Vol. 61 • No. 4

April 2018

Microwave Journal

60 YEARS

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BETTER COMMUNICATION SOLUTIONS

MECA 5G Products & Equipment

MECA Electronics designs and manufactures an extensive line of RF/Microwave Equipment and components with industry leading performance including D.A.S. Equipment, Low PIM Products, supports 5G & Millimeter-Wave, Power Dividers & Combiners, Directional & Hybrid Couplers, Fixed & Variable Attenuators, RF Terminations, Circulators/Isolators, DC Blocks & Bias Tees, Adapters & Jumpers. Models available in industry common connector styles: N, SMA, 2.92mm, TNC, BNC, 7/16, 4.1/9.5 & 4.3/10.0 DIN as well as QMA, Reverse Polarity SMA, TNC and various mounting solutions.

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Up to 120 watts

Circulators/Isolators

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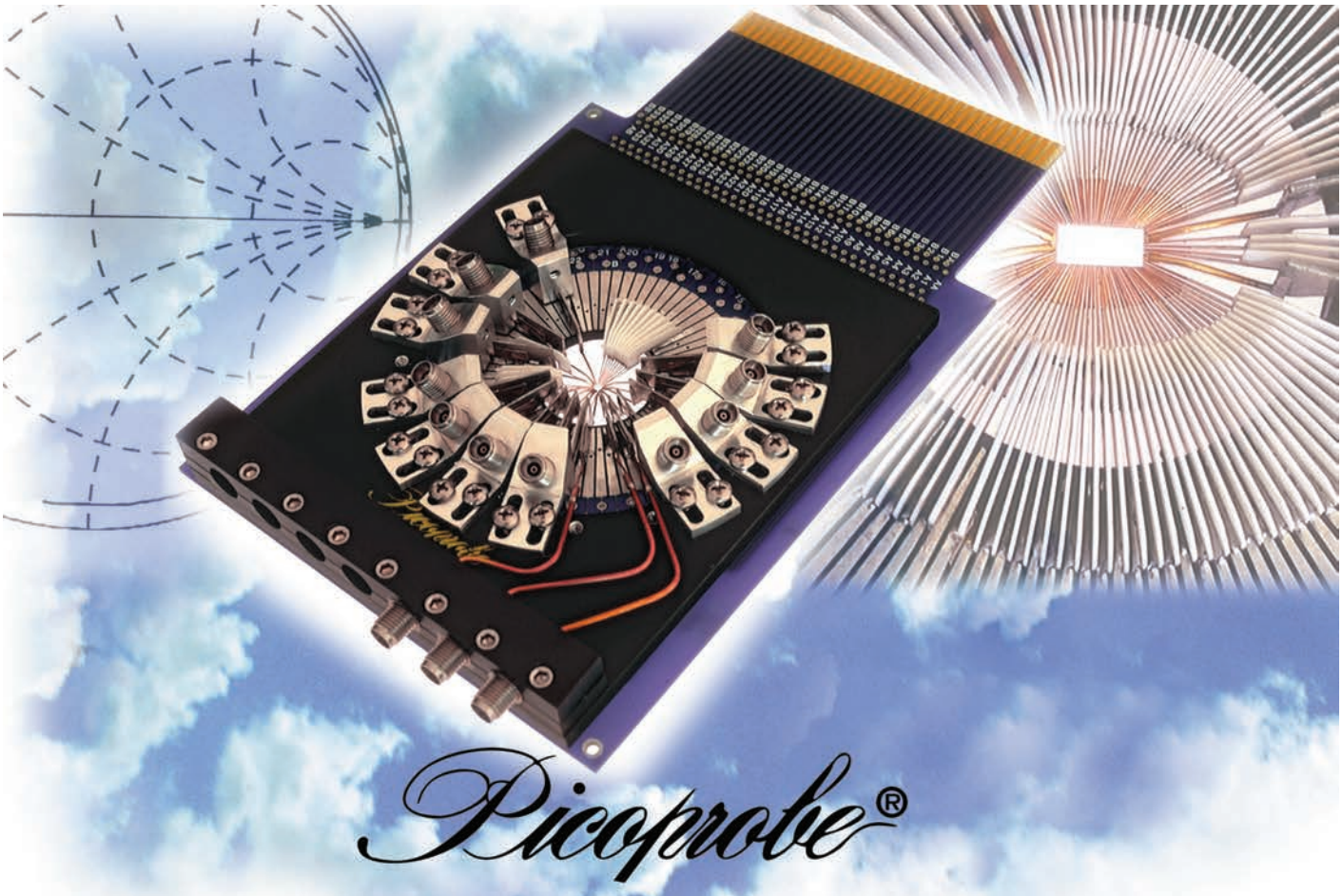

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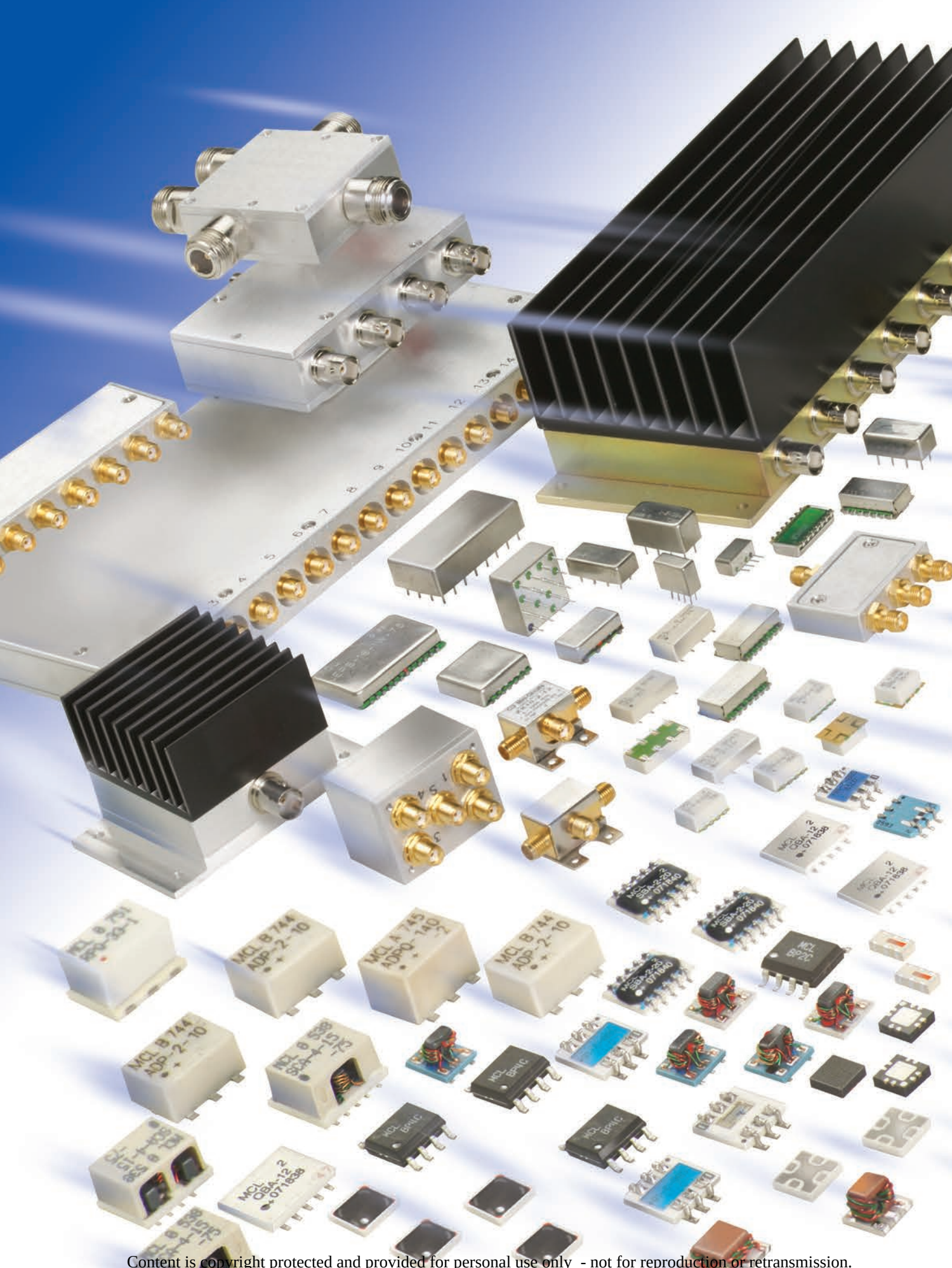
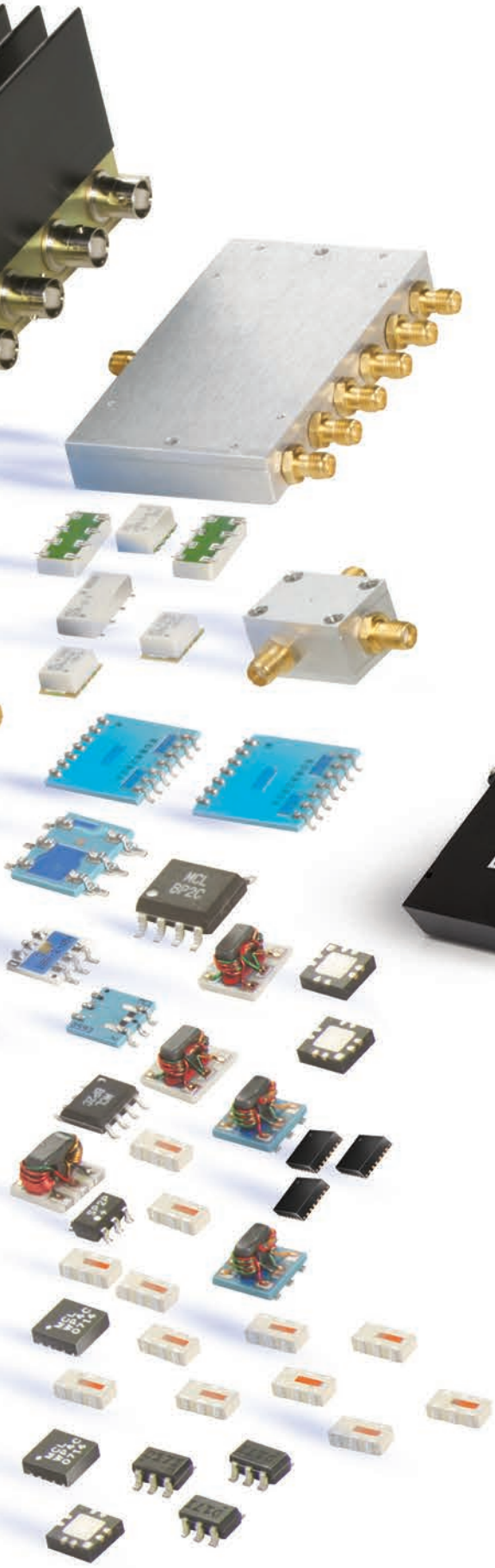
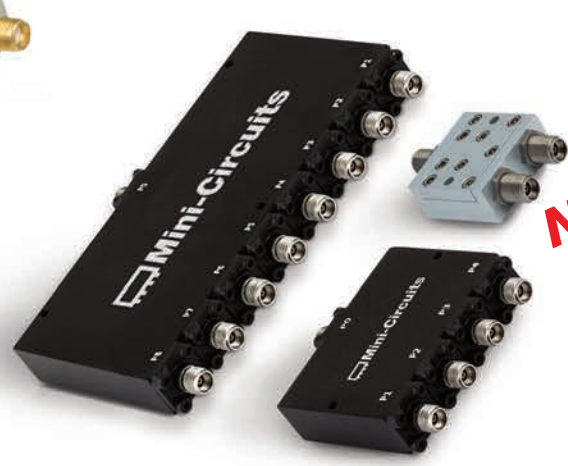




POWER SPLITTERS/ COMBINERS

from **2 kHz to 40 GHz** *as low as* **89¢** *ea. (qty. 1000)*



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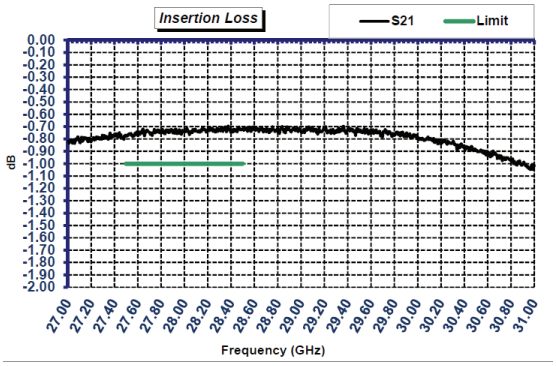

- No Metal Bias Needed
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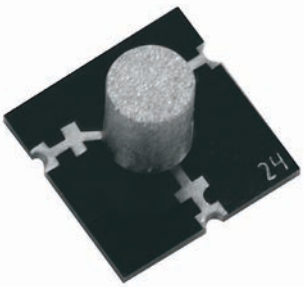
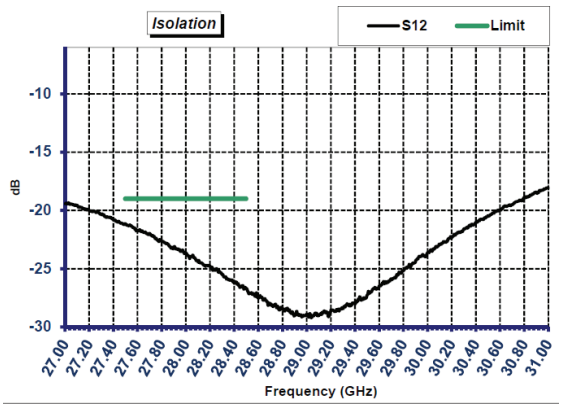


- 200kpcs Sold For Similar Array Application
-Proven Technology



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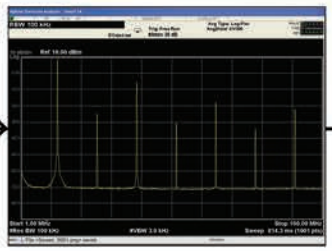
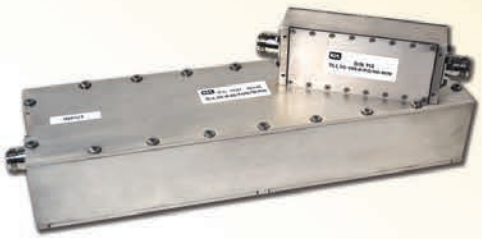


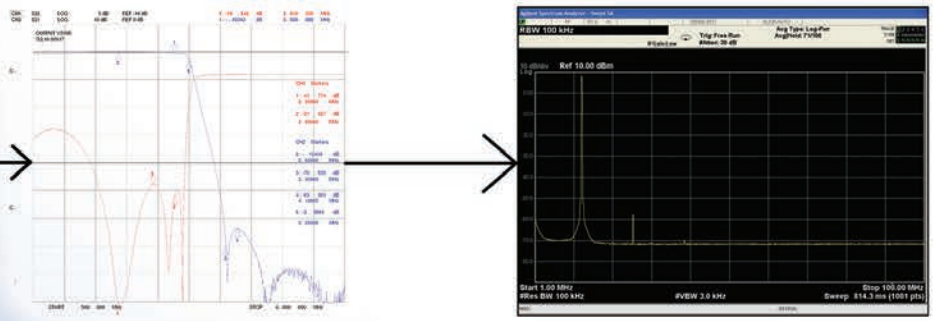
+60 dBm at Fundamental
Multiple Spurious Responses



Which Would Be Better For Your Customer?

+59 dBm at Fundamental
No Spurious Responses

+60 dBm Amplifier



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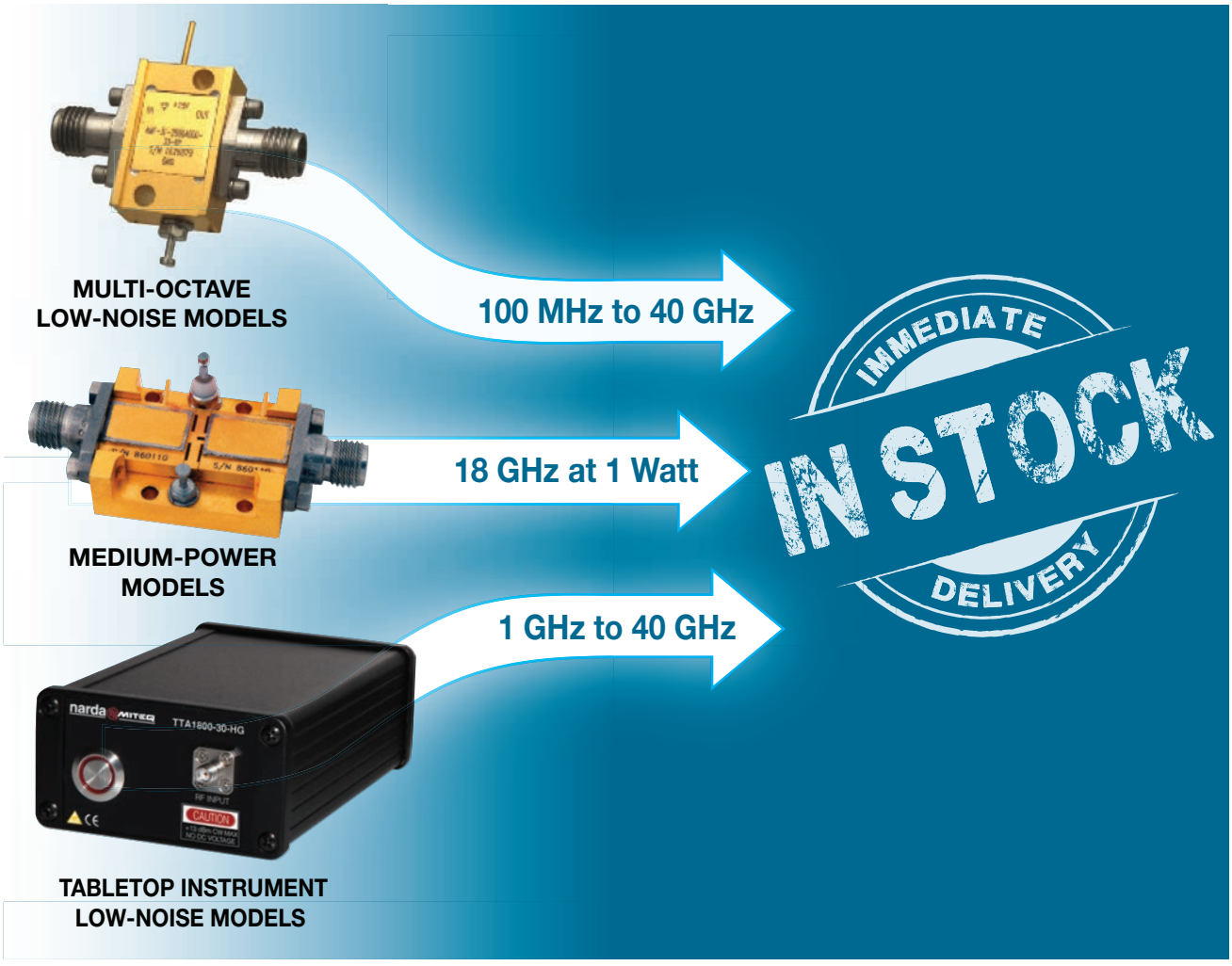

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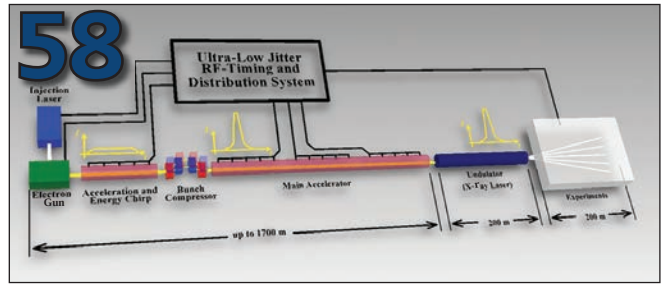

