has released its new 2017/2018 Product Catalog. The new catalog showcases several new additions to PPI's expanding HI-Q Capacitor library, including new performance charts, new capacitor sizes and an expanded Broadband Capacitor line. The new catalog is available for download on PPI's website. Specializing in magnetic and non-magnetic HI-Q capacitors product lines, PPI supplies reliable quality components to the military, medical, semiconductor, broadcast and telecommunications industries.

**Passive Plus Inc.**
**www.passiveplus.com**

## Precision Microwave Components Catalog


RLC Electronics is a leader in the design and manufacture of RF and microwave components. In this catalog, you will find standard RLC products, including coaxial switches and filters up to 65 GHz, as well as power dividers, couplers, attenuators and detectors up to and beyond 40 GHz. As you will see, many of these components are available in surface mount or connectorized packages. RLC can also provide customized designs to meet specific customer requirements not shown in the catalog.

**RLC Electronics**
**www.rlcelectronics.com**

## Test & Measurement Catalog 2017

VENDORVIEW


Almost 300 pages full of information about the Rohde & Schwarz test and measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and the ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order from Customer Support (order number: PD 5213.7590.42 V 07.01).

**Rohde & Schwarz GmbH & Co.**
**www.rohde-schwarz.com**

# CatalogUpdate

## Contactless Data (Real-Time) & Power Transmission

VENDORVIEW


The new edition of the Contactless Data & Power Transmission brochure from SPINNER covers all available "contactless slip ring" techniques for use in industrial and military applications. These entirely maintenance-free contactless data transmission modules are available for various Ethernet BUS protocols up to 1 Gbit/s (real-time data transfer rate: 100 Mbit/s). The data transfer cannot be monitored (Wi-Fi is not used). Rotating DC/DC converters are available for stand-alone use or combining with data transmission. Hybrid slip rings and customized solutions for data or power transmission for use in radar systems are available.

**SPINNER**

**www.spinner-group.com**

## RMS Digital In-Line Power Meters

Werlatone's® RMS Digital In-Line Power Meters allow accurate, instantaneous and simultaneous local and/or remote monitoring and alarm capability. With a 40 dB dynamic range, the Power Meters provide measurement and alarm capability of forward and reverse power, load VSWR and two external temperature sensors. Includes six general purpose inputs/relays and is powered by AC power adapter or POE. Remote interface through TCP-IP (with SNMP and browser interface via LAN), RS232 and RS485 form addressable serial network. User ID and password protection provides secure, off-site monitoring. Multiple units can be networked and simultaneously monitored.

**Werlatone Inc.**
**www.werlatone.com**

## GaAs and GaN Wafer Foundry Services

WIN Semiconductors is the leading global provider of pure-play GaAs and GaN wafer foundry services for the wireless, infrastructure and networking markets. WIN provides its customers with a diverse portfolio of Hetero-junction Bipolar Transistor, Pseudomorphic High Electron Mobility Transistor, GaN HEMT, PIN Diode and Optical Device solutions that support leading edge products for applications from 50 MHz to 150 GHz and through light-wave. Custom products built by WIN are found in multiple markets, including smartphone, optical components, defense and automotive.

**WIN Semiconductors Corp.**
**www.winfoundry.com**

# NEW PRODUCTS

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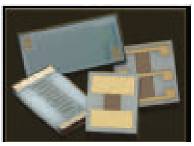
## COMPONENTS

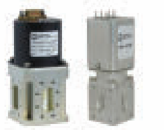
### Wire-Bondable and Edge-Terminated Resistors



For years customers have asked Compex to bring their short lead times, outstanding customer service and quality focus to the thin film resistor industry. As is the Compex way, they listened. Compex now offers a full line of wire-bondable and edge-terminated resistors built to customer's exact specifications. Available alternatives include single, dual, center-tap, array and custom configurations in Alumina, AlN, BeO, Silicon and Quartz. The company is happy to provide samples to ensure you have the right parts for your needs.

**Compex**
**www.compexcorp.com**

### Waveguide Switches



Dow-Key® Microwave, a manufacturing leader with over 40 years of spaceflight heritage, now supplies Next Generation Waveguide products with an emphasis on more compact, lightweight and cost effective designs. With superior RF performance and power handling capability, now, nearly all of the company's waveguide switches can be supplied in either "C" or "R" configuration for use in complex switching systems, making Dow-Key® Microwave an ideal partner for space programs.