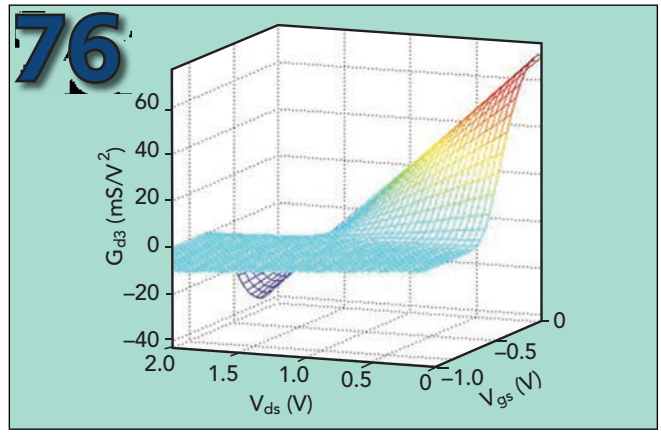

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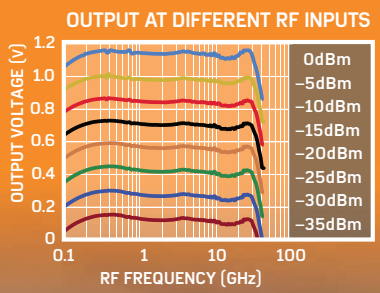

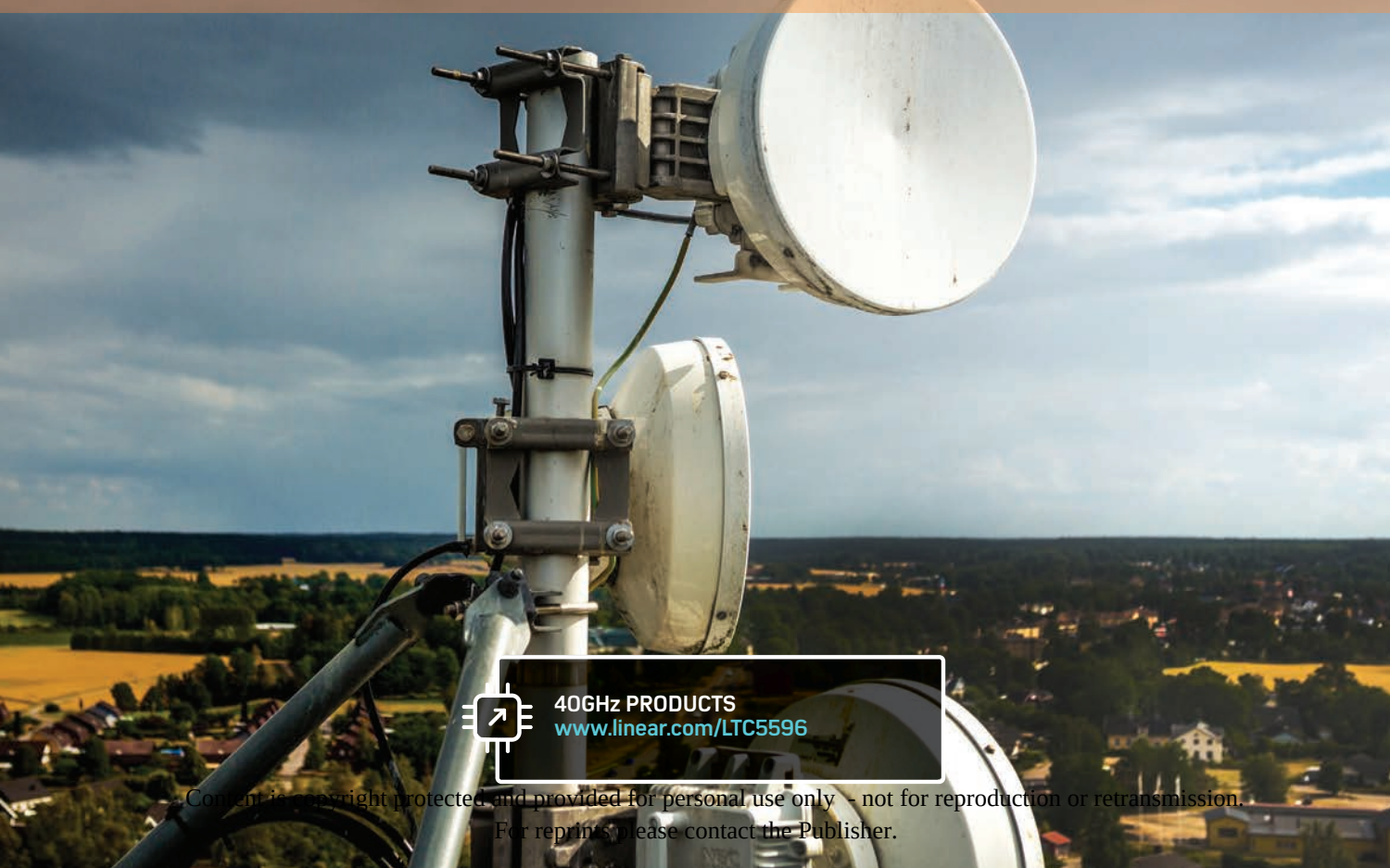

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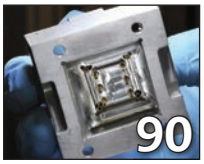

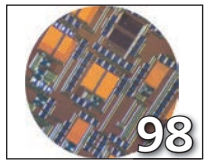

Product Features

Tech Briefs

Departments

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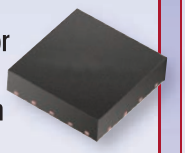

RF Amplifiers
- Gain Blocks
- Coaxial Module
- Low-Noise
- Linear Drivers
- High Power
- Variable Gain

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- GaAs
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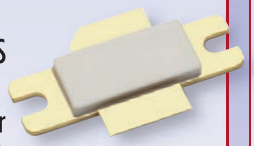
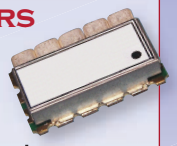
- High Frequency



RF Filters
- Monoblock
- SAW / BAW
- HP / LP / BP
- Ceramic Resonator
- Duplexer / Diplexer
- Cavity



RF Oscillators
- OCXO
- VCXO
- TCXO
- PLL Synthesizers
- RF Generators

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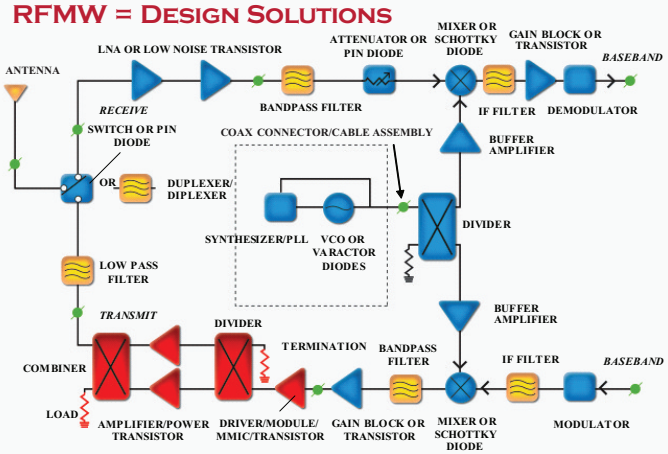
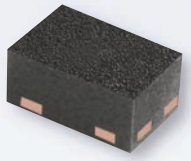
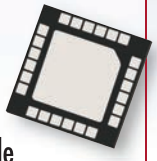


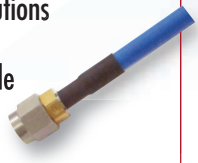
RF Diodes
- PIN
- Schottky
- Varactor
- Limiter
- Gunn



RF Attenuators
- Fixed
- Digital
- Coaxial
- Chip
- Voltage Variable
- Temperature Variable



RF Cable Assemblies
- High-Performance Test
- In-Box Solutions
- Pigtails
- Conformable
- Flexible
- Semi-Rigid



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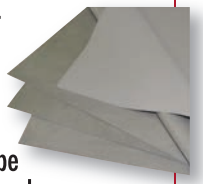

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Best Design Practices for Systems with PDN Noise Sensitive Designs Like PLLs, ADCs, and DACs
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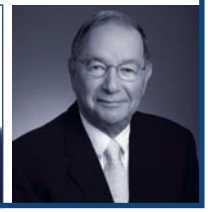
Ken Karnofsky, Senior Strategist at **MathWorks**, discusses the challenges faced by wireless designers and how EDA tools like MATLAB and Simulink are aiding the development of applications like 5G and autonomous driving.

Executive Interviews

RF Superstore CEO **Jason Wright** and co-founder **Murray Pasternack** discuss the products and services offered by this new distributor and how they intend to win customers in a crowded market.



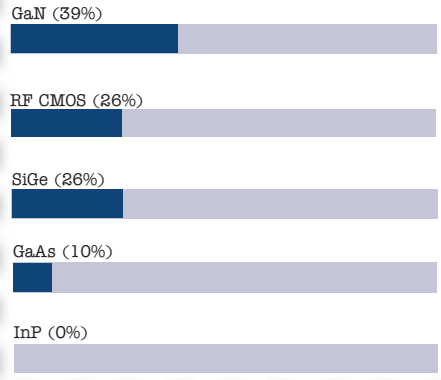
Web Survey

Where do you (personally) fall on the technology adoption curve?

Look for our multiple choice survey online at mwjournal.com

February Survey

What semiconductor technology will underlie most of the RF components in a 28 or 39 GHz fixed wireless access link?



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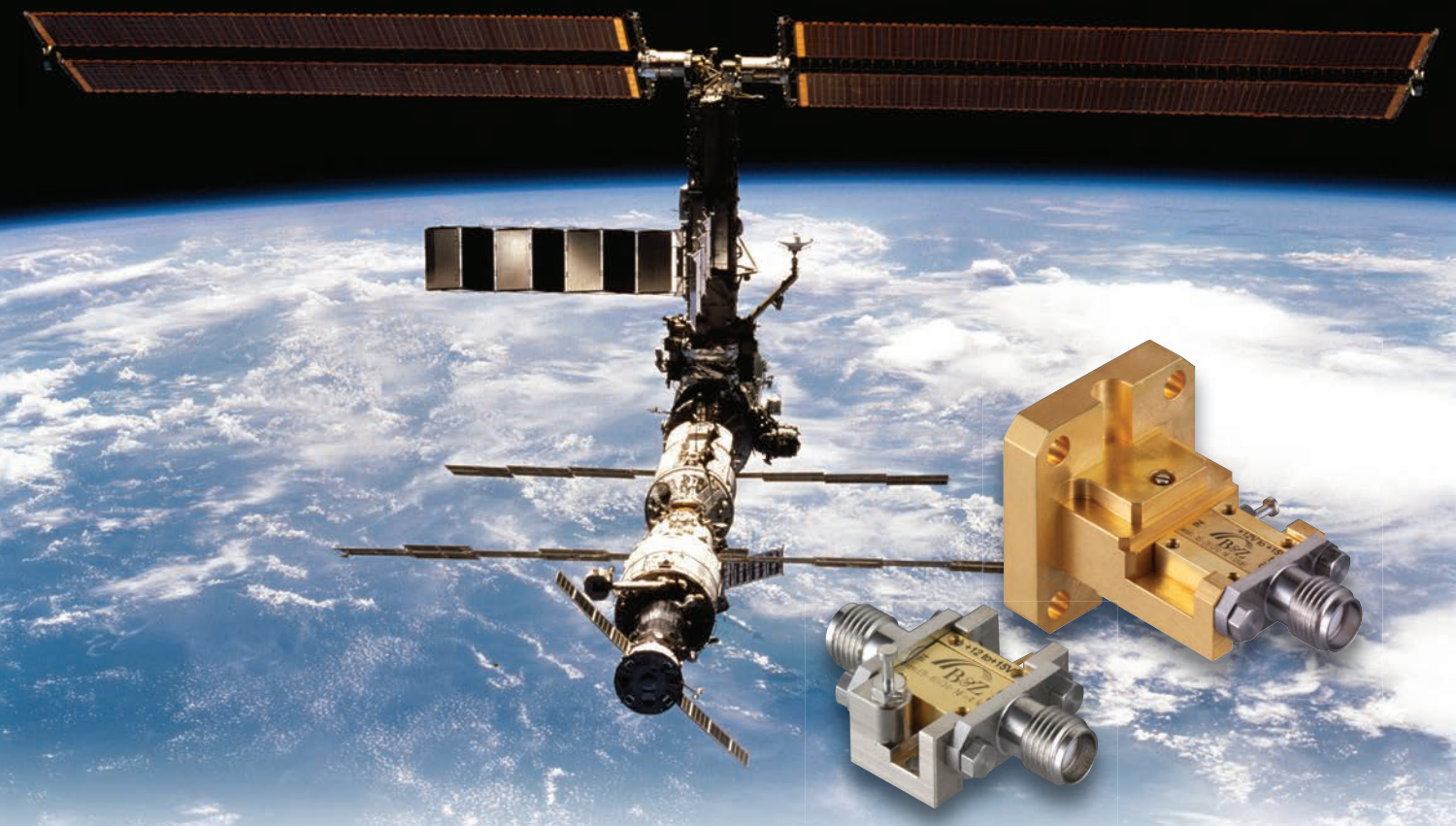
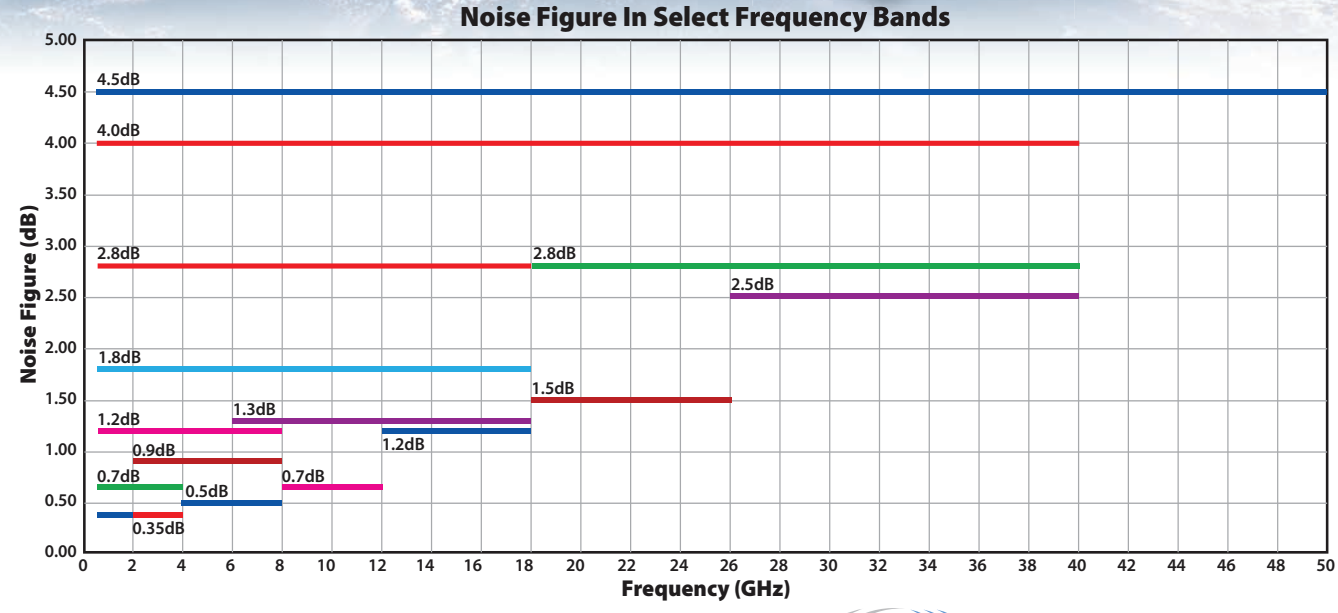
Has Amplifier Performance or Delivery Stalled Your Program?





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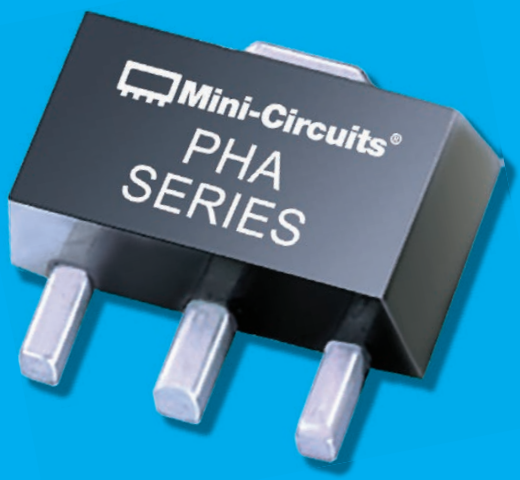

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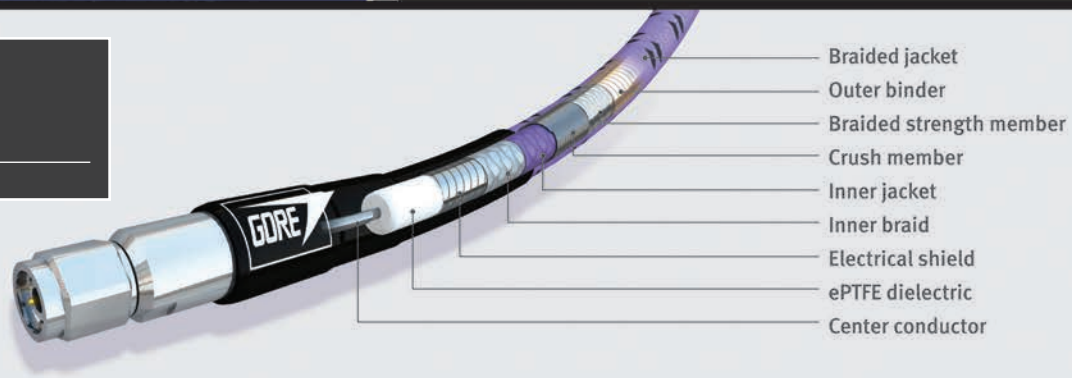

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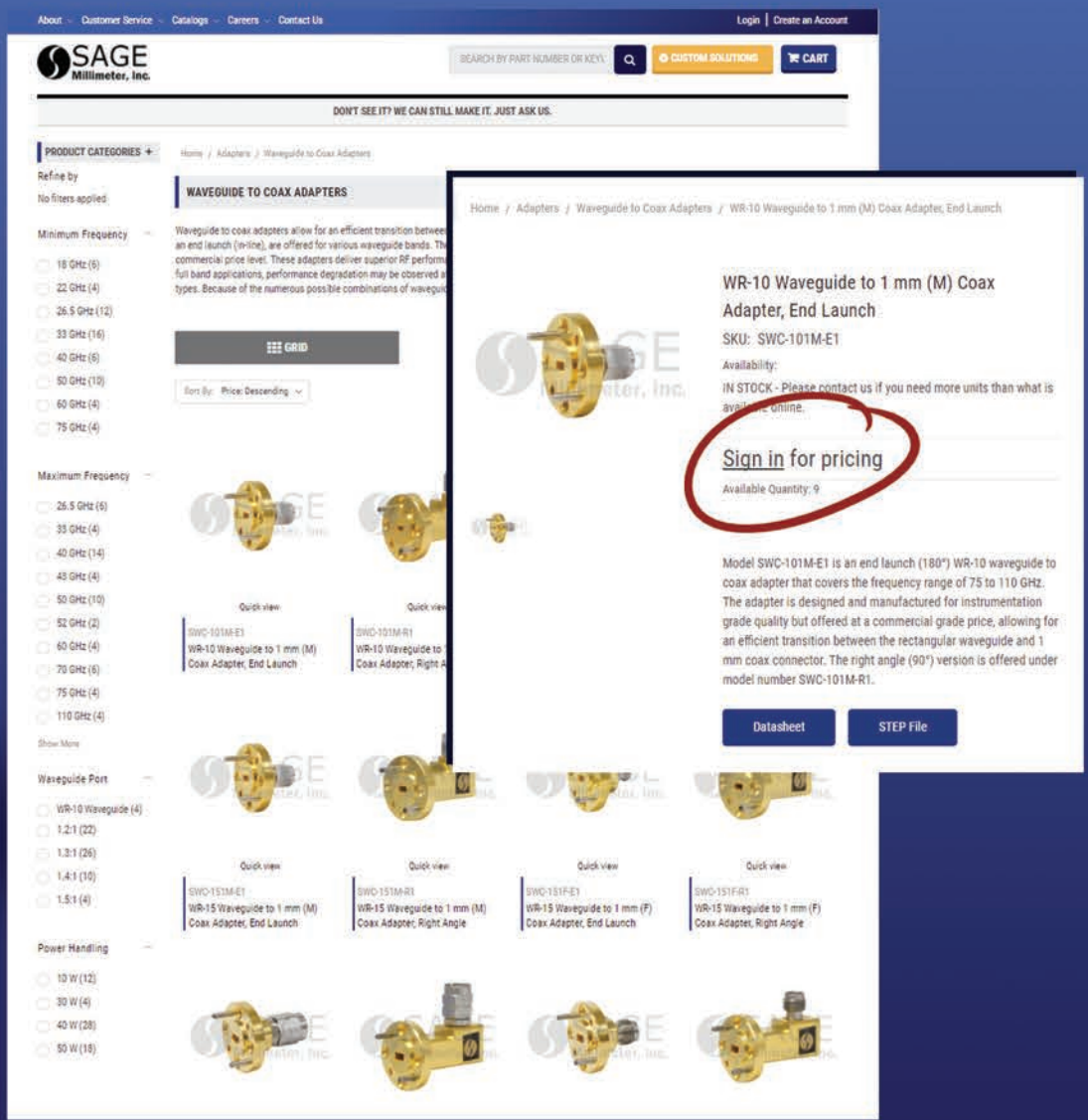

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Design of a Single Chip Front-End Module for 28 GHz 5G

Stuart Glynn, Robert Smith, Liam Devlin, Andy Dearn and Graham Pearson
Plextek RFI Ltd., U.K.