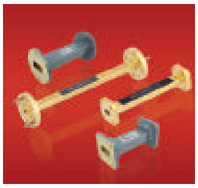
**Dow-Key Microwave**
**www.dowkey.com**

### 60 to 90 GHz Block Down-Converter

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

**Ducommun**
**www.ducommun.com**

### Waveguide Straights

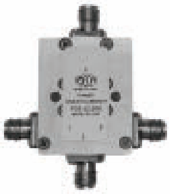


Fairview Microwave, a supplier of on-demand microwave and RF components, has launched a new line of straight waveguide sections that operate in the frequency range of 5.85 to 110 GHz and in 13 waveguide bands from C- to W-Band. Typical applications include test benches, instrumentation, MILCOM, SATCOM, telecom, radar and high-efficiency RF/microwave transmission networks. Fairview's new line of straight waveguide sections consists of 61 models that are available in sizes ranging from WR-10 to WR-137.

**Fairview Microwave Inc.**
**www.fairviewmicrowave.com**

### 6 to 18 GHz Multi-Octave 3-Way Power Divider

VENDORVIEW



MECA's newest 3-way Wilkinson power divider has been optimized for excellent performance covering 6 to 18 GHz (P3S-12.000) with specifications such as isolation of 20 dB min/25 dB typical, VSWR 1.4:1 max, 0.7 dB max insertion loss and amplitude balance of 0.4 dB max, all in a compact package of 1 in × 1.5 in × 0.4 in. Made in the U.S. with 36 month warranty.

**MECA Electronics Inc.**
**www.e-MECA.com**

### Lowpass RF Filters

Microwave Filter Company Inc. provides medium power lowpass RF filters from 50 to 500 MHz. These high quality filters are designed for use in any medium power application (100 W or less) that requires harmonic band rejection of up to 6x the fundamental (cut-off) frequency (Fc). The filters provide less than 0.5 dB passband insertion loss with more than 16 dB passband return loss. Housed in compact aluminum housings (2.75 in × 1.25 in × 1.04 in) with N-female connectors.

**Microwave Filter Company Inc.**
**www.microwavefilter.com**

### 20 dB DC Pass High-Power Bi-Directional Coupler

VENDORVIEW

Mini-Circuits' ZGBDC20-33H+ broadband high-power bi-directional coupler offers excellent performance across a wide range

of popular frequency bands. Built using low loss suspended substrate construction, the ZGBDC20-33H+ can pass up to 3 A of DC current from input to output and handle up to 50 W CW. Rugged sealed construction makes this coupler ideal for use in field applications or remote monitoring sites; however, it is also ideal for high-power lab testing.

### Coaxial Power Splitter/Combiner

Mini-Circuits' ZC10PD-26W+ is a 10-way 0° splitter/combiner providing 10 W RF power

handling as a splitter across the 2250 to 2800 MHz range, covering a variety of applications including cellular, ISM and more. It provides a high port-count with low insertion loss, high isolation and low amplitude unbalance, making this model ideal for systems requiring distribution of signal into many channels. The splitter/combiner comes housed in a rugged aluminum alloy case (6.13 in × 3.00 in × 0.53 in) with SMA connectors.

**Mini-Circuits Inc.**
**www.minicircuits.com**

### Transformer

VENDORVIEW

MiniRF's RFXF9504 transformer is designed for applications that require small, low cost

and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. Frequency range: 5 to 3000 MHz, low cost and RoHS compliant, industry standard SMT package, impedance ratio: 1:1, 50 Ω characteristic impedance, for broadband and wireless applications.

**MiniRF**
**www.minirf.com**

## K-, Ka-Band Cavity Filters

NIC introduces Cavity Bandpass filters spanning from K- to Ka-Band. Bandwidths vary from 1 to 50 percent. These filters provide low insertion loss and sharp rejection in a small profile package, making it perfect for use in airborne, ship-mount or vehicle mount applications in harsh military environments. Custom designs are available from 18 to 30 GHz.

**Networks International Corp.**
**www.nickc.com**

## RF Limiter

VENDORVIEW

PMI Model No. LM-10M2D5G-100CW-1KWP-SFF is a RF limiter that operates in the 10 MHz to 2.5 GHz frequency range. This limiter can handle 100 W CW and 1 KW peak

(1 percent duty cycle, 1 μs maximum pulse width) input power and provides a maximum leakage of +13 dBm CW input. This module has a low insertion loss of 0.5 dB and a recovery time of 2 μs typical. Package size is 1.86 in × 0.65 in × 0.38 in with SMA female connectors.

**Planar Monolithics Industries Inc.**
**www.pmi-rf.com**

## High-Power Quad Hybrid for Radio Applications

Response Microwave Inc. is pleased to announce the availability of a new high-power 3 dB 90° hybrid for use in radio applications. Operational from 100 to 450 MHz, the unit offers 0.7 dB insertion loss, 1.3:1 VSWR and 18 dB minimum isolation with N female connectors. Power handling is 100 W CW over the -40°C to +105°C range. Custom configurations are available on request. For more information on this new line or to discuss your application specific requirement, please contact Response Microwave Inc. at (978)-772-3767.

**Response Microwave Inc.**
**www.responsemicrowave.com**

## Multiplexers

RLC Electronics' multiplexers are available in two, three or four channel versions. Adjacent passbands may be designed for a contiguous or non-contiguous response. For passband frequencies below 2 GHz, lumped element designs will often achieve the desired response in the smallest package. At higher frequencies (up to 40 GHz), distributed coaxial structures are employed to realize the lowest possible loss. RLC Electronics can supply multiplexers for most applications, including commercial, telecommunications and military specifications.

**RLC Electronics**
**www.rlcelectronics.com**

## Compact Faraday Isolator Line for V- through D-Band

VENDORVIEW

For subassemblies and instrumentation applications, SAGE Millimeter has released a new line of compact Faraday isolators to cover 50 to 170 GHz. For E-Band, model STF-12-S1-C is a full band Faraday isolator that operates from 60 to 90 GHz. The Faraday isolator is constructed with a longitudinal, magnetized ferrite rod that causes a Faraday rotation of the incoming RF signal. The compact, robust package is ideal for system integration and testing applications.

**SAGE Millimeter**
**www.sagemillimeter.com**

# CABLES & CONNECTORS

## Military Grade Fiber Cables and Connectors

MilesTek, a leading manufacturer and supplier of products designed to address military and avionics applications, announced that they have launched a new line of military grade fiber cables and connectors designed to address high speed fiber connectivity in harsh military and industrial environments. MilesTek's military grade fiber cable series consists of IP67-rated assemblies in both multimode and single-mode variants and LC, SC and ST assemblies built with impact and crush resistant cable in OM1, OM2 and OM3 styles.

**MilesTek**
**www.milestek.com**

## Handheld RF Analyzer Phase-Stable Cable Assemblies

VENDORVIEW

Pasternack has launched a new series of handheld, RF analyzer, rugged, phase-stable cable assemblies. Typical applications include field testing, tower measurements, base station analyzers, handheld network analyzers, portable spectrum analyzers, distance-to-fault measurements and site maintenance. Pasternack's new line of test cables for handheld RF analyzers consists of 19 models designed to deliver optimal amplitude and phase stability with flexure. They boast VSWR as low as 1.2:1 and maximum operating frequency of 27 GHz, depending on the configuration.

**Pasternack**
**www.pasternack.com**

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## Single and Multiport PCB Connectors

SV Microwave's complete line of single and multiport PCB connectors meet the industry need for high performing, easy-to-use threaded and blindmate/push-on compact designs. SV offers edge launch, board mount and through hole variations in 2.92 mm, 2.4 mm, SMA, SMP, SMPM and SMPS series. Pre-tinned options available.

**SV Microwave**
**www.svmicrowave.com**

# AMPLIFIERS

## Pulsed Amplifier

VENDORVIEW

New 20000SP1G2 pulsed amplifier provides up to 20,000 W, AR's 20000SP1G2 broadband solid state microwave pulsed amplifier provides 20,000 W of output power from 1 to 2 GHz and recently won 2017 EMC Product of the Year. It is designed for short pulse applications at low duty factors where instantaneous bandwidth and high gain are required. The amplifier can be used for a variety of applications in test and measurement, including EMC RF pulse susceptibility testing, industrial and university research and development and service applications.

**AR RF/Microwave Instrumentation**
**www.arworld.us/html/18200.asp?id=1313**

## Amplifier-Sub-System

Ciao Wireless Inc. has introduced a 1:12 distribution amplifier–sub-system which features integrated internal cooling fans, AC power VAC, on/off switch (with fuse) and normal operation/fault status indicators. Designs are available for alternate frequency ranges between 10 MHz and 27 GHz with additional "N-Way" distribution configurations offered (1:8, 1:16, 1:24, 1:32 and more). Alternate rack style packages are available. Multiple gain, variable gain, internal switching and different output levels are also available.