With the roll-out of mmWave 5G expected to commence soon, the research and development activities of the industry's key players are now well advanced and reached the point where custom components have been specified, designed and evaluated. An essential component required to enable future mmWave 5G systems is the front-end module (FEM) providing the final stages of amplification in a transmitter and the earliest stages of amplification in a receiver together with a transmit/receive (Tx/Rx) switch to allow time division duplex (TDD) operation. The FEM must demonstrate high linearity in transmit mode and low noise figure in receive mode. As mmWave 5G systems are likely to require user terminals containing multiple FEMs as part of a phased array or switched antenna beam architecture, they must also be highly efficient, compact and low cost. Ease of control and monitoring is also highly desirable.

This article describes the design, realization and evaluation of an FEM MMIC for the 28 GHz 5G band (27.5 to 28.35 GHz) which satisfies all of these requirements. The part was developed by Plextek RFI and designed on WIN Semiconductors' PE-15 process which is a 4 V, 0.15 µm, enhancement mode GaAs PHEMT process. It is realised in a compact, low-cost 5 mm x 5 mm plastic overmolded SMT compatible QFN package making it suitable for high volume, low cost manufacture. It covers 27 to 29 GHz and so encompasses the full 28 GHz 5G band.

DESIGN GOALS

The design of the FEM's transmit path focused on achieving high efficiency when operating at back-off to provide linear amplification, as will be required by 5G systems. A target power added efficiency (PAE) of 6 percent at back-off was specified, with third-order intermodulation (IMD3) levels below -35 dBc (around 7 dB backed-off from the 1 dB compression point). The RF output power at the 1 dB compression point (P1dB) was specified at 20 dBm. For the receive path, a noise figure of below 4 dB (including switch losses) was required with very low current consumption—a target of 15 mA maximum from the +4 V supply was specified.

A block diagram depicting the functionality of the FEM MMIC is shown in ***Figure 1***. The transmit signal path runs from left to right in the top half of the diagram; the input is at the pin labelled "PA_RF_{in}."

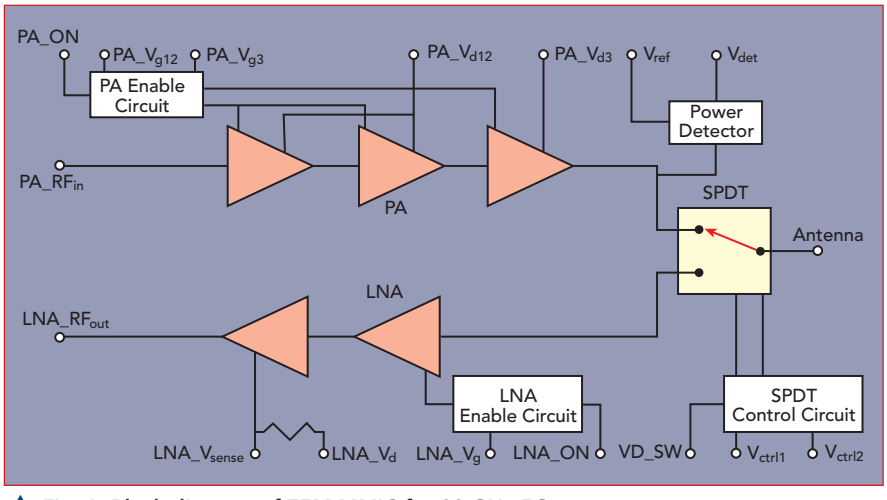

Fig. 1 **Block diagram of FEM MMIC for 28 GHz 5G.**

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The signal is amplified by a three-stage PA and then routed to the antenna via an RF power detector and a single pole double throw (SPDT) switch. The on-chip directional power detector allows monitoring of the transmitted RF output power and incorporates temperature compensation. The compensated detector output is given by the difference between the voltages "V_{ref}" and "V_{det}." A fast switching enable circuit "PA Enable Circuit" is included on-chip and is controlled by the (active low) logic signal "PA_ON." This is used to rapidly power up and power down the PA when switching between Tx and Rx mode such that it draws only 0.1 mA when not in use, maximizing the overall system efficiency.

The PA will typically operate backed-off from compression to preserve modulation fidelity of the transmitted signal. The design approach was to optimize the performance of the PA when operating 7 dB back-off from P1dB. In order to optimize PAE at this operating point the PA was biased in deep class AB.

DESIGN TRADE-OFFS

The design was initiated by running device level simulations on candidate unit cell transistors. This work forms a solid foundation for the subsequent detailed PA design as it yields key information such as device sizes, bias points, impedance targets, required number of PA stages and drive ratios.

A significant part of this work was aimed at identifying how to maximize PAE at back-off. Generally speaking, this is achieved by reducing the device quiescent bias current density. However, the extent to which this approach can be adopted is limited by the gain and linearity, both of which degrade as the current density is reduced. There is a clear trade-off of PAE (at back-off) with gain and linearity.

The main linearity metric of interest was the IMD3 level at back-off which had to be below -35 dBc. It was found that the IMD3 performance at reduced bias currents became particularly sensitive to the fundamental load condition, as illustrated in ***Figure 2***. Figure 2a shows load-pull simulation results for an 8 × 50 µm device biased toward deep class AB at 75 mA/mm at 4 V and highlights the optimum load for PAE at P1dB. It also shows the corresponding simulated IMD3 performance at back-off for this load and indicates that there is about 4 dB margin on the specification of -35 dBc. The simulated PAE at the same back-off was about 15 percent which is for the device only and excludes any output losses. Figure 2b shows similar information for the load condition that is best for power at P1dB. The IMD3 performance at the same relative back-off is considerably worse, more than 5 dB outside the specification, PAE at back-off was similar at around 15.7 percent.

Other points on the Smith Chart were also evaluated for performance at P1dB and at back-off, but the load condition, highlighted in Figure 2a, was found to be the best overall and was selected for the out-

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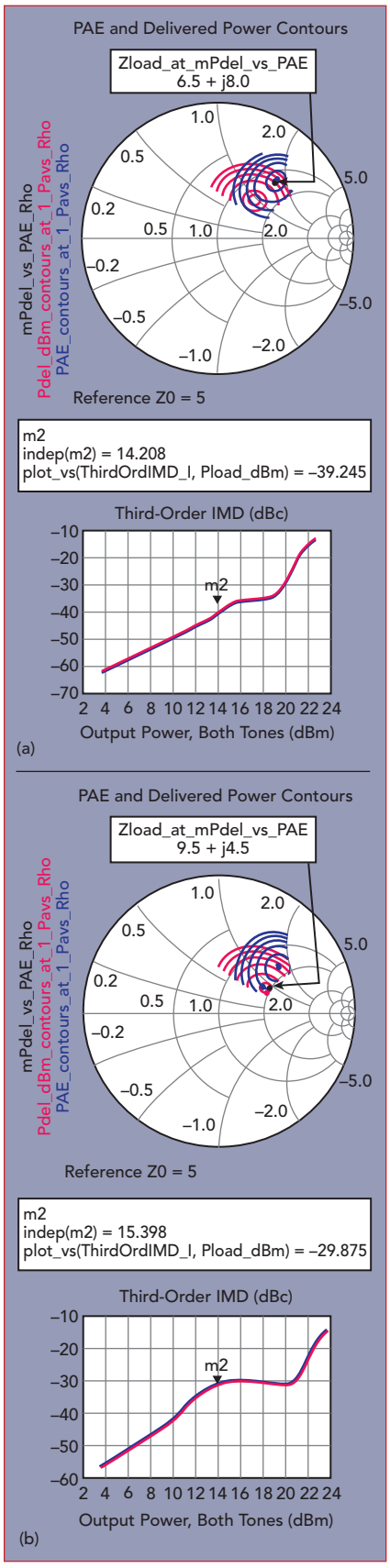

▲ **Fig. 2 Load for optimum PAE at P1dB and corresponding IMD3 at back-off (a) and load for optimum power at P1dB and corresponding IMD3 at back-off (b).**

put stage design. This also offered scope for further bias current reduction, into deep class AB, to trade some IMD3 performance for PAE performance while still maintaining adequate gain. A bias current of 52 mA/mm was ultimately chosen and an 8 × 50 µm device selected as a suitable unit cell for the output stage, allowing the power specification to be met. It was also determined that three stages would be required to meet the overall transmit gain specification.

The design of the complete three-stage PA progressed with selection of the optimum transistor sizes for the driver and pre-driver stage. Again careful trade-offs were considered; larger transistor sizes improve the overall linearity but reduce the PAE. With the size and bias of all transistors selected the detailed design of the matching and biasing circuitry could proceed. The layout was considered from an early stage of the design process to ensure a practical implementation was possible without incurring unacceptable parasitics. A common gate bias line was used for stages one and two (applied at pin PA_V_{g12}) and a separate bias line for stage three (PA_V_{g3}). This allowed the possibility of separately optimizing the two voltages for potential linearity or PAE improvements to the PA. The drain supplies were similarly applied through two separate pins, although these were connected on the PCB; the +4 V drain supply is applied at "PA_V_{d12}" and "PA_V_{d3}."

The SPDT switch is a series-shunt design incorporating multiple transistors in both the series and shunt arms for improved linearity.[1] The off-state capacitance of the transistors limits the inherent isolation of the off-state device at high frequencies; at 28 GHz the switch transistors will have an isolation of just a few dB.[2] Reducing the transistor size to improve the inherent isolation increases the on-state insertion loss and degrades its linearity and so was not an option. The approach taken was to include on-chip inductive compensation to improve the off-state isolation. Care was taken to ensure low insertion loss in the on-state to enable a high output power from the transmit path and a low noise figure from the receive path. The switch is controlled by a single bit, "V_{ctrl1}," which is set to 4 V for Tx mode or 0 V for Rx mode. Single bit control is facilitated by the "SPDT Control Circuit," which is essentially a one to two line decoder. The combined supply current drawn by both the control circuit and the SPDT itself is just 1 mA from the +4 V applied at "VD_SW."

The input to the receive path is at the "Antenna" pin which is routed to the input of a two-stage LNA by the SPDT. The output of the receive path is at the pin labeled "LNA_RF_{out}." As with the PA, the LNA also has a fast switching enable circuit such that the LNA draws as little as 0.1 mA when not in use. A key part of the LNA design process was to produce a design which had low current consumption but good noise figure and adequate linearity.

Selection of appropriate transistor sizes was an important first step. Multiple short fingers were used to reduce the gate resistance of the transistors and improve the noise figure. Series inductive feedback was added to both stages to shift the impedance required for optimum noise figure closer to that required for a conjugate match and optimum gain.

The first stage of the LNA was optimized for noise figure but still had to produce enough gain to adequately reduce the impact of the second stage noise figure. The noise figure of the second stage is not as critical, and this stage was designed with higher gain than the first. The resulting LNA design requires just 10 mA of DC supply current from its +4 V supply. The gate bias voltage is applied at pin "LNA_V_g" and the +4 V drain bias is applied at "LNA_V_d." The "LNA_V_{sense}" pin is provided to allow for bias current monitoring. Monitoring the bias current allows control of the gate voltage to compensate for changes in environmental conditions, for example a change in temperature. When correctly biased this monitoring pin is at 3.9 V. The use of an enhancement mode process meant that only positive supply voltages were required, making the MMIC very convenient for system integration.

Careful EM simulation was essential to ensure good RF performance

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from the various blocks. A step by step approach was adopted adding a part of the circuit to the EM simulation at a time with the rest of the block still simulated using Process Design Kit (PDK) models. As the IC was destined for packaging in an overmoulded plastic package, the presence of the moulding compound on top of the IC also needed to be accounted for in the EM simulation.

EVALUATION AND TEST

A photograph of the FEM die is shown in ***Figure 3***. The FEM MMIC die measures 3.38 mm × 1.99 mm. Its pad/pin positions are similar to those shown in the block diagram although it incorporates a number of GND pads in order to make it fully RF-on-wafer (RFOW) testable. It was designed to be packaged in a low-cost plastic overmolded 5 mm × 5 mm QFN. In addition to accounting for the effects of the moulding compound, the RF transition from IC to PCB needed to be carefully designed. A custom leadframe was designed to facilitate this and the RF ports of the package are all implemented as ground-signal-ground interfaces.

Following fabrication, several of the die were tested RFOW which confirmed that the first pass design had been successful prior to packaging. The RFOW results are not presented here but all measurements were made on a packaged assembled IC mounted on a representative evaluation PCB.

The evaluation PCB was designed using a low cost laminate PCB material suitable for mass volume production. Samples of the packaged FEMs were assembled on to the evaluation PCBs; all of the measured performance is calibrated to the package pins on the evaluation PCB and include the effects of the IC to PCB transition. A TRL calibration tile was designed to allow the calibration of the measured performance to the reference planes of the package. A photograph of one of the evaluation PCBs next to a TRL calibration PCB is shown in ***Figure 4***.

Evaluation results for the packaged FEM MMIC mounted on the PCB and referenced to the package's RF pins. Throughout the evaluation, a commercially available multi-channel DAC and ADC IC was used to control and monitor the FEM. The FEM does not require any negative voltages as it was designed on an enhancement mode process. A comparison of the measured to simulated S-parameters of the Tx path of a typical FEM are shown in ***Figure 5***. The measured data and simulated results match reasonably well. In this mode, the LNA is powered down, the SPDT control bit "V_{ctrl1}" is toggled high and the

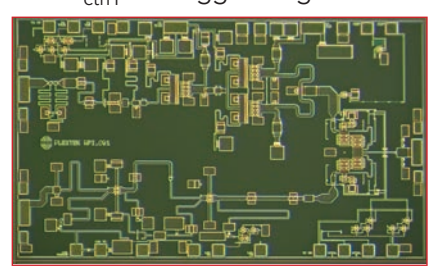

Fig. 3 Die photograph of FEM MMIC for 28 GHz 5G.

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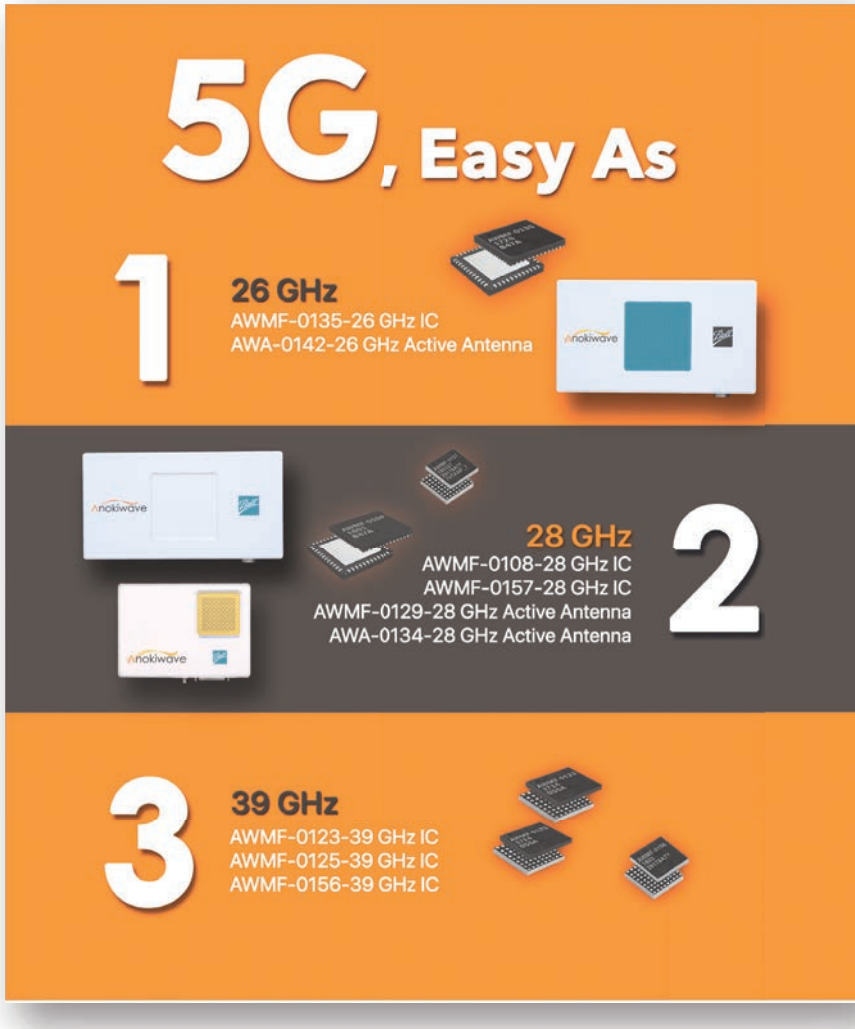

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PA biased to around 70 mA total quiescent current from +4 V. Small signal gain (S_{21}) is 17.1 dB ± 0.4 dB from 27 to 29 GHz. The input return loss (S_{11}) is better than 18 dB across the band. The output is matched for best PAE at back-off rather than best S_{22} but the measured S_{22} (not shown) is 8 dB or better across the band.