**Ciao Wireless Inc.**
**www.ciaowireless.com**

## SGA/SGN Series SSPAs

Kratos General Microwave's SGA/SGN Series SSPA's offer GaAs/GaN technology reliability that can be customized to meet specific pulse or CW output powers. The product line supports both X-Band and Ku-Band applications with bandwidths up to 10 percent and offers peak power outputs up to 400 W. Designed for demanding defense, aerospace and satellite communication applications. Kratos SSPA's have excellent power efficiency with demonstrated field proven performance and reliability. Kratos' vertical integration process affords flexible layouts and architectures to meet individual specifications for electrical, mechanical and environmental parameters.

**Kratos General Microwave**
**www.kratosmed.com**

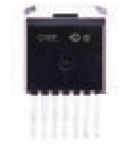
## Gain Control Detector Amplifier Multi-Function Modules

Originally designed for radar and microwave test instrumentation, these Gain Control Detector Amplifier Multi-Function Modules (MFM) provide the gain control, amplification and detection for an integrated automatic level control (ALC) function, all within a single package. The functions of voltage controlled gain, amplification and detection can be specified in any order as may be desired by the system designer in order to minimize noise figure or maximize overall dynamic range. The amplification inserted either ahead of or after the voltage controlled attenuation.

**Microwave Solutions Inc.**
**www.microwavesolutions.com**

# NewProducts

## 1200 V, 75 mΩ SiC MOSFET



Richardson RFPD Inc. announced the availability and full design support capabilities for a new silicon carbide power MOSFET from Wolfspeed, a Cree Company. The 1200 V, 75 mΩ C3M0075120J features Wolfspeed's C3M™ SiC MOSFET technology and is available in a compact, seven-lead TO-263-7 surface mount package. The Kelvin source Pin 2 in the TO-263-7 package supports driving the device at higher frequencies and enables highly efficient designs.

**Richardson RFPD Inc.**
**www.richardsonrfpd.com**

## Bi-Directional Amplifier

The TTRM1076D is a dual bi-directional amplifier designed for high data rate military and commercial radios. It is capable of 12 W 64QAM OFDM output and 32 W peak power for lower data rate FM/BPSK applications. High speed switching of 1 uS makes it compatible with TDD mesh radio systems.

**Triad RF Systems**
**www.triadrf.com**

# SOURCES

## Frequency Synthesizers

Cobham Microelectronic Solutions has developed a new series of frequency synthesizers designed to meet the stringent phase noise, spurious and harmonic specifications demanded by today's airborne applications. Cobham specializes in balancing tradeoffs to optimally achieve challenging requirements. Cobham's new 1018 Synthesizer measures 2.6 in × 2.6 in × 0.6 in, weighs just 0.25 lbs and delivers full frequency coverage from < 450 MHz to > 18 GHz in 10 MHz steps with < 250 µs switching speed.

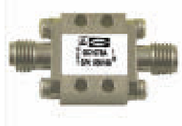
**Cobham Advanced Electronic Solutions**
**www.cobham.com**

## T1265 and T1266 Series TCXOs

Greenray Industries Inc. has announced the availability of the T1265 and T1266 Series TCXOs. The new TCXOs (temperature compensated crystal oscillators) are available from 50 to 125 MHz with squarewave CMOS (T1265) or sinewave (T1266) output. With very low phase noise down to a floor of -165 dBc/Hz, both units deliver OCXO-like performance, but without their input power requirements and warm-up characteristics. In addition, they offer temperature stability down to ±0.5 ppm and external voltage control, with sufficient pull range to cover the total stability of the oscillator over the lifetime of the part.

**Greenray Industries Inc.**
**www.greenrayindustries.com**

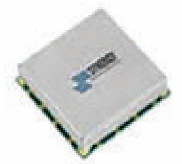
## Comb (Harmonic) Generators



Herotek has designed ultra broadband comb generators with output frequency spectrum (from 1 to 75 GHz) in a single unit. The comb generators are used for frequency multipliers, frequency synthesizers and built-in test source. Ideal frequency multiplication base element for generation of mmWave frequencies. Typical output power per picket -15 dBm up to 20 GHz and to -55 dBm at 60 to 75 GHz. Output frequency starts from the second harmonic of the input frequency and up.

**Herotek**
**www.herotek.com**

## 500 to 1200 MHz Excellent Phase Noise VCO



The DCM050120-5 is an octave band VCO operating from 500 to 1200 MHz over a tuning range of 24 V. This device provides excellent temperature stability with a buffered output in a planar resonator construction. Output power is +7 dBm minimum, tuning sensitivity is 25 to 50 MHz/V typical, harmonic suppression is 15 dB typical and the typical phase noise performance is -102 dBc/Hz at 10 kHz and -121 dBc/Hz at 100 kHz offsets.