The output referred third-order intercept point (OIP3) of the Tx path was evaluated with a tone spacing of 100 MHz to reflect the wide channel bandwidths anticipated in 5G systems. ***Figure 6*** is a plot of the measured OIP3 of a typical FEM with the wanted output tone powers ranging from 1 to 11 dBm per tone. It can be seen that the OIP3 is around +28 dBm across the 5G band and shows very little variation with tone power over a 10 dB dynamic range. A plot comparing the measured to simulated OIP3 versus frequency is shown in ***Figure 7*** and demonstrates good agreement.

Although 5G systems will require linear amplification to preserve modulation fidelity, the output referred P1dB and PAE were also measured to provide a figure of merit for comparative purposes. The measured performance is shown in ***Figure 8*** and shows a P1dB around 20.2 dBm, which rises to 21 dBm at saturation. The PAE of the FEM Tx path is around 20 percent, falling slightly at the top of the band.

As mentioned above, the FEM is designed for optimum performance (OIP3 and PAE) when operated at around 7 dB backed-off from P1dB, specifically with the IMD3 at a level of below -35 dBc relative to the wanted products during a two-

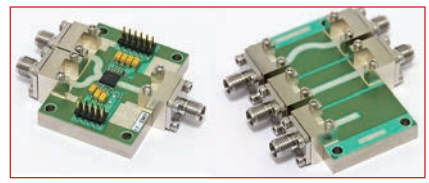

Fig. 4 Photograph of packaged FEM evaluation PCB and TRL calibration PCB.

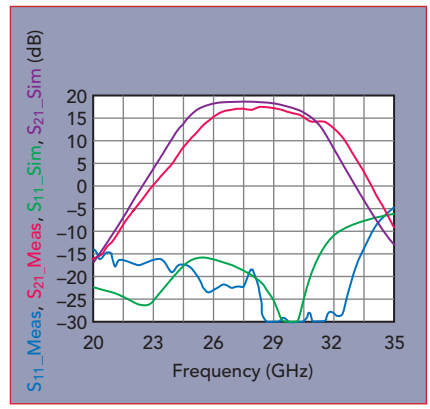

Fig. 5 Measured to simulated small-signal performance of the Tx path of the FEM.

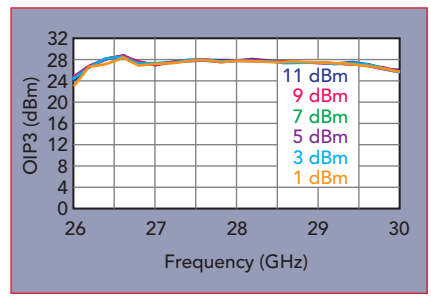

Fig. 6 FEM Tx OIP3 vs. frequency vs. output tone power (100 MHz tone spacing).

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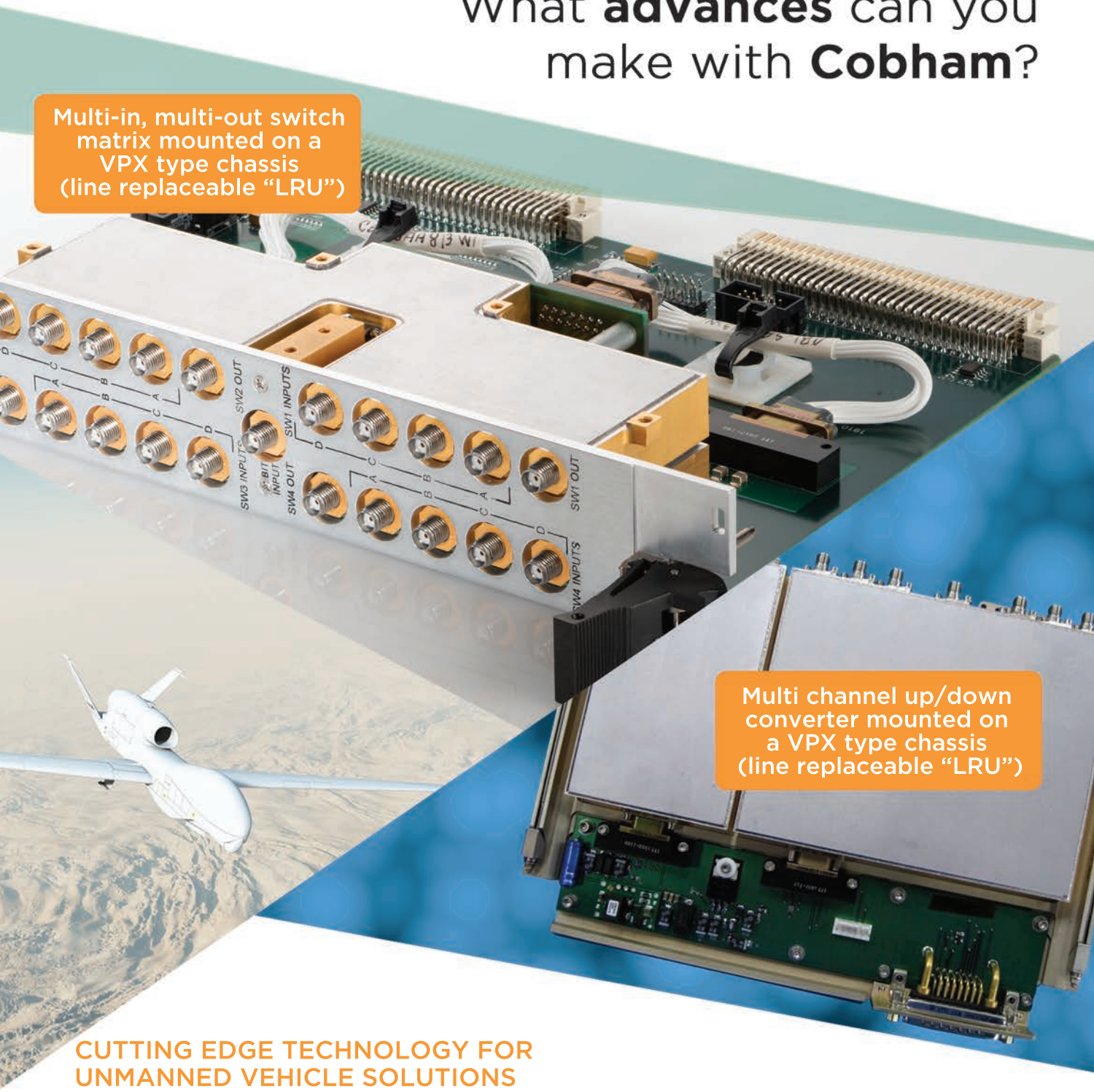

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tone test with 100 MHz tone spacing. This operating point is close to that envisaged in the 5G system for which the FEM was designed.

Figure 9 shows a plot of the measured and simulated PAE and total RF output power when operating at an IMD3 point of -35 dBc. The measured PAE is 6.5 percent, which is good and largely due to the PA being designed to operate in deep class AB. The total RF output power is around 13.5 dBm, which equates to an OIP3 level of +28 dBm.

The on-chip Tx power detector characteristic provides a DC voltage that allows monitoring of the RF output power. The temperature compensated detector output "V_{ref}-V_{det}" is plotted in mV on a logarithmic scale against output power in dBm over a 15 dB dynamic range in ***Figure 10***. On this scale the characteristic is linear making power monitoring easier.

When the Rx path of the FEM is selected the PA is powered down, "V_{ctrl1}" is set to 0 V and the LNA biased to around 10 mA from +4 V with 3.9 V observed on the "LNA_V_{sense}" pin. ***Figure 11*** is a plot comparing the measured and simulated gain and noise figure (NF). The measured small signal gain is around 13.5 dB with a gain flatness of just ±0.3 dB across the band. The Rx path has an excellent noise figure of typically 3.3 dB from 27 to 29 GHz with good agreement between simulated and measured performance.

The Rx path also demonstrates impressive linearity for the modest power consumption (just 40 mW: 10 mA at 4 V). Key parameters such as P1dB and OIP3 are around 6.2 and 21 dBm, respectively, across the band. ***Figure 12*** is a plot of the

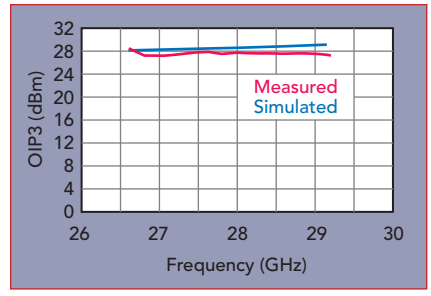

Fig. 7 Comparison of measured and simulated OIP3 vs. frequency.

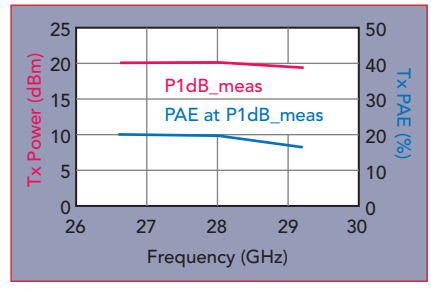

Fig. 8 Measured P1dB and PAE of the Tx path vs. frequency.

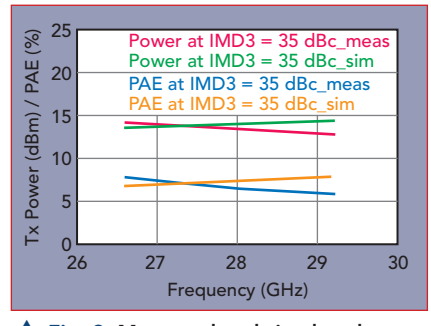

Fig. 9 Measured and simulated Tx power and PAE operating at ~7 dB backed-off.

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measured P1dB and OIP3 versus frequency.

CONCLUSION

The FEM MMIC described here will potentially play a key role in future 28 GHz, 5G systems. The part has been shown to address all the requirements for integration into mmWave phased-array or beam switched terminals and offers excellent Tx linearity and efficiency together with outstanding Rx noise figure. The key performance specifications for both transmit and receive paths were met, ensuring that the part is highly suitable for mmWave 5G applications. The IC also includes useful features such as a Tx power detector, Tx and Rx enable circuits, an SPDT decoder circuit and Rx bias monitoring. Realized on a state of the art 0.15 µm enhancement mode GaAs PHEMT process the part is extremely easy to control and monitor using widely available multi-channel ADC and DAC ICs. In addition, the part is conveniently housed in a compact and low cost 5 mm × 5 mm plastic overmolded QFN SMT package.■

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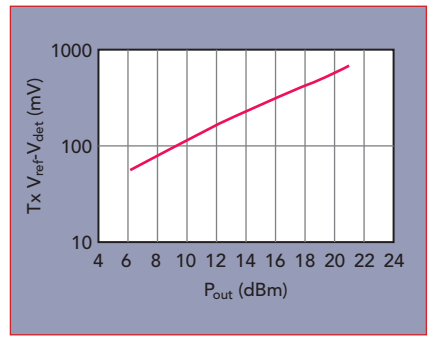

Fig. 10 FEM Tx on-chip power detector measured characteristics at 28 GHz.

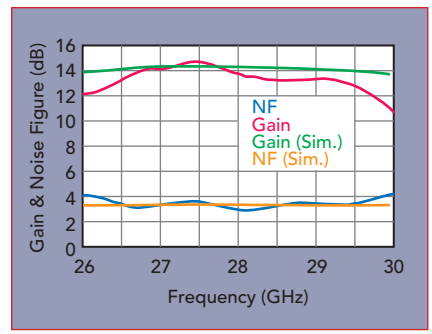

Fig. 11 Rx path measured and simulated gain and NF.

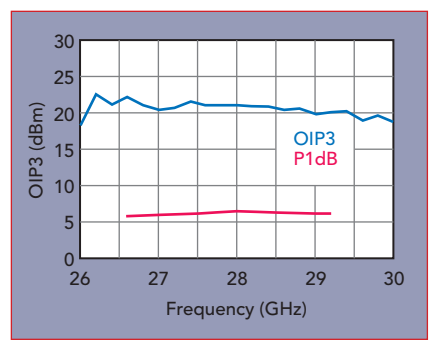

Fig. 12 Rx path measured P1dB and OIP3.

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Cliff Drubin, Associate Technical Editor

LM's Unmanned Vehicle Software Can Simultaneously Control Multiple UAVs

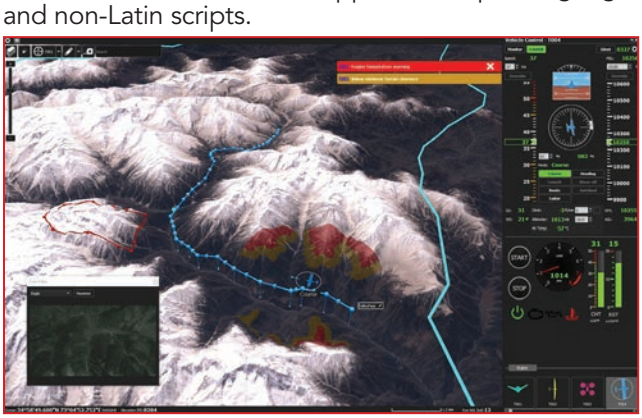
Lockheed Martin (LM) software has been simultaneously flying, on average, at least six unmanned aircrafts during every hour of the last 25 years, completing missions as diverse as reconnaisance, inspection, mapping and targeting. LM recently launched VCSi, a new vehicle control software, as the culmination of more than two decades of experience and 1.5 million hours of operational use.

"VCSi is a safe and reliable software platform that can be adapted to any vehicle—from one you can hold in your hand, to a 50,000-pound machine; from a vehicle that flies for a few minutes to a vehicle that flies for months at a time," said John Molberg, business development manager, LM CDL Systems. "The user can integrate as many vehicles as required to complete their missions, including boats, quadcopters, fixed-wing aircraft or even high-altitude pseudo satellites. Across commercial or military missions, VCSi is adaptable to the challenge and further extends the power of the human-machine team."

VCSi's major enhancements include:

- Multi-Vehicle: Control interfaces to allow for true 1:n control of dissimilar vehicles anywhere on Earth.
- Intuitive: Advanced fly-by-mouse interface to enable easier training and reduce operator/analyst task loads.
- Affordable: Priced competitively with all unmanned systems in mind, customers can buy essential modules for their mission set.
- Modular: Offers a robust plug-in architecture, which allows for custom content to be added by the user or selected from pre-existing modules.
- International: Commercial software, made in Canada and free of export restrictions.

VCSi is designed around the NATO Standardization Agreement known as STANAG 4586, which supports unmanned vehicle interoperability. Customers can build attachments or plug-ins beyond 4586 to customize the VCSi software, which also supports multiple languages and non-Latin scripts.



VCSi (Image courtesy of Lockheed Martin)

Dawn of the Drone Age

Amazon, Uber and a host of other companies are betting big on a future that includes drone delivery services and flying fleets of taxis. But first, the government needs to sort out new flight rules, regulations and standards as well as modernize air traffic control systems to ensure friendly skies for so many unmanned aircraft. Air-traffic authorities must build the infrastructure for a crowded, low-level airspace that is safe for those in the skies and on the ground. That is a challenging task, especially when it comes to urban areas.

Raytheon has a technology that can help bring on the new drone economy—low-power radar (LPR). Instead of one, massive radar installation, it consists of smaller, one-meter square active electronically scanned array (AESA) software-defined radar units. A network of such small radar units could cover and control the low-altitude flights of smaller craft. "It could aid drone delivery services, flying cars and provide highly localized information like ground fog or flash-flooding in remote or urban locations; things that today's radars can't do," said Michael Dubois, Raytheon's LPR lead.

In a live flight-check demonstration for U.S. government agencies, Raytheon recently showcased how its LPR can support flights within 20 nautical miles. Air traffic controllers used the radar, which measures a single square meter and uses beam-scanning technology, to guide the pilot to touchdown with surgical precision.

Raytheon is working with small business and academia on a vision: a distributed LPR network that will create a merged, complete picture for multiple missions. Besides supporting safe landings, the network could support aviation surveillance, precision weather observations (including 3D wind information and urban hydrology), small drone detection and tracking, border security and surveillance, wildfire detection and elevation and geographic gapfills, providing coverage where none now exists. Using LPR, Raytheon could offer radar data as a service, offering data to pilots, companies, the government, weather forecasters and others with a need for low-level radar information. "This service could be used by media outlets needing information about structures and obstacles before flying a drone over the scene of a news event to shoot footage, or by UberAir to get wind information before dispatching a flying taxi to pick up riders," he said.

Dubois envisions a distributed network of LPRs every 20 miles or so, mounted atop cell phone towers, mountains and hilltops and tall buildings. Such a network could monitor activity at very low altitudes. "It's the economy of scale; instead of building several big things, we'd manufacture thousands of little things. Active phased array radar offers adaptive beam scanning, can track 100x more targets and can also interleave

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between different radar applications. With no moving parts, LPRs are more reliable and easier to maintain than conventional radar systems, giving them longer lifetimes and lower life-cycle costs.

Raytheon has conducted a low-rate initial limited run of LPRs for integration, test and demonstration. "We'd be ready for deployment as early as 2020," Dubois said. "And it works; and it works very well."

Northrop Grumman-Built G/ATOR Approved for Early Fielding

The Northrop Grumman Corporation (NGC) AN/TPS-80 Ground/Air Task-Oriented Radar (G/ATOR) has been approved for early fielding by the U.S. Marine Corps. This milestone follows the delivery of the final Lot 1 and Lot 2 Low Rate Initial Production (LRIP) G/ATOR system to the Marines. The Marines will field their first two systems by delivering them to Marine Air Control Squadrons 1 and 2 for operational use.

Early fielding, also known as Initial Operational Capability (IOC), is a significant milestone that indicates that a system is ready for operational deployment. It is achieved when production systems, spares, logistic support items and documentation have been tested and validated through a rigorous process. As the developer and system integrator, NGC has taken G/ATOR from concept through to production.

NGC has delivered six G/ATOR systems with GaAs technology to the Marines in Lots 1 and 2. Beginning with Lot 3 deliveries and including all Full Rate Production systems, G/ATOR will incorporate high-power, high efficiency GaN antenna technology that can further enhance operational capabilities.

G/ATOR is designed to detect UAS, cruise missiles, air breathing targets, rockets, artillery and mortars, replacing five legacy systems operated by the Marines. It provides significant improvements in performance when compared with the legacy radar families in each of its modes. Software loads optimize the multi-mission capabilities. When all modes are fully implemented, an operator is able to switch modes at the press of a button. The system has been designed to be light and compact for deployment, and for rapid emplacement by helicopter or vehicle. Its system architecture allows it to interface directly with multiple types of command and control systems on a plug-and-fight basis.

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CCS Supports UK Government's £5M 5G Smart Tourism Testbed

A successful bid by the West of England Combined Authority consortium is utilising Cambridge Communication Systems (CCS) Ltd.'s 60 GHz mmWave Metnet technology to provide superfast wireless backhaul for the U.K. government's £5 million 5G Smart Tourism testbed to be delivered in Bath and Bristol.

The U.K. government's Department of Digital, Culture, Media and Sports (DCMS) is investing in a world-class 5G technology test network that will aim to put the U.K. at the forefront of the next wave of mobile technology—potentially adding up to £173 billion to the U.K. economy by 2030.

The highly-skilled 5G Smart Tourism consortium includes 5G network and service providers CCS, BT, Zeetta, InterDigital and Bristol is Open. The cutting-edge testbed will demonstrate self-provision of 5G and Wi-Fi plus innovative mmWave backhaul capabilities. The testbed will also address safety issues by providing emergency service capacity through network slicing.

Delivering high capacity, ultra-low latency and ultra-fast deployment, Metnet is optimised for performance edge today while providing an upgrade path to much higher multi-gigabit capacity, and is currently powering networks to mmWave 5G performance in major live deployments across the world. Metnet offers its SON multipoint solution in the 24/26/28 GHz area based licensed bands, plus its recently launched Metnet 12 Gbps 60 GHz 3D SON™ mmWave access and backhaul system in the unlicensed 60 GHz band, using Metnet SON for frequency agility and interference management.