**Synergy Microwave Corp.**
**www.synergymwave.com**

## LTE Cat M1 Cellular Module

TOP-electronics USA announces sales support for Quectel's BG96, an LTE Cat. M1/Cat.NB1/EGPRS module with a maximum data rate of 375 kbps downlink/uplink, pin-to-pin compatible with Quectel LTE modules EG91/EG95, Cat.NB1 (NB-IoT) module BC95, UMTS/HSPA modules UG95/UG96 and GSM/GPRS module M95. With a cost-effective SMT form factor of 22.5 mm × 26.5 mm × 2.3 mm, integrators and developers can easily design their applications and take advantage of the module's ultra-low power consumption. Its advanced LGA package allows fully automated manufacturing for high volume applications.

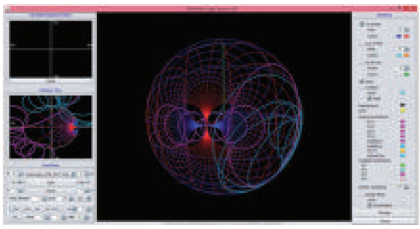
**TOP-electronics**
**www.TOPelectronicsUSA.com**

# MICRO-ADS



# SOFTWARE

## 3D Smith Chart Tool



The 3D Smith chart tool is an advanced analysis and educational design tool including both 2D and 3D Smith charts in both impedance/admittance configurations. Based on state of the articles written by its developers, full 3D visualizations, intuitive highly configurable interface it is ideal for both active and passive microwave circuits analysis, simultaneous optimizations of S-parameters, group delays and quality factors while displaying stability circles analysis and unilateral power gains. It includes a unique educational (matching) module on r, x, g, b circles both in 2D and 3D.

**3D Smith Chart**
**www.3dsmithchart.com**

# PACKAGING

## Monolithic Circular Cutting Tools

Controx introduced monolithic circular cutting tools in solid carbide and high speed steel for the depaneling process of printed circuit boards (PCB) in a four page, full-color brochure. This informative literature details special saw blade designs which are ideal for cutting PCBs produced in "panel" or "multi-block" designs, which group multiple smaller PCBs together for maximum production. Controx designs for straight line depanelling of glassfiber and ceramic based PCBs like FR2, FR4, CEM1, CEM3 as well as aluminum and copper circuit boards.

**Controx**
**www.controx.com**

# TEST & MEASUREMENT

## Dynamic Range Power Sensor

VENDORVIEW

LadyBug's thermally stable LB5908A True-RMS, a 1 MHz to 8 GHz, wide dynamic range power sensor delivers fast accurate measurements on any signal with any modulation, including wideband digital signals. Its unique two path design delivers better dynamic range than many three path sensors. SCPI commands and use either USBTMC, USBHID or connect directly with

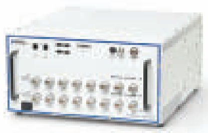
I2C or SPI. Get the accuracy or a thermal sensor with the speed and dynamic range of a diode sensor.
**LadyBug Technologies**
**www.ladybug-tech.com**

## Probe Positioner

withwave Inc.'s probe positioner is designed for precise RF probing measurement using T-probe which have GSG and GS contact structure. The magnetic switch on metal base plate can be turned on and off to keep the positioner firmly to its position or moved and lifted to a new position easily. Its articulated arm is controlled by on arm knob at the middle joint that keep the arm firm and steady.
**withwave Inc.**
**www.with-wave.com**

## Wireless Test System

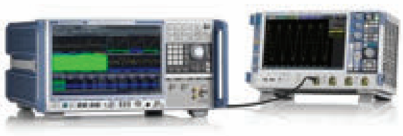
VENDORVIEW



The Wireless Test System (WTS) upsets the status quo in wireless production test. The WTS couples NI's PXI vector signal transceiver (VST) and multicore processing technologies to deliver industry-leading test speeds. With faster measurements, you can reduce the cost of manufacturing test for wireless devices such as mobile phones, tablets, and infotainment systems. The WTS supports wireless standards from LTE-A to 802.11ax to Bluetooth LE. Its advanced switching topologies are ready for multisite and MIMO test.
**National Instruments**
**www.ni.com**

## R&S FSW-B5000 Option

VENDORVIEW



Rohde & Schwarz introduced the new R&S FSW-B5000 option. In combination with the R&S RTO2064 digital oscilloscope as an external digitizer, the R&S FSW85 signal and spectrum analyzer equipped with the new hardware option provides equalized 5 GHz signal analysis bandwidth. The amplitude and phase response of the R&S FSW85 together with the R&S FSW-B5000 are fully characterized at the factory across the entire frequency range. The amplitude and phase measurement accuracy are guaranteed throughout the measurement bandwidth.
**Rohde & Schwarz**
**www.rohde-schwarz.com**

# MICRO-ADS

## Meter-Wave Synthetic Aperture Radar For Concealed Object Detection

Hans Hellsten

A synthetic aperture radar (SAR) with a wavelength around a meter has several important uses: detecting targets hidden by trees, finding underground objects, mapping the ground topography below a forest and penetrating buildings. Writing this book, Hans Hellsten's goal was to present the physics and technology that enable such applications, explaining the challenges and how they are solved, beginning with perhaps the fundamental hurdle: achieving microwave resolution at much lower frequencies.

After an interesting story about the motivation and background that led to the book, Hellsten delves into the technical discussion, first addressing the scattering characteristics of meter-wavelength electromagnetic energy, then devoting a chapter to the imaging principles of SAR and moving to design considerations for a radar using these principles, including additive noise, antenna systems and waveforms. Continuing through the block diagram, the final chapters address SAR signal processing and multidata target detection.

Hellsten is a principal engineer and product manager at defense firm Saab, and he teaches radar at Halmstad University in Sweden. His experience with meter-range radar began while he was with the Swedish Defense Research Agency, contributing to research that led to the development of the first airborne SAR radar that operated between 20 and 90 MHz. He left the government agency to lead the development of an industrial SAR prototype at Ericsson Microwave Systems, now Saab.

Perhaps reflecting his PhD in theoretical physics, Hellsten thoroughly covers the theory and mathematics underlying the topic. The book is equally practical, however, with many images from meter-wavelength SAR systems, allowing the reader to visualize the output and capabilities of such systems.

**To order the book:**

Published by Artech House
www.artechhouse.com
ISBN: 978-1-63081-025-2
363 pages
$179
Available in Print or eBook Format

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**13 – 16 November 2017**
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## KEYNOTE SPEAKERS

**Professor J.-C. Chiao**
University of Texas at Arlington, USA
***Wearable and Implantable Devices for Healthcare IoT***

**Dr. Mazlan Abbas**
CEO – FAVORIOT, Malaysia
***IOT & The Anatomy of a Smart City***

## INVITED SPEAKERS

**Professor Amir Mortazawi**
University of Michigan, USA
***Switchable and Tunable Ferroelectric Devices for Adaptive and Reconfigurable RF Circuits***

**Professor Naoki Shinohara**
Research Institute for Sustainable Humanosphere (RISH),
Kyoto University Uji, Japan.
***Current Research and Development of Wireless Power Transfer via Radio Waves and the Application [DML]***

**Walid Ali-Ahmad**
VP Technology, Qualcomm
San Diego, California.
***RF Front-end and Transceiver Systems Overview for Carrier Aggregation based 4G/5G Radios***

## EUMA SPECIAL INVITED SPEAKERS

**Colombo R. Bolognesi**
Chair, Millimeter-Wave Electronics Group
Eidgenössische Technische Hochschule Zürich
***Millimeter-Wave Transistor Research at ETH-Zurich***

**Joachim Oberhammer**
Nano and Microsystem department
Stockholm, Sweden
***THz MEMS – micromachining enabling new solutions at millimeter and submillimeter-wave frequencies***

**Patrick Reynaertt**
ESAT–MICAS,Microelectronics and Sensors,
Leuven, Belgium
***MM-wave and THz circuit design in standard CMOS technologies: challenges and opportunities***

## CALL FOR PARTICIPATION

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## TUTORIAL

**Tutorial 1: Internet of Microwave Things (IoMT) – Consumer vs. Industrial**
Professor Widad Ismail, Universiti Sains Malaysia, Malaysia
13 November 2017

**Tutorial 2: Calculation and Measurement of MMIC Junction Temperatures**
Professor Andrew Tay, National University of Singapore, Singapore
13 November 2017

**Tutorial 3: Towards Orbital Angular Momentum for Microwave Communication**
Professor Rabindra Kishore Mishra, Berhampur University, India.
13 November 2017

**Tutorial 4: Multiband Filtering for Future 5G – Design and Synthesis Techniques Based on Hybrid Polynomials**
Associate Professor Dr Wong Peng Wen, Universiti Teknologi Petronas, Malaysia.
13 November 2017