"We're really proud to be playing a pivotal role in this ground-breaking 5G Smart Tourism project, and to be working with our bid partners to pioneer a 5G network that will put the U.K. at the forefront of next-generation wireless technology," said CCS CEO Steve Greaves. "We'll be very excited to see the public response to this world-first innovation, which marks a key step towards U.K.'s first smart regions."

Flemish Scientists Win DARPA Cash Prize

Scientists from IDLab, a core imec research group embedded in the universities of Ghent and Antwerp, are working on an innovative system for wireless networks to enable smooth communication even in crisis situations, for which it was awarded $750,000 by the U.S. DARPA.

Colleagues Ingrid Moerman (UGent/imec) and Steven Latré (UAntwerp/imec) entered the DARPA Challenge with their IDLab research group. For the project they also collaborate with scientists from Rutgers University, U.S. For the project the researchers use a "clean slate" approach, which enables them to ignore the limitations of existing technologies and concentrate on developing their own communication system.

Moerman commented: "We decided to focus on artificial intelligence (AI). Things can go wrong nowadays if the digital information sent out by different wireless devices 'collides' because the devices are using the same channel on the wireless spectrum. By teaching wireless devices like smartphones to figure out what other devices are doing and predict when they will use which channels, we can avoid these collisions. That way, it's no longer necessary to make wireless communication plans or agreements in advance—something that's impossible in crisis situations anyway."

While the researchers are mainly working on fundamental research at the moment, practical applications are already twinkling on the horizon. "The AI-based solutions should be ready for use in the short term," said Latré. "We are already working with Antwerp's fire department. For them, it would be a huge advantage to be able to stream live images of fires to their command vehicles. And to get those images from the fire site to the command vehicle, we need to build a new wireless network. So that's what we're going to do."

ESA Selects LimeSDR for App-Enabled SATCOMS

Lime Microsystems has announced a project with the European Space Agency (ESA), which will see its LimeSDR platforms used to develop innovative satellite telecommunications solutions based on software-defined radio (SDR), both on the ground and in space.

ESA will become an official backer of the LimeSDR Project and the company will make 200 LimeSDR Mini units for developers wanting to create applications in the field of SATCOM. The move forms part of ESA's ARTES programme, and comes as part of the Space Agency's drive to speed up SATCOM developments, ensuring that European and Canadian industry remains competitive.

Source: LimeSDR ESA

Applications will be developed by the LimeSDR community, and shared via Lime-Canonical SDR App Store for SATCOM, which is being developed. Applications are anticipated to focus on satellite connectivity and IoT—for

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example, IoT services via low-cost satellites such as Cubesats; and also the use of SDR on-board larger satellites. In addition, new ideas coming from the ongoing 5G efforts in moving toward an SDR-based open architecture, enabling fully integrated heterogeneous networks will also be prototyped in a satellite context.

"With modern SATCOM, many design challenges are unique, requiring testing and experimentation to reveal what does and does not work," said ESA's Frank Zeppenfeldt, working in the future systems group of ESA's SATCOM department. "For this reason, fast prototyping of promising technology concepts is absolutely essential."

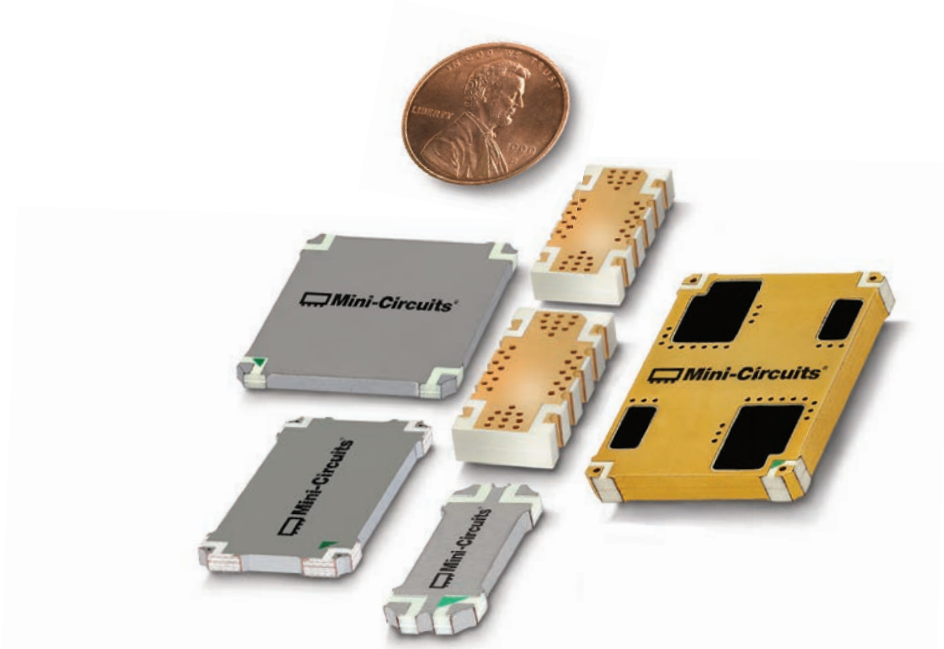
£25M for 5G Projects

On the first anniversary of its Digital Strategy, the U.K. government has announced the winners of a £25 million competition to pave the way for a future rollout of 5G technology. The six projects led by small and medium-sized enterprises (SME), universities and local authorities represent the best of U.K. innovation, resources and expertise.

They will test 5G across a range of applications and are part of a £1 billion commitment through the Digital Strategy to keep Britain at the forefront of connectivity by accelerating the deployment of next generation digital infrastructure and driving forward new 5G business opportunities.

Each testbed will receive between £2 and £5 million in government grants, as part of a total investment of £41 million from private sector and other public sector funding, to explore new 5G mobile communications technologies that use high frequency spectrum to deliver internet speeds of over a Gbps.

Professor Rahim Tafazolli, founder and director of 5GIC and leader of 5GUK Networks said: "The 5GIC is extremely pleased and proud to have been able to play a leading part in supporting the DCMS U.K. 5G testbeds and trails programme. 5G represents a fundamental transformation of the role that mobile technology plays in society, delivering rich new services in sectors such as finance, transport, retail and health. It will drive trillions of dollars of additional activity through the world digital economy and the DCMS programme will ensure that the U.K. stays at the forefront of this exciting global race."



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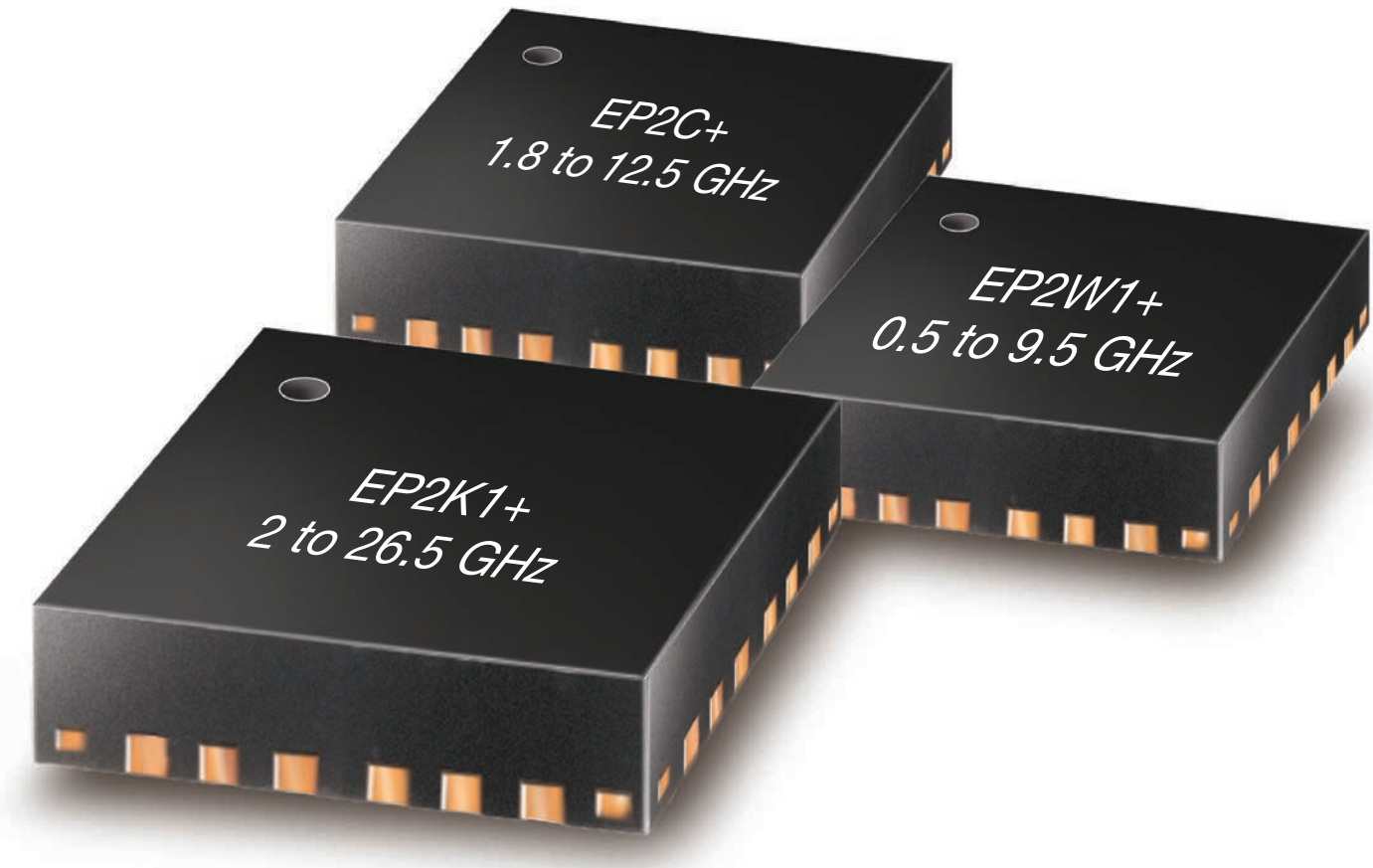

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IIoT Platforms: A $16 Billion Opportunity

If Industrial Internet of Things (IIoT) platform providers hope to keep their offerings relevant, they must work with suppliers of other transformative technologies to provide the most valuable functions and components," says Pierce Owen, principal analyst at ABI Research. "For instance, AR applications require business rule functions, digital twin functionality, near real-time metrics, zero-touch onboarding and advanced analytics features."

It seems that almost every company that has built a piece of software for the IIoT calls it a platform, and as such, IIoT platforms come in a variety of flavors. Perhaps the "platforms" that most suit that word fill the role of an application enablement platform (AEP). AEPs extract data from devices and move it to applications based at the edge or in the cloud. This platform might have connectivity or device management tools. It might also act as a data orchestration system and include an app store or have app development capabilities whereby users can create and access applications that generate insights from their data.

Siemens Mindsphere currently leads the pack of AEPs largely due to Siemens' domain knowledge as an automation supplier, its M&A strategy, R&D budget and its size. In addition, Siemens has a large installed base of its own physical products to which it can connect Mindsphere easily, a vast ecosystem in the manufacturing sector, and its own manufacturing facilities where it can perform internal proof-of-concepts. These advantages empowered Siemens to add 2900 digital manufacturing customers in 2017, doubling its total from the start of the year.

Other IIoT platforms specialize in a specific piece of application enablement or microservice such as fog computing or processing raw sensor data. ABI Research sees FogHorn Systems as a key innovator in real edge computing and complex event processing (CEP) at the edge. FogHorn faces the challenge of shifting from a successful start-up with a few big deals to embedding its software on millions of devices and assisting clients with large-scale implementation.

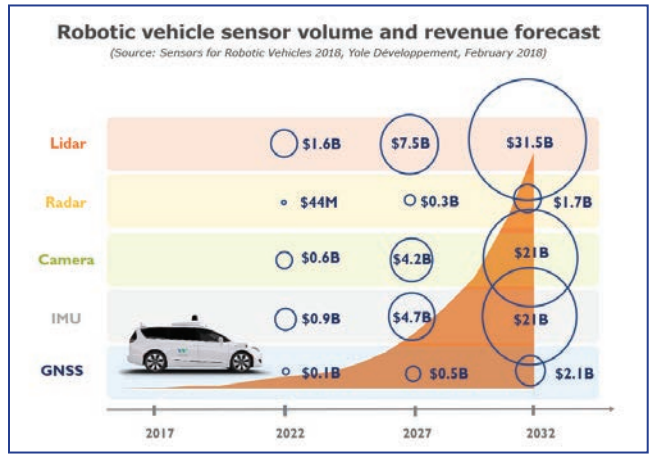
Sensors for Robotic Vehicles Will Become Industries of Their Own

In 2017 production of robotic vehicles was in the range of a few hundred worldwide. Today, Yole Développement is expecting production volumes to reach 3.1 million units annually, with cumulative production of 10.5 million units, by 2032. That market growth is in excess of 2500-fold, or 58 percent CAGR for the next 15 years. Fifteen years from now, the yearly revenue associated with the production of robotic vehicles will reach $300 billion; 52 percent of that figure will originate from the vehicles themselves, 26 percent will come from sensing hardware, 17 percent from computing hardware and the remaining 5 percent will be from integration. "Within 15 years complete industries will be structured around robotic vehicle technologies," asserts Pierre Cambou at Yole.

Looking closer to the present, in 2022, sensor revenues are expected to reach $1.6 billion for LiDAR, $44 million for radar, $0.6 billion for cameras, $0.9 billion for IMUs and $0.1 billion for GNSS. The split between the different sensor modalities may not stay the same for the 15 years to come, nevertheless the total for sensing hardware should reach $77 billion in 2032, while, for comparative purposes, computing should be in the range of $52 billion.

Today the car sales market accounts for $2.4 trillion per year and is the natural target of internet giants like Google, Baidu, Amazon and Uber. Such companies are mostly attracted by transportation as a service (TaaS) market. "TaaS should reach the same value of $2.4 trillion in 2032," according to Cambou. "With an additional $1.1 trillion to be generated by sales of personally owned autonomous driving (AD) vehicles, the added value of AD is expected to reach a total of $3.5 trillion." Due to the numbers at stake, the stealth players in everybody's minds are Apple and Samsung, the latter of which is not so stealthy, having bought Harman in 2017. As a consequence, their entry should take place at some point in time, with a possible "mobile to smartphone style" transformation of the industry.

Within the robotic vehicle technology space, high-end industrial sensors will play a key role. There are key differences between automotive advanced driver assisted systems (ADAS) technology and equipment that will fit into early robotic vehicles. ADAS must focus on reliability and cost issues serving a market with sales of millions of units, while the technologies to serve the robotic vehicle market will be mainly driven by performance and availability and will serve a market of only



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tens of thousands units by 2022. The orders of magnitude are in fact totally different between the two worlds. To generalize, high end industrial sensors will win in the early robotic vehicle sensor suite.

The consequences for existing players and technologies will be huge; some high-end markets such as LiDARs or industrial grade IMUs will more than double in the next few years. The impact will also be strongly felt by industrial camera makers. Technologies are expected to specialize by 2022 and possibly merge partially with ADAS by 2027. Technology-wise 2032 is expected to be another world, with a complete paradigm shift. The industry is facing deeply transformative changes powered in part by sensing technologies.

Massive MIMO Comes of Age in 2021 on the Back of 5G Rollout Momentum

Massive MIMO antennas stand ready to deliver on the promise of cost-effective delivery of capacity density in LTE networks now and set the stage for 5G networks to come. "The optimum massive MIMO system will balance deployment challenges with the promise of increased sector capacity, and improved radiated energy efficiency," says Nick Marshall, research director at ABI Research. "We believe that the radio propagation characteristics in the sub-6 GHz bands remain the most favorable for massive MIMO today for many scenarios and that future 5G mmWave massive MIMO systems will become essential for unprecedented levels of spectral efficiency and capacity density."

In 2017, Softbank (Japan), T-Mobile Netherland and Vodafone U.K. announced commercial deployments. Also, major operators globally have started massive MIMO trials or limited deployments in 2017 and are planning commercial deployments in 2018. Among these operators are Sprint, Deutsche Telekom, China Mobile, China Telecom, China Unicom, Singtel, T-Mobile Netherland, Vodafone Australia, Optus and Telefónica.

Growing from a small number today, massive MIMO penetration for both LTE-Advanced Pro and 5G will reach almost 5 percent of the worldwide MIMO antenna installed base by 2021. This is equivalent to nearly 500,000 installations, with the Asia Pacific being the largest region followed by Western Europe and North America.

The massive MIMO vendor ecosystem includes major multi-national radio and antenna vendors such as CommScope, Ericsson, Huawei, Kathrein, Nokia and ZTE. It also comprises innovative start-up companies such as Anokiwave, Blue Danube and Pivotal Commware.

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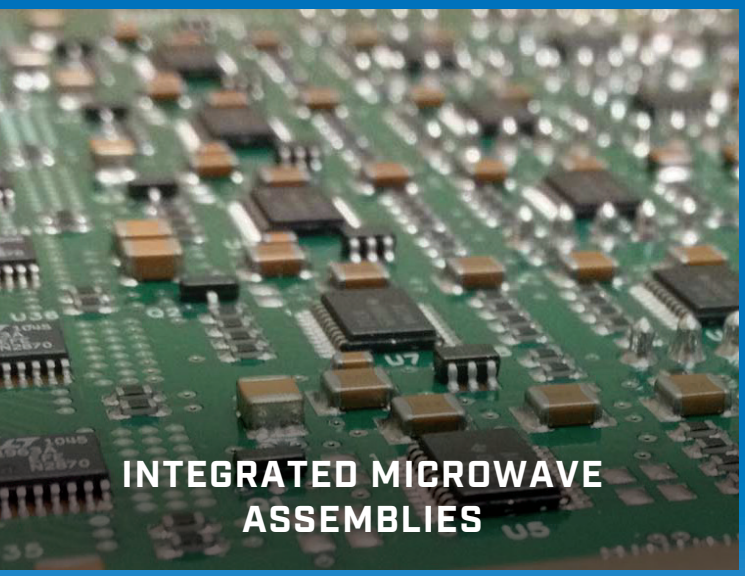
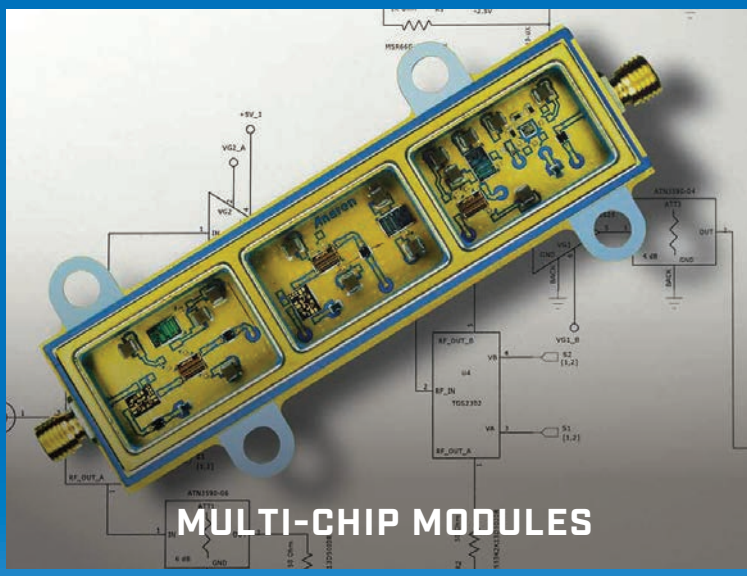


INTEGRATED MICROWAVE ASSEMBLIES



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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Cree Inc. has acquired assets of **Infineon Technologies AG RF Power Business** for approximately €345 million. The transaction expands the Cree Wolfspeed business unit's wireless market opportunity. Infineon continues to drive key growth areas such as electro-mobility, autonomous driving, renewables and technologies for a connected world. Infineon and Cree have a long-standing history of technology leadership, collaboration and shared business interests. The acquired Infineon RF Power team and capabilities will complement Wolfspeed's existing offerings and expertise with additional technology, design, packaging, manufacturing and customer support.