**Tutorial 5: RF-SOI for High Performance Front End Modules**
Venkata Vanukuru, GLOBALFOUNDIRES, India
13 November 2017

**Tutorial 6: Material Characterizations at Microwave Frequencies Using Waveguide Techniques**
Dr. You Kok Yeow, Universiti Teknologi Malaysia, Malaysia
13 November 2017

## WORKSHOP

**Workshop 1: Integrated Tunable Systems for 5G Communication**
Associate Professor Gaetan Prigent, Institut National Polytechnique de Toulouse (INPT), Toulouse, France.
13 November 2017

**Workshop 2: Front End Modules for LTE Carrier Aggregation and Beyond**
Florinel Balteanu, Skyworks Solutions Inc., Irvine, CA, United States of America.
13 November 2017

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For submission and enquiries, please contact ***sponsor@apmc2017.org***

Microwaves for the Internet of Things

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|---|---|---|---|
| KBL | Precision measurement, including phase, through 40 GHz | DC-40 | 2.92mm |
| CBL-75+ | Precision 75Ω measurement for CATV and DOCSIS® 3.1 | DC-18 | N, F |
| CBL | All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz | DC-18 | SMA, N |
| APC | Crush resistant armored cable construction for production floors where heavy machinery is used | DC-18 | N |
| ULC | Ultra-flexible construction, highly popular for lab and production test where tight bends are needed | DC-18 | SMA, N |
| FLC | Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more! | DC-26 | SMA, N |
| NEW! SLC | Super-flexible spaghetti cables with 0.047" diameter and 0.25" bend radius, ideal for enviromental test chambers. | DC-18 | SMA |
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* All models except VNAC-2R1-K+

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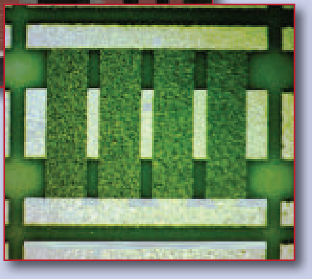
# Weinschel Associates – A Forward Leaning Approach to Legacy



Weinschel Associates (WA), a leading manufacturer of high-power, broadband, microwave components is building on the legacy of founder Bruno Weinschel. One sign of this is adding capacity, reflected in WA's expansion into a brand new facility in Mount Airy, Md. Conveniently located off I70, the new facility has more than 10,000 square feet of customized manufacturing space, allowing WA to consolidate, vertically integrate and maintain control of core technologies, while developing new technologies and processes.

WA traces its core technologies back to its founder. Dr. Weinschel started fabricating coaxial attenuators in the mid-1940s while working at Industrial Instruments in New Jersey. He began to develop what would eventually become Weinschel Engineering while employed at the National Bureau of Standards, now the National Institute of Standards and Technology (NIST). Following stints as president of the IEEE and chairman of the Committee on U.S. Competitiveness, Weinschel established WA in 1989.

The mission of the company allowed Weinschel to pursue high quality design and manufacturing through an expanded line of passive microwave devices and precision instrumentation. Key to the success of Weinschel's pioneering efforts in RF/microwave components was his ability to surround himself with talented engineers and scientists and a drive to be the best in the industry. He was a hands-on leader who, along with his staff, developed the essential techniques and processes that remain the core technologies of WA.

Weinschel led the company into his 80s, until failing health forced him to step down in 2002, when the company's leadership was handed from one engineer to another and Frank Wodoslawsky assumed the roles of CEO and president. Leveraging more than 25 years experience in the military and industry, Wodoslawsky reorganized and revitalized the business, establishing skilled engineering and manufacturing teams comprised of longtime Weinschel employees and new recruits from industry. Their focus is maintaining Weinschel's approach to innovation: combining modern manufacturing processes and techniques with the technologies at the bedrock of the company.

These efforts have dramatically increased the manufacturing throughput while maintaining high standards of product quality. Standard product lines (attenuators, terminations and power splitters/dividers) have expanded, with new product lines (DC blocks, adapters, digital attenuators) added. In 2009, WA became a qualified supplier of space level products, taking its longstanding high-reliability manufacturing capability to a new level.

This continued organic growth drove the move to a larger, more flexible facility. Among the strengthened capabilities: expansion of resistor fabrication to include a four target, computer-controlled sputtering system, supplementing the vapor-phase deposition techniques pioneered by Weinschel. The in-house CNC machining and Swiss turning capabilities have also been expanded to enable quick-turn prototyping and internally-controlled manufacturing. WA capabilities include laser engraving for customized, high quality product marking.