Microchip Technology Inc. and **Microsemi Corp.** announced that the two companies have signed a definitive agreement pursuant to which Microchip will acquire Microsemi for $68.78 per share in cash. The acquisition price represents a total equity value of about $8.35 billion, and a total enterprise value of about $10.15 billion, after accounting for Microsemi's cash and investments, net of debt, on its balance sheet at December 31, 2017. Following the closing, the transaction is expected to be immediately accretive to Microchip's non-GAAP earnings per share. Based on currently available information, Microchip anticipates achieving an estimated $300 million in synergies in the third year after close of transaction.

TMD Technologies Ltd. has announced the acquisition of **G2 Engineering Ltd.**, a small, specialist hi-tech microwave design and manufacturing company currently based in Greenford, West London. Established over 18 years ago, G2 Engineering is engaged in the design and manufacture of a range of radar transponders and support equipment for applications that include UAVs, missiles and manned aircraft. Prominent existing customers of G2 Engineering include MBDA and QinetiQ.

COLLABORATIONS

HUBER+SUHNER signed a strategic cooperation and board-to-board connectivity collaboration agreement with **Huada Technology Co. Ltd**. Thilo Koeppe, managing director of HUBER+SUHNER NAS; Sales Director James Huang; Sun Weilong, general manager of Xijing company; Wang Zhiyin, chairman of Huada, as well as General Manager Fan Junwei all attended the signing ceremony at the Huada premises in X'ian. As the world's leading RF interconnect product manufacturer, HUBER+SUHNER has a strong technical and product knowledge in coaxial connectors, RF and microwave cables, E-/V-Band antennas, RF microwave devices etc., while Huada is a core national enterprise for the development and production of RF coaxial connectors and the formulation of national standards.

Rohde & Schwarz and **CommSolid** have successfully completed the verification of 3GPP Release 14 location services (LCS), which is one of the new positioning technologies for Narrowband-IoT (NB-IoT). The Cat-NB2 verification was performed with CommSolid's NB-IoT modem solution against the R&S CMW500 mobile communication tester. The R&S Location Based Services (LBS) solution based on R&S CMWcards GUI, a subset of TS-LBS, allows the verification of chipsets and mobile devices for mobile manufacturers, chipset manufacturers, test houses and network operators with the target to get permission to operate them in a particular network.

Anritsu Corp. announces its new 5G test platform to help support test development for **Qualcomm Technologies Inc.**, a subsidiary of Qualcomm Inc., on 5G chipsets. Anritsu is working with Qualcomm to support test development for devices such as baseband chips. Anritsu's test platform for 5G, the next generation communication system beyond 4G LTE, is designed to support Qualcomm in its effort to commercialize next generation 5G NR technologies. By offering measurement solutions supporting early deployment of 5G services, Anritsu will play a key role in the transition from 4G LTE to 5G systems.

Antenna Systems Solutions S.L. (Celestia Technologies Group) announced it has been selected to supply a new customer, **Tübitak BILGEM**, Turkey, with a near field measurement system as part of the ATAM Project. The range will allow the customer to perform planar and cylindrical measurements on a scanner measuring 9 m x 9 m. ASYSOL will be working in consortium with partners Emerson & Cumming Anechoic Chambers (E&C) and Albatross Projects. E&C will supply the anechoic materials and Albatross Projects the RF shielding for the structure.

Gryphon Sensors announced a partnership with **WhiteFox Defense Technologies**, a proven drone analytics and mitigation provider. Under this partnership, Gryphon Sensors is integrating WhiteFox's non-jamming, non-kinetic mitigation and analysis capabilities with its Skylight system. The resulting RF-based sensor-driven system provides an industry leading unclassified and exportable counter-UAS system. Gryphon Sensors' Skylight employs a suite of radar and multispectral sensors that provide a comprehensive, real-time, 3D, low-altitude airspace picture, with superior accuracy and long-range detection performance on small UAS.

Nokia and **Telefónica Germany** have signed a Memorandum of Understanding (MoU) for the development of a joint 5G Innovation Cluster. They will test network solutions and technologies on the path to 5G in Telefónica's lab in Munich, Germany. This will be followed by trials in the operator's live network, currently planned with priority in Berlin with the objective of building a benchmark network with 4.5G, 4.9G and 5G technol-

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Fixed	10	1000	-110	LNFT-10-1000-15

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ogy, providing the best user experience to Telefónica's customers. Nokia's 4.5G, 4.9G technologies deliver advances such as increased speed, capacity and improved latency, providing a clear path to 5G.

Airgain Inc. and the **McLaren Technology Group** have signed a multi-year partnership that will build on the reputation of both companies in leading-edge, high performance technologies. Airgain has a crucial role to play in the connected vehicle market by providing antenna technology to support advanced wireless connectivity solutions for in-vehicle, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications. It has a portfolio of connectivity solutions and a wealth of experience in developing antenna applications for government, public safety and enterprise applications. Airgain's partnership with McLaren extends to the broader business, including McLaren Applied Technologies, as the two organizations explore the co-creation of wireless connectivity solutions.

CEVA has announced that it is supporting **Nokia** in the development of its ReefShark baseband system-on-chips (SoC), set to be deployed for 4.9G and 5G wireless infrastructure applications. Under the agreement, CEVA has adapted its widely-deployed CEVA-XC architecture framework to address the massive increase in signal processing complexity in multi-RAT (Radio Access Technology) network architectures. Nokia ReefShark is based on the 3GPP 5G NR specifications, which help offset deployment costs and TCO, while fulfilling architecture-driven network requirements. ReefShark reduces the size, cost and energy consumption at each cell site, while simultaneously boosting the intelligence and performance of massive MIMO antennas.

NEW STARTS

Ericsson announced plans to create a series of new innovation hubs serving Middle East and Africa markets following the same global concept of Ericsson Garage. This is an open innovation platform, inspired by lean startup methodology. Ericsson Garage in Kista, Sweden is where it all started, however ground-breaking ideas need a space to flourish in every corner of the planet to benefit humanity as a whole, that is why Ericsson started opening several affiliates across the globe in different locations including Budapest, Aachen, Paris, Silicon Valley, Gothenburg, Croatia, Montreal, Ottawa, Lund, Linkoping, Poland and Beijing. In order to continue the global expansion plans, new Ericsson Garage sites will be created in the Middle East and Africa.

AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO and **Orange** have jointly announced the creation of the Open Radio Access Network (ORAN) Alliance. This is a worldwide, carrier-led effort to drive new levels of openness in the radio access network of next generation wireless systems. ORAN will combine and extend the efforts of the C-RAN Alliance and the xRAN Forum into a single operator led effort. As mobile traffic increases, mobile networks and the equipment that runs them must become more energy efficient (green), software-driven (soft), virtualized, flexible and intelligent. The ORAN Alliance is committed to evolving radio access networks—making them more open and smarter than previous generations.

Michael Maslana, CEO, announced the launch of **RFE**. RFE is the current generation of its founding company Spinnaker Microwave. Dating back to 1991, its reputation was earned in the design and manufacture of a broad and diverse offering of voltage-controlled oscillators (VCO), which it continues to support to this day. Joining Maslana to lead RFE is industry veteran Mike England as president and CTO.

ACHIEVEMENTS

The **Northrop Grumman Corp.** AN/TPS-80 Ground/Air Task-Oriented Radar has been approved for early fielding by the U.S. Marine Corps. This milestone follows the delivery of the final Lot 1 and Lot 2 Low Rate Initial Production (LRIP) G/ATOR system to the Marines. The Marines will field their first two systems by delivering them to Marine Air Control Squadrons 1 and 2 for operational use. Early fielding, also known as Initial Operational Capability (IOC), is a significant milestone that indicates that a system is ready for operational deployment.

Exceed Microwave announced that it has passed the Rev D upgrade audit for AS9100. Exceed Microwave, based in Torrance Calif., is an ITAR Registered, custom, high performance passive microwave component design company, focusing on designs up to 67 GHz for commercial, defense and space applications.

Fractal Antenna Systems has been awarded a patent for its flat lens technology. The new lens technology is a spinoff application of the firm's invisibility cloak research from over a decade ago. They demonstrated cloaking at numerous technical conferences, and, in 2012, with microwaves, cloaked a person—the realization of the mythical invisible man. In the flat lens technology, fractal metamaterials are configured as magnifiers and wave guides, producing super-thin flat lenses, bendable conformal lenses and even edge-oriented lenses, with broad bandwidths. Conventional optics uses shaped, rigid, thick media, such as glass, with much larger form factors and weight.

Harris C4i Pty. Ltd., an Australia-based operation of Harris Corp., has been recognized among the most successful and innovative export operations in the State of Victoria. The business received the prestigious Victorian Export Award for Innovation Excellence during the 2017 Governor of Victoria Export Awards (GOVEA) held in Melbourne and hosted by the Honourable Linda Dessau AC, Governor of Victoria. Harris C4i is a global leader in IP and data distribution service-based secure voice communications for mission-critical envi-

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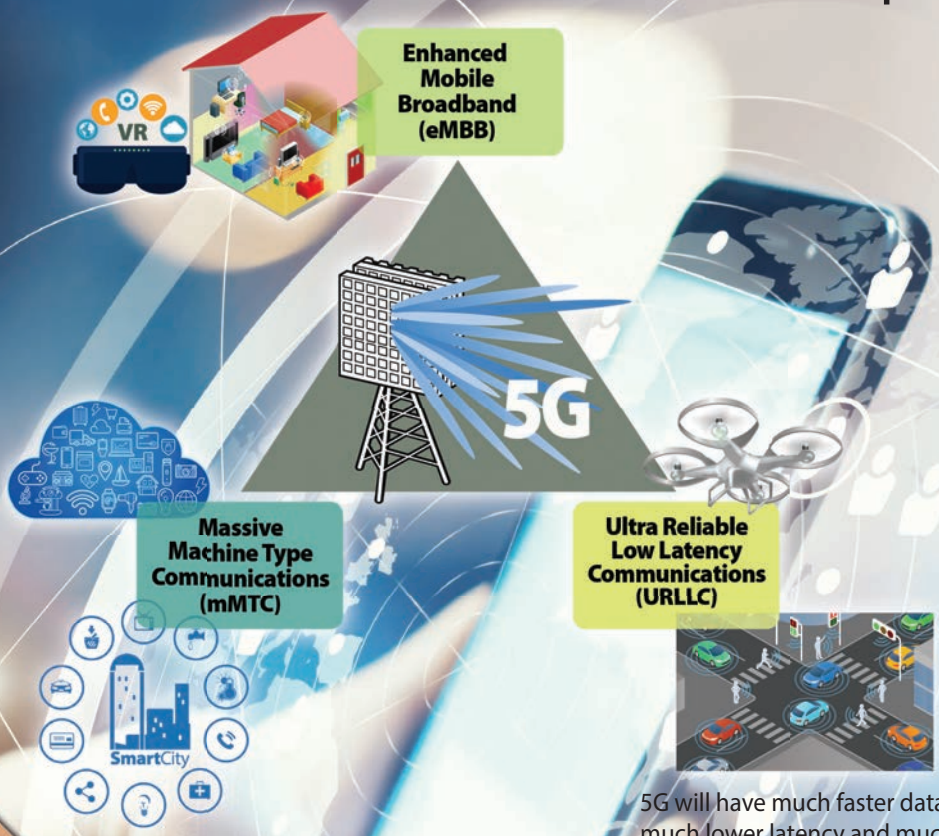

Rogers Materials for Circuits from 600 MHz up to mmWave

Material	Dk	Df	Features
AMPLIFIERS /MICROWAVE RADIOS			
RO4350B™	3.48	0.0037	Processes Like FR-4. Integrated Thin-film Resistors
RO4835™ LoPro®	3.48	0.0037	High Oxidation Resistance
RO4360G2™	6.15	0.0038	Enables Circuit Size Reduction
RO3003™	3.00	0.0010	Lowest Loss
CLTE-MW™	3.05	0.0015	Low Loss, Thin
TC350™	3.50	0.0020	High Thermal Conductivity For High Power Handling
ANTENNAS			
AD255C™	2.55	0.0014	Low PIM, Cost Effective Solution
AD300C™	2.97	0.0020	Low PIM, Cost Effective Solution
RO4730G3™	3.00	0.0029	Low PIM
RO4533™	3.30	0.0025	High Thermal Conductivity For High Power Handling

Notes: Dk and Df are both measured at 10 GHz.

Circuit materials for the next generation of wireless communications

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

For circuits from 600 MHz up to mmWave

Rogers has you covered with circuit materials for next-generation 5G components, including massive MIMO antennas and GaN-based high-power-density amplifiers. Wireless network circuit designers have trusted in Rogers' high-performance circuit materials for nearly 30 years, since the earliest 1G analog systems to present-day 4G LTE-A systems.

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ronments. The organization's interoperable communications solutions are used in more than 35 countries by a wide range of industries—including aviation, defence, public safety, utilities and transport.

Akash Systems, a company focused on resolving the explosive growth of data consumption by enabling smarter and lighter satellite systems has raised $3.1 million to close its seed funding round. Led by Khosla Ventures, the seed round also included Social Capital, Data Collective, Ruvento Ventures, Sriram Krishnan and Backstage Capital. The funding will allow Akash to further its mission of reimagining tomorrow's communication systems by developing the next generation of small satellites and the components that power them. Today's worldwide data demand is outpacing the bandwidth and power capabilities of our current communication infrastructure.

CONTRACTS

With the growing threat of weapons of mass destruction, it has never been more important for the U.S. military to possess sufficient means to prevent and respond to this threat. The mission of the Joint Program Executive Office for Chemical Biological Defense (JPEO CBD) is to protect the nation's armed forces from weapons of mass destruction by equipping them with the latest chemical, biological, radiological and nuclear and high-yield explosives (CBRNE) defense equipment and capabilities. To support this mission, the **Department of Defense (DoD)** has awarded **Booz Allen Hamilton** a spot on the $8.27 billion Joint Enterprise Research Development, Acquisition and Procurement (JE RDAP) IDIQ contract to strengthen the nation's CBRNE defense systems and capabilities.

The **U.S. Navy** proposed spending $299 million in fiscal year 2019 on laser systems to protect ships against current and anticipated future threats, as part of a rapid prototyping, experimentation and demonstration initiative, USNI News reports. For nearly a decade, the Navy has considered laser weapons technology a more cost-efficient and effective tool to protect ships from emerging threats such as unmanned aerial vehicles (UAV) and small patrol craft that could swarm a surface ship, according to a Congressional Research Service report, "Navy Lasers, Railgun and Hypervelocity Projectile: Background and Issues for Congress." The Navy wants to move development of lasers a step closer to deployment, according to budget documents released by the Navy earlier this month.

Comtech Telecommunications Corp. announced that during its second quarter of fiscal 2018, its Command & Control Technologies group, which is part of Comtech's Government Solutions segment, has received a three year contract award valued at approximately $123.6 million to provide ongoing sustainment services for the AN/TSC-198A SNAP (Secret Internet Protocol Router (SIPR) and Non-classified Internet Protocol Router (NIPR) Access Point), Very Small Aperture Terminals (VSAT). SNAP terminals provide quick and mobile satellite communications capability to personnel in the field

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The front touch panel allows complete control of all the amplifier functions.

Options shown: Power Monitor and Gain Control

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The remote option of the M-Series is controlled via an Ethernet connection. The remote display, via a laptop, allows the same power and functionality as the local screen.

A front touch panel allows complete control of all amplifier functions. Like all Elite RF amplifiers, the M-Series also comes with a **5-year warranty** and is proudly made in the USA.

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Model	Frequency (MHz)	Power (Watts)
M.502.5G4450AC	500 - 2500	25
M.801.0G4745AC	800 - 1000	50
M.502.5G5050AC	500 - 2500	100
M.011.0G5050AC	*10 - 600	1,000
M.02.50G6050AC	*20 - 500	10,000
M.026.0G4045AC	20 - 6000	10
M6.0012G4045AC	6000 - 12000	10

*Band specific models
Many standard models available in stock, visit our website for details.
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Around the **Circuit**

and Comtech will be the sole provider of these sustainment services.

Raytheon Co. has been awarded a $73 million FAA contract modification to perform Technical Refresh 1 of the Standard Terminal Automation Replacement System (STARS). This update will enable future Terminal NextGen air traffic control tools to be incorporated into STARS and further enhance the safety and efficiency of the National Airspace System. STARS is the automated air traffic control system operated by both the FAA and DoD to manage airspace in both large, complex terminal areas, such as New York, and in small, but security-sensitive airspace. STARS simplifies the implementation of next-gen enhancements that will improve air traffic flow and separation in the NAS.

The **U.S. Army** has awarded **Ceradyne Inc.**, a 3M company, an additional $34 million to continue supplying its ballistic helmet of the future. The Integrated Head Protection System (IHPS)—which *Popular Mechanics* described as "straight out of science fiction"—uses advanced materials, an ultramodern design and add-on accessories to give soldiers greater comfort and advanced protection for modern missions. This brings Ceradyne's total IHPS contract value to more than $52 million. The U.S. Army created the highly technical IHPS to give soldiers a lighter-weight ballistic helmet with passive hearing protection and increased blunt-impact performance.

U.S. military researchers are turning to sensor data analysts at **Two Six Labs LLC** in Arlington, Va., to capitalize on IoT technology to help prevent terrorists from placing and detonating atomic bombs in or around the nation's large metropolitan areas. Officials of the **U.S. Defense Advanced Research Projects Agency (DARPA)** in Arlington, Va., announced a $13.2 million contract to Two Six Labs for the SIGMA project. The company will help DARPA apply IoT technologies to potential networks of thousands of low-cost radiation sensors linked throughout U.S. cities by Wi-Fi and cellular phone systems to a cloud-based network backbone.

PAR Technology Corp. announces that its subsidiary, **PAR Government Systems Corp.**, was awarded a $4.5 million research and development contract from the **U.S. Air Force** called "Synchronized Command and Control Multi-Domain Test and Integration (SC2MDTI)." SC2MDTI is a three-year program with the Air Force Research Laboratory (AFRL) Information Directorate, under which, PAR Government will perform research and development of state-of-the-art solutions for Command, Control, Communications and Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) systems across the cyber, air and space domains. PAR will integrate and experiment with next generation computing and network architectures.

Mercury Systems Inc. announced it received a $3.8 million follow-on order from a leading defense prime contractor for state-of-the-art RF subsystems that are integrated into an advanced airborne electronic war-

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fare (EW) system. The orders were booked in the company's fiscal 2018 second quarter and are expected to be shipped over the next several quarters. Mercury's comprehensive portfolio of commercial RF and microwave solutions include high performance components, integrated multi-function modules and pre-integrated subsystems ruggedized for the harsh operating environments typically encountered by military forces.

PEOPLE

▲ *Kevin McCormack*

RFMW Ltd. announced that **Kevin McCormack** has joined their organization as the RF/Microwave & Coaxial Component Business Unit Manager. McCormack has served in senior level positions in product and sales with over 35 years' experience in the RF/microwave industry. His experience includes holding roles such as vice president of RF Interconnect and RF Passive Products and vice president sales within RF/microwave distribution companies. Most recently, McCormack was with BJG Electronics Inc. as general manager of their RF/microwave division. McCormack brings his technical and managerial skills to his new position where he is tasked with growing RFMW's worldwide RF Interconnect and Coaxial Component Business Unit.

REP APPOINTMENTS

Modelithics Inc. and **GBIT** announced a new partnership to establish GBIT Testing Technology Co. in Shenzhen, China as the regional sales representative for Modelithics' high frequency simulation model libraries and precision RF, microwave and mmWave measurement services. GBIT is a leader in the field of semiconductor and microwave testing in China, providing representation for multiple major companies in the RF and microwave industry and supporting customers from Chinese businesses, research institutes, universities and factories. The Modelithics COMPLETE Library of exceptional RF and microwave simulation models, including advanced scalable Microwave Global Models™, currently represents over 15,000 commercially available electronic components from over 65 popular vendors.

Richardson RFPD announced that it has entered an agreement with **Wall Industries Inc.** to distribute Wall Industries' full line of DC/DC converters, AC/DC power supplies and custom solutions to customers worldwide. Wall Industries has designed and manufactured power products since 1961. Its DC/DC power converters range from 0.5 to 1008 W and include encapsulated, PC board mount, surface mount, chassis mount, air-ventilated enclosed and open frame types. Its line of AC/DC power supplies are available from 1 to 3006 W and includes open frame, air-ventilated enclosed, U-chassis, encapsulated, DIN rail, enclosed with fan, wall mount and desktop types.

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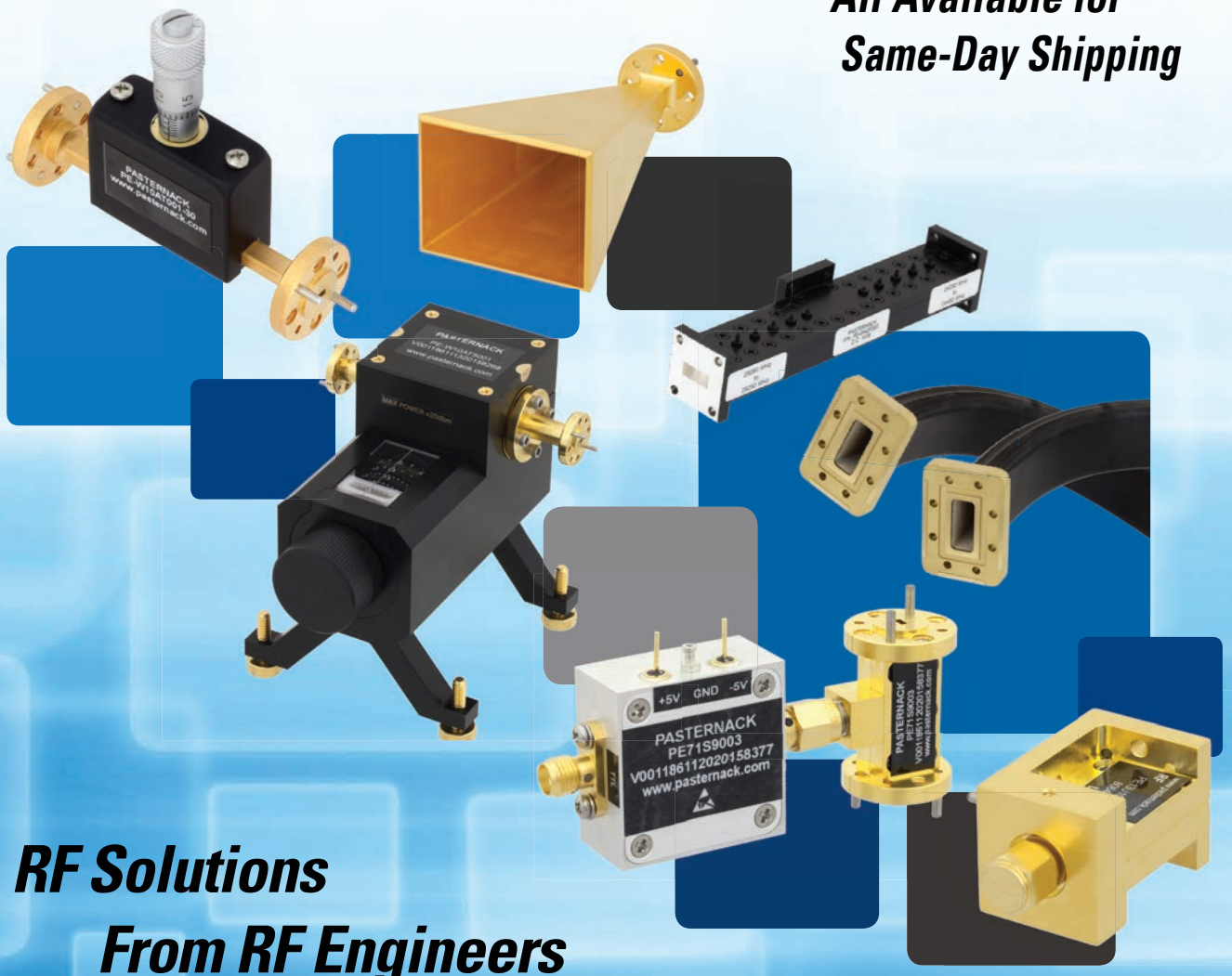

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INVITED PAPER

Ultra-Low Phase Noise Oscillators with Attosecond Jitter

Andreas Gronefeld
Ingenieurbüro Gronefeld, Germany

*Two designs of ultra-low noise dielectric-resonator oscillators (DRO) for 2.856 GHz[1] and 3.9 GHz[2] with sub-femtosecond jitter (shown in **Figure 1**) are reviewed. This work was motivated by contracts with research institutions Deutsches Elektronen-Synchrotron,[3] Hamburg, Germany and Pohang Accelerator Laboratories,[4] Pohang, Korea that require this level of performance for optimum operation of their X-ray Free Electron Laser (X-FEL) installations. However, other applications like the microwave synthesizers found in Caesium-Fountain atomic clocks or high performance radars also may benefit from ultra-low noise signal sources of this kind. And the design methodology presented can, in principle, be transferred to any frequency in the 1 to 20 GHz range.*

X-FELs are still a rare breed of research facilities, with just four installations worldwide that are capable of generating extremely intense (GWatts), ultra-short (20 to 50 fs) flashes of coherent radiation, reaching down to and below 0.1 nm wavelength (see ***Figure 2***). These short-wavelength ("hard") X-rays are in high demand by researchers for imagery at the molecular, atomic and even subatomic level.[5-6] Even more unique, the ultra-short flashes allow sampling of the dynamics of atomic bonds or chemical reactions to generate video-like sequences of those picosecond processes[7-8] at the atomic level.

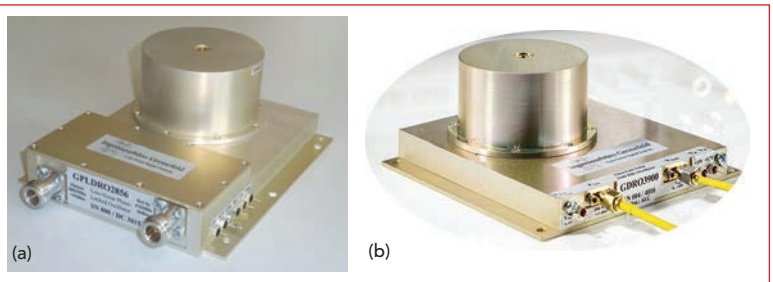

Fig. 1 2.856 GHz PL-DRO (a) and 3.9 GHz DRO (b).

X-FELs work by accelerating bunches of electrons to extremely high energies (10 to 20 GeV) and converting a small amount to coherent X-rays of a very narrow spectral range. The "lasing" action takes place in a long chain (> 100 m) of alternating polarity magnets, called "undulators,"[9] and requires the accelerated electrons to have a very small energy spread (see ***Figure 3***).

The acceleration process makes use of a microwave signal (mostly 2.856 or 1.3/3.9 GHz), distributed throughout the installation and amplified in many substations to tens of megawatts of pulse power. Each high-power amplifier drives a group of cavity resonators, (forming a long chain of up to 1700 m), with their extremely large electromagnetic fields propelling the electrons forward. For optimum energy transfer, the phase relationship of the microwave signal must be precisely matched to the locus of the electron bunch. Phase stability to 0.01° (10 fs at 3 GHz) is needed for optimum acceleration with minimal energy spread and the ability to compress the electron bunch down to femtosecond duration and maintain it.

The targeted phase stability requires extremely stable signal sources, containing jit-

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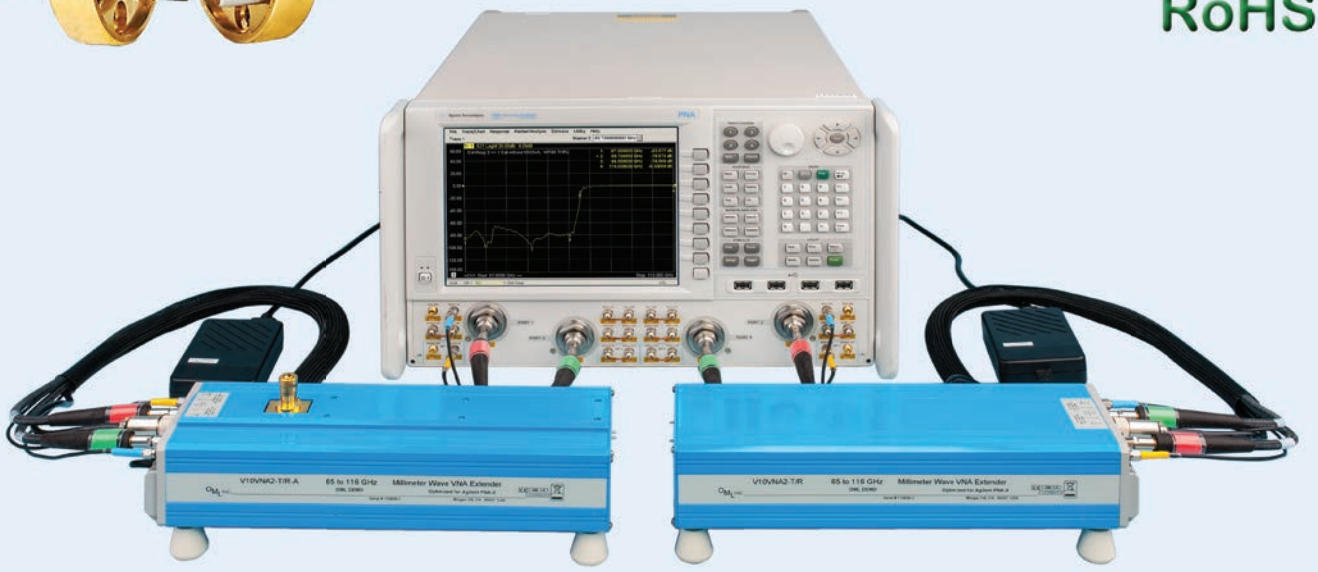
50 GHz to 500 GHz

RoHS



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- Unmatched 25 dB manual power control with optional attenuator
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- Premium accessories: waveguide calibration kits, sections and S-bends
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Fig. 2 **Aerial view of the PAL X-FEL at Pohang, Korea (courtesy PAL[4]).**

ter ideally to just a few femtoseconds. But how does this relate to phase noise, the quantity usually used to describe the short term stability of a signal source?

JITTER VERSUS PHASE NOISE

While the phase noise spectral density function $L(f_m)$ completely describes the short term stability of a signal source, phase jitter, the measure of the output waveform zero-crossing's time deviation, is computed by integrating $L(f_m)$ over a certain offset frequency range, implying that jitter numbers must always be accompanied by that integration range and can only be compared when the integration ranges match.

$$J = \frac{1}{2\pi f_0}\sqrt{2\int_{f_1}^{f_2} L(f_m)\,df} \qquad (1)$$

Computing jitter with Equation 1 neglects all contributions of the phase noise spectrum below f_1 and above f_2 and is well justified, if f_1 and f_2 are chosen in a meaningful way for a given system. Typically a system has a "maximum observation time," defining f_1 (slower phase changes do not alter the system's output) and a "maximum processing bandwidth," that sets f_2 (faster phase changes are not processed by the system).

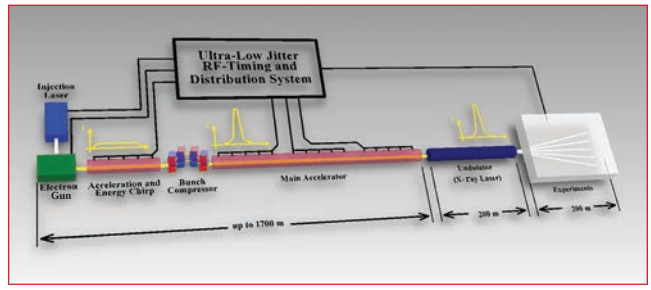

Fig. 3 **Simplified X-FEL block diagram.**

In FELs, the processing bandwidth ranges from 10 to 30 MHz, with 100 MHz on the horizon, giving a first hint at what to look for in designing a low jitter signal source, as the higher f_2, the more important a low oscillator noise floor becomes.

With the lower bound f_1 typically specified as 1 Hz, to ensure pulse to pulse stability and keep low frequency noise from interfering with drift countering measures, signal sources for FELs are always a combination of a microwave oscillator that defines phase noise from 1 to 10 kHz to f_2, phase locked to quartz crystal oscillators, determining phase noise from 1 Hz to 1 to 10 kHz. For the oscillators discussed here, jitter numbers integrating phase noise over 1 kHz to 30 MHz or 10 kHz to 30 MHz are relevant.

ULTRA-LOW PHASE NOISE OSCILLATOR DESIGN

There are only a few elements needed to build an oscillator: a (lossy) resonator to set the frequency, an amplifier to compensate the resonator's losses and both arranged in a feed back loop.

Oscillator Topologies

The first decision in designing an oscillator involves how the amplifier and resonator are coupled in a feedback arrangement. Most oscillators use the "reflection"

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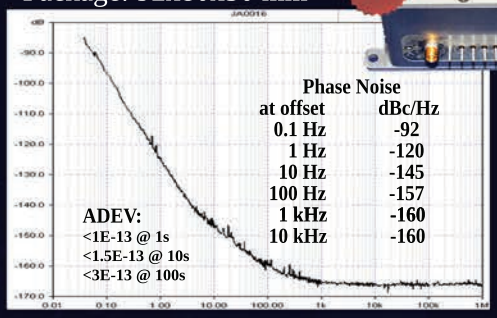

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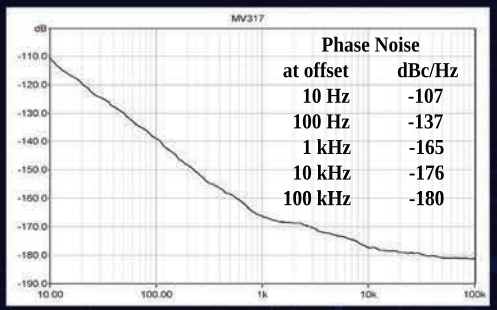
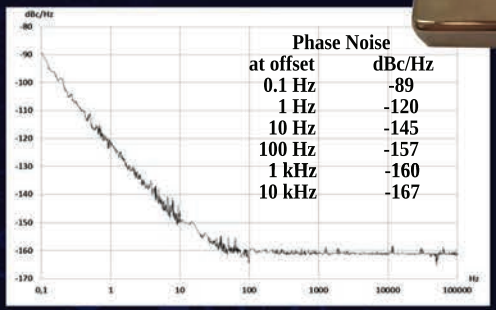
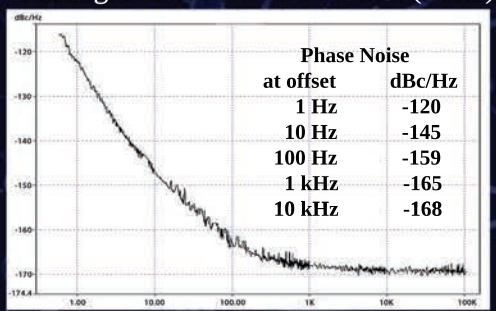
- Aging: ±1E-7 per year
- Package: 25.8x25.8x10.3 mm



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



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



MV333M 10 MHz
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- Allan Deviation: <5E-13 per sec.
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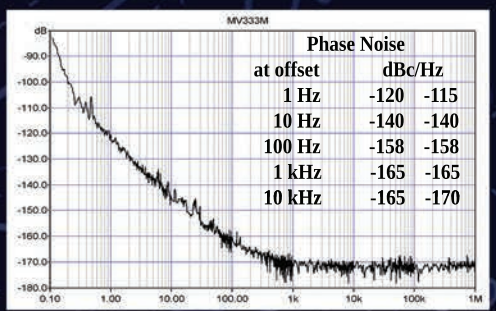

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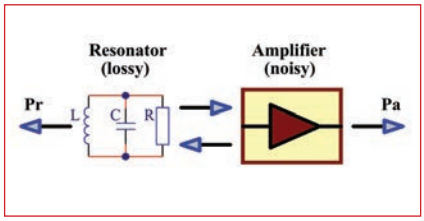

Fig. 4 Reflection oscillator topology.

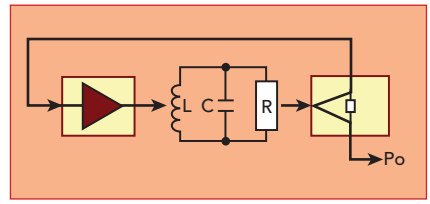

Fig. 6 Optimum transmission oscillator topology.

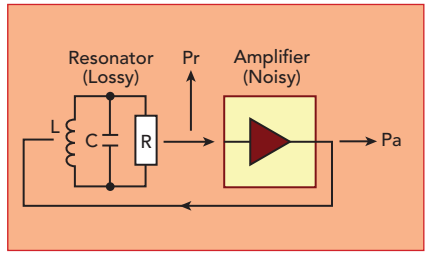

Fig. 5 Transmission oscillator topology.

type topology shown in ***Figure 4*** (negative resistance oscillator[10]). Note the possibility of either taking the oscillator's output power (Po) from the amplifier (Pa) or coupling to the resonator (Pr). This topology, albeit simple, has the drawback that a number of important parameters like resonator loading, output power and amplifier compression are tightly coupled and hard to control separately.

For narrowband sources, the topology of a transmission type oscillator, shown in ***Figure 5***, gives much better control of the critical parameters, is widely used[11-13] and chosen here. Again, the designer has the choice to take the output power from the amplifier (Pa), maximizing Po, or from the resonator (Pr). The latter reuses this element as a filter to suppress the amplifier's broadband noise outside the resonator's passband,[12,14] outweighing the loss of signal power that is easily compensated by a following buffer amplifier. Using this topology (see ***Figure 6***) is key to achieving low noise floors of -180 dBc/Hz (see trace 6 in ***Figure 7***).