These capabilities and the expanded capacity will enable WA to further grow its presence in the passive microwave and mmWave component market. Yet, despite the growth, the company still reflects the vision of Dr. Bruno Weinschel: hands-on, process-driven leadership focused on designing and producing state-of-the art components, now for a technology obsessed society ever more dependent on wireless systems.

**www.weinschelassociates.com**

# WERLATONE®

# We Are High Power

## Test & Measurement Directional Couplers

**Up to 1000:1 Bandwidth • Low Insertion Loss • Covering DC-6.5 GHz!**

### Directional Couplers

| Model | Type | Frequency (MHz) | Power (W CW) | Coupling (dB) | Insertion Loss (dB) | VSWR (ML) | Flatness (± dB) | Size (Inches) |
|---|---|---|---|---|---|---|---|---|
| C6021 | Dual | 0.01-1000 | 500 | 40 | 0.45 | 1.30:1 | 0.5 | 6.7 x 2.27 x 1.69 |
| C5725 | Dual | 0.1-1000 | 500 | 40 | 0.5 | 1.25:1 | 0.5 | 5.2 x 2.67 x 1.69 |
| C9688 | Dual | 1-1000 | 800 | 40 | 0.5 | 1.20:1 | 1.0 | 6 x 2.2 x 2.2 |
| C7734 | Dual | 30-2500 | 100 | 43 | 0.35 | 1.25:1 | 1.5 | 3.5 x 2.6 x 0.7 |
| C8188 | Uni | 30-3000 | 20 | 20 | 2.4 | 1.35:1 | 1.0 | 6 x 1.5 x 1.1 |
| C3910 | Dual | 80-1000 | 200 | 40 | 0.2 | 1.20:1 | 0.3 | 3 x 3 x 1.09 |
| C8373 | Bi | 100-2500 | 200 | 20 | 0.8 | 1.25:1 | 1.75 | 9.58 x 1.48 x 0.88 |
| C7711 | Dual | 100-3000 | 100 | 40 | 0.35 | 1.25:1 | 1.0 | 3 x 2.2 x 0.7 |
| C7058 | Bi | 200-2000 | 200 | 10 | 0.3 | 1.25:1 | 1.0 | 6.4 x 1.6 x 0.72 |
| C8060 | Bi | 200-6000 | 200 | 20 | 1.1 | 1.40:1 | 2.25 | 4.8 x 0.88 x 0.5 |
| C7248 | Bi | 300-3000 | 100 | 6 | 0.35 | 1.25:1 | 1.0 | 6 x 2 x 0.85 |
| C8000 | Bi | 600-6000 | 100 | 30 | 0.4 | 1.25:1 | 1.0 | 1.8 x 1 x 0.56 |
| C8214 | Bi | 700-2500 | 100 | 6 | 0.35 | 1.25:1 | 1.0 | 6 x 2 x 0.85 |
| C10462 | Dual | 700-4200 | 250 | 40 | 0.2 | 1.30:1 | 1.0 | 2 x 2 x 1.06 |
| C10525 | Dual | 700-4200 | 700 | 50 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10537 | Dual | 700-4200 | 700 | 60 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10536 | Dual | 700-4200 | 1000 | 50 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10751 | Dual | 700-4200 | 1000 | 60 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10006 | Dual | 700-4200 | 2000 | 50 | 0.2 | 1.35:1 | 1.0 | 3 x 3 x 1.59 |
| C10117 | Dual | 700-6000 | 250 | 40 | 0.2 | 1.30:1 | 1.0 | 2 x 2 x 1.06 |
| C10364 | Dual | 700-6000 | 500 | 50 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10762 | Dual | 1000-6000 | 300 | 40 | 0.2 | 1.30:1 | 0.5 | 2 x 2 x 1.06 |
| C10958 | Dual | 1000-6000 | 400 | 40 | 0.2 | 1.35:1 | 0.5 | 2 x 2 x 1.06 |
| C10761 | Dual | 1000-6000 | 600 | 40 | 0.2 | 1.35:1 | 0.5 | 2.15 x 2 x 1.36 |
| C8644 | Bi | 1800-6100 | 60 | 20 | 0.4 | 1.25:1 | 1.0 | 1.1 x 0.75 x 0.48 |
| C10743 | Dual | 2000-6000 | 500 | 40 | 0.2 | 1.30:1 | 0.5 | 2.15 x 2 x 1.36 |
| C10746 | Dual | 2000-6500 | 500 | 50 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |
| C10748 | Dual | 2000-6500 | 500 | 60 | 0.2 | 1.35:1 | 1.0 | 2.15 x 2 x 1.36 |

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