Oscillator Optimization for Low Noise

For determining what measures need to be taken to arrive at a low

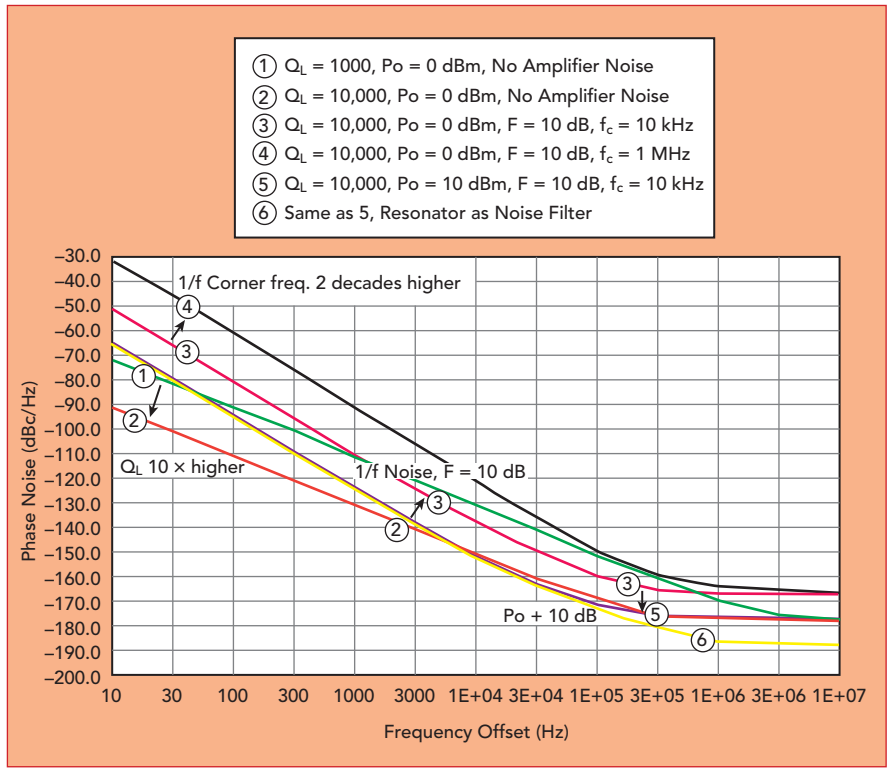

Fig. 7 Oscillator phase noise from Equation 2 with varying parameters.

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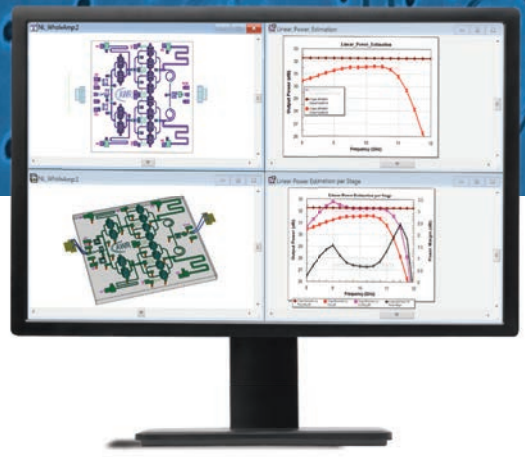

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noise, low jitter oscillator, the old phase noise model of Leeson[15] is still helpful:

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

It relates the single sideband (SSB) phase noise L (in dBc/Hz) as a function of the offset frequency f_m around centre frequency f_0 to four important parameters. To minimize noise, this model dictates:

- Maximize S/N in the loop, by maximizing signal power P_S with respect to noise power FkT (F: noise factor).
- Maximize the loaded Q $Q_L = f_0/BW_{3dB}$ of the resonator.
- Minimize the amplifier's flicker corner frequency f_c.

Figure 7 shows a number of simulated phase noise diagrams and the influence of those four parameters. Obviously, optimizing Q_L is of most efficiency, as it enters Equation 2 squared. Less obvious, the highly device technology dependent f_c can have a huge impact, as it is not unusual to find GaAs devices to have 100x higher 1/f-noise corner frequencies than their silicon counterparts.

Resonator Q, Unloaded/Loaded

For single-frequency oscillators, dielectric resonators placed inside a metallic cavity offer the highest Q and for the frequencies discussed here, resonators with unloaded Q (Q_U) of 30,000 at 2.856 GHz and 25,000 at 3.9 GHz were obtained.

Coupling to the resonator (loading it) reduces Q_U to Q_L and Parker[16] established that optimum coupling should occur at S_{21} = -6 dB, where Q_L =1/2 Q_U. This coupling factor, leading to Q_L of 15,000, was used for the 2.856 GHz design. For 3.9 GHz, the reasoning[16] was questioned, as 2 dB better phase noise can be achieved by looser coupling with a resonator insertion loss of 9 dB. The necessary increase in amplification and output power by 3 dB also increases the amplifiers output noise power by 3 dB, but that increase gets suppressed by the resonator's filtering action. With the above choice, the 3.9 GHz-design was also realized with a Q_L of 15,000, despite the lower Q_U.

Amplifier Optimization

The most crucial design decision in the amplifier electronics involves selection of the active device. Here, bipolar silicon transistors are preferred to ensure low f_c. Also, designing for high output power pays off, as it lowers the noise floor. Finally, as with all oscillator designs, the device's transition frequency should be as low as practically possible for building an amplifier with acceptable gain.

That gain has to be some dB above the losses in the loop to accommodate variations over temperature and account for the resonator's amplitude response over the tuning range. Of course, the occurring gain compression must not lead to instabilities of the amplifier. Low noise device biasing was added to the amplifier design in a two tier regulation scheme that virtually eliminates frequency pushing.

Add-Ons

No oscillator is complete without a buffer amplifier that isolates the oscillator sufficiently from the load. For both designs, double stage buffers were built, reducing pulling to < 1 ppm with a fully reflecting load over all angles, while keeping the noise floor at -180 dBc/Hz. Also an ALC was added to stabilize output power to < 0.1 dB, helping reduce phase drifts, due to (tuning induced)

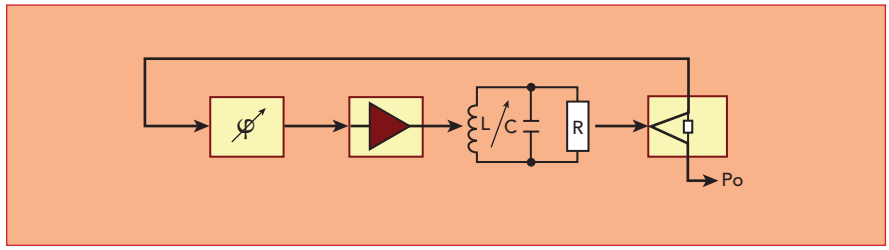

Fig. 8 Frequency tuning the transmission oscillator.

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Temperature Stability

Frequency tuning of a DRO can be done by either tuning the resonator or varying the phase in the loop (see ***Figure 8***). Most high performance DROs[10-13] and the designs presented here provide a coarse mechanical tuning of the resonator (some MHz) and use a phase-shifter (PS) for electronic tuning. Electronic tuning of the resonator, though possible,[17] risks degradation of Q as it involves coupling to varactor diodes that have much higher losses.

The available frequency shift from an in-loop PS, however, is confined to a portion of the resonator bandwidth (-2 dB points in this case). With a Q_L of 15,000, the tuning range amounts to ±25 ppm. This poses a problem, when the temperature coefficient (TC) of the resonator assembly becomes too high with respect to the targeted temperature range. On top, metallic enclosure (cavity) and dielectric resonator (puck) have different TCs with, even worse, different time responses.[12,18]

With the aluminium cavity at -1 ppm/K and the 2.856 GHz resonators at +1.5 ppm/K, both TCs cancel well enough, such that this DRO design has no problem to safely operate over a 0°C to 50°C temperature range, more than adequate for the highly temperature controlled accelerator environments.

The -3 ppm/K TC of the 3.9 GHz resonators, however, adds to the cavity's TC and allows for just ±6°C of temperature variation that can be compensated with the electronic tuning. As this was felt to be insufficient, a mild sort of oven was incorporated, keeping the assembly at +35°C for long time reliable operation.

As the problem of temperature drift mounts with rising Q_L, it will be even more pronounced at lower frequencies (e.g. 1.3 GHz), where Q_L may increase to 30,000 or more, leaving ±12 ppm or less to be electronically compensated. Meeting this challenge either requires further oven control and thermal insulation or alternative means of electronically tuning the resonator.

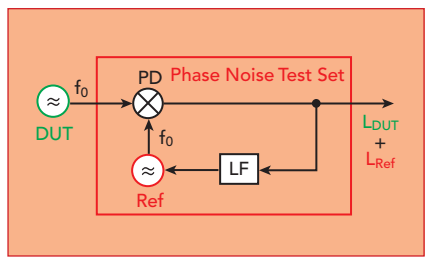

Fig. 9 **Typical phase noise test setup.**

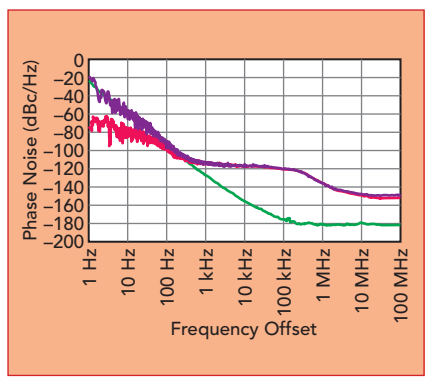

Fig. 10 **Phase noise measurement of 3.9 GHz DRO with noisy reference.**

Phase Noise Measurement Techniques and Challenges

Measurement of phase noise is a time measurement and as such carried out by comparing two clocks. In addition to the oscillator, or device, under test (DUT), a second oscillator (reference clock) of the same frequency is needed and the time (phase) difference between both oscillators is recorded using a phase detector (PD) (see ***Figure 9***).

However, the PD's output is a measure of the sum of the DUT's and the reference's noise power. As long as the reference clock is known to have, say, > 10 dB lower noise than the DUT, the measurement yields a correct result within ±1 dB.

Commercial phase noise test sets[19-23] that cover wide frequency ranges, however, incorporate microwave synthesizers as reference clocks. With the phase noise of those synthesizers being decades higher than the phase noise of the oscillators presented here, simple phase detection will not produce the phase noise of the DUT, but rather that of the measurement device's synthesizer. ***Figure 10*** shows such a measurement (purple trace) that for f_m > 300 Hz reproduces the noise of the reference (red trace), whereas the true result of the 3.9 GHz DRO is actually the green trace.

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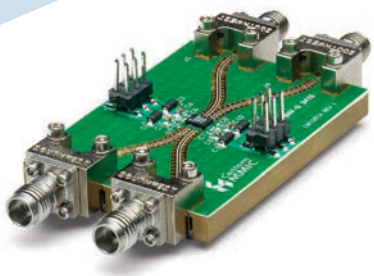

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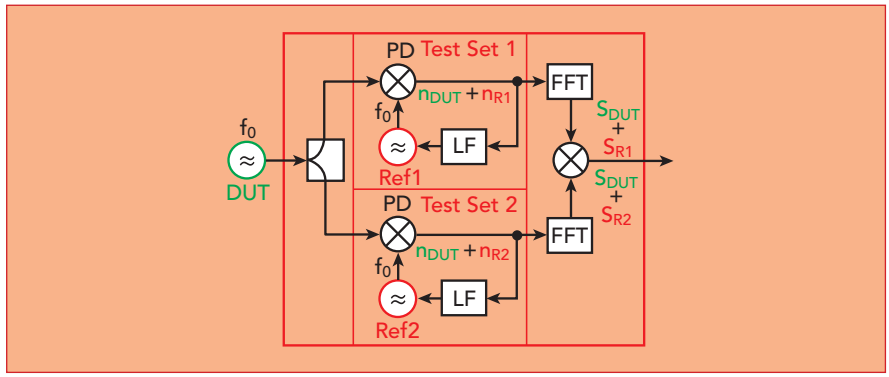

Fig. 11 **Cross-correlation test setup.**

Phase Noise Measurement Using Cross Correlation

A clever way out of this dilemma, enabling phase noise test sets to measure sources with far less noise than their reference has, is the use of a second identical test set, with a second independent reference clock. By letting both test sets measure the DUT simultaneously and combining their outputs by a cross-correlator, it is possible to bring down the noise of the test sets considerably (see ***Figure 11***).

In fact, this cross-correlation technique, that most commercially available phase noise test sets today offer, theoretically, leads to a noise-free test set. The scheme works by transforming the output of the two PDs into the spectral domain (FFT), multiplying them and storing the result. The process is repeated (theoretically forever!) and all stored results are averaged. Mathematically this is represented by:

$$\overline{(S_{DUT}+S_{R1})(S_{DUT}+S_{R2})} = \overline{(S_{DUT})^2} + \overline{S_{DUT}S_{R1}} + \overline{S_{DUT}S_{R2}} + \overline{S_{R1}S_{R2}} \quad (3)$$

It is important to note that the first term of the right hand side is the phase noise spectral density of the DUT, L_{DUT}. The remaining three terms on the right hand side are called cross-spectral densities, relating two different noise processes and whenever two noise processes are uncorrelated, these quantities are known to be zero.

$$\overline{(S_{DUT}+S_{R1})(S_{DUT}+S_{R2})} = L_{DUT} \quad (4)$$

So in order to build a noise-free phase noise test set, the noise sources n_{R1} and n_{R2} in the two test sets must be uncorrelated and the measurement must be carried out forever (ideal averaging requires infinite summations). While the first requirement can be sufficiently fulfilled by sound engineering, the latter requirement is disillusioning, as it ruins the perspective of a noise-free test set in practice.

Yet, the technique is very powerful, as it reduces the test set noise by:

$$5\log_{10}(N) \quad [\text{dB}] \quad (5)$$

with N the number of cross spectra averaged. So for every 10-fold lengthening of measurement time, 5 dB noise reduction is gained.

It must be stressed that measurement sensitivity with the cross-correlation technique is solely dependent upon measurement time. Most commercial instruments[19-23] allow the user to input the number of cross spectra to be averaged as the lever to set sensitivity and measurement time. Less obvious, lowering the start frequency by a decade also lengthens measurement time by a factor of 10 and yields a 5 dB gain in sensitivity. This is because in the time it takes to collect sufficient samples for one correlation in the lowest offset frequency decade (e.g. 1 to 10 Hz), 10x the amount of data is available in the adjacent decade (10 to 100 Hz), allowing 10 cross spectra to be computed and averaged here.

This pattern continues up to the stop frequency of the measurement. Lowering the start frequency by one decade usually has the same effect as increasing the correlations setting by a factor of 10, simply because both steps lead to an increase

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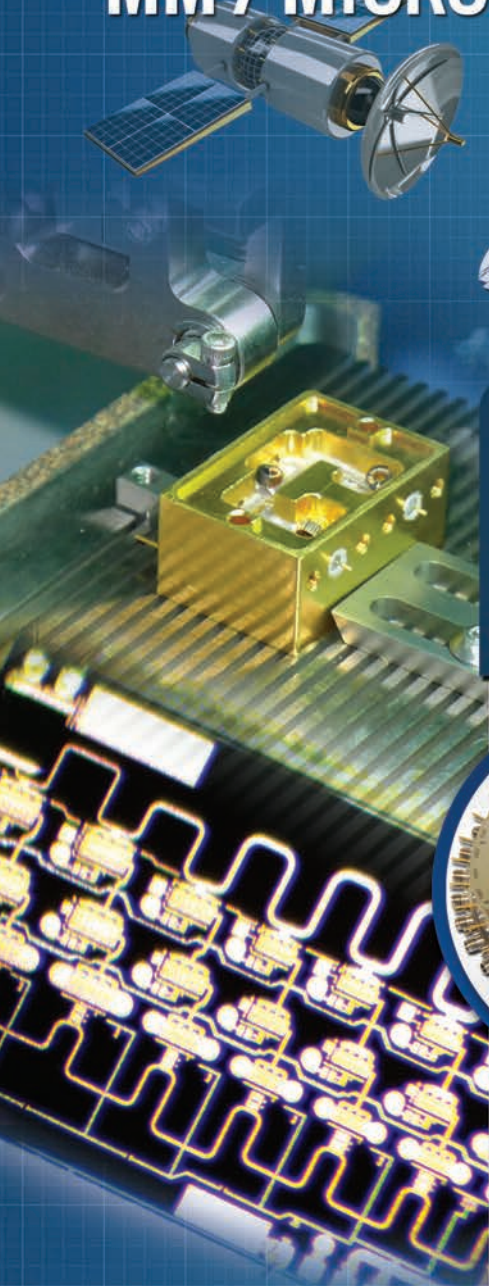

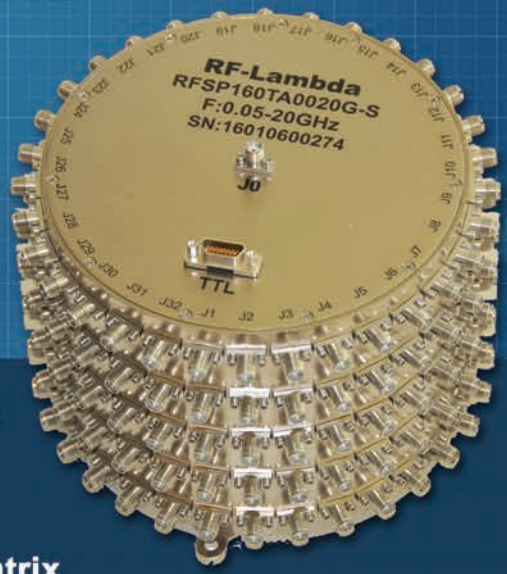

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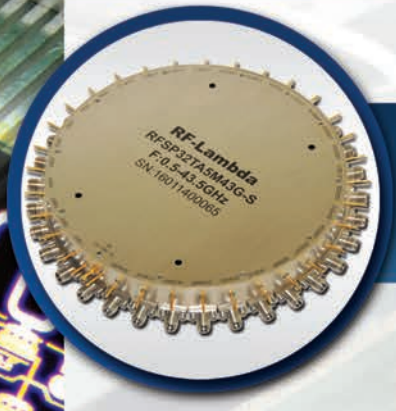

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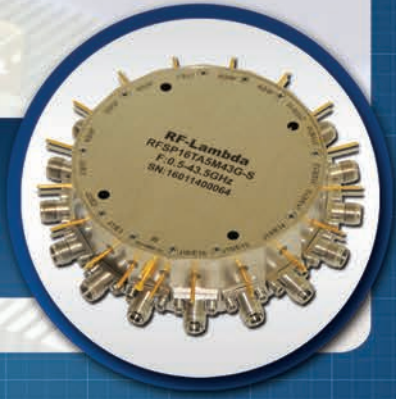

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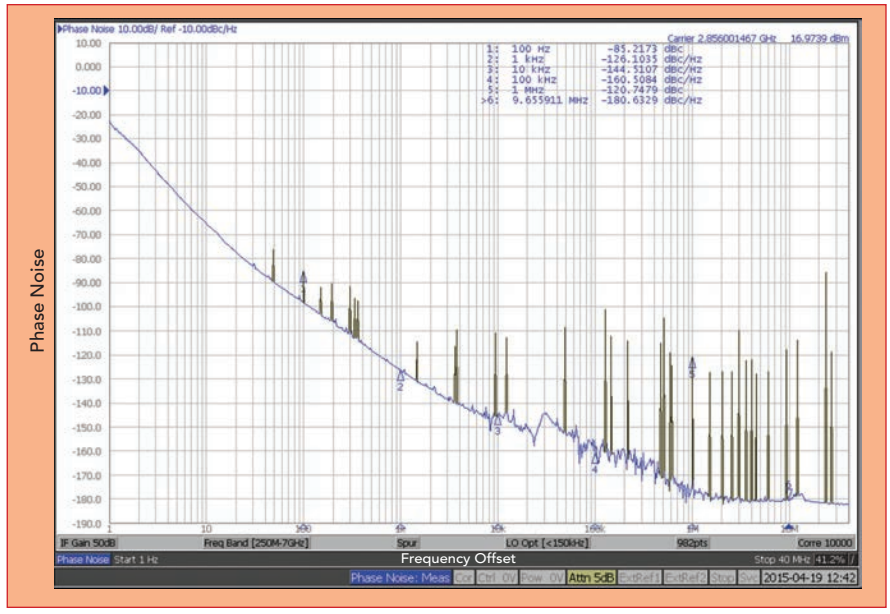

Fig. 12 **Measurement of the 2.856 GHz DRO using a test setup with maximum sensitivity (36 h).**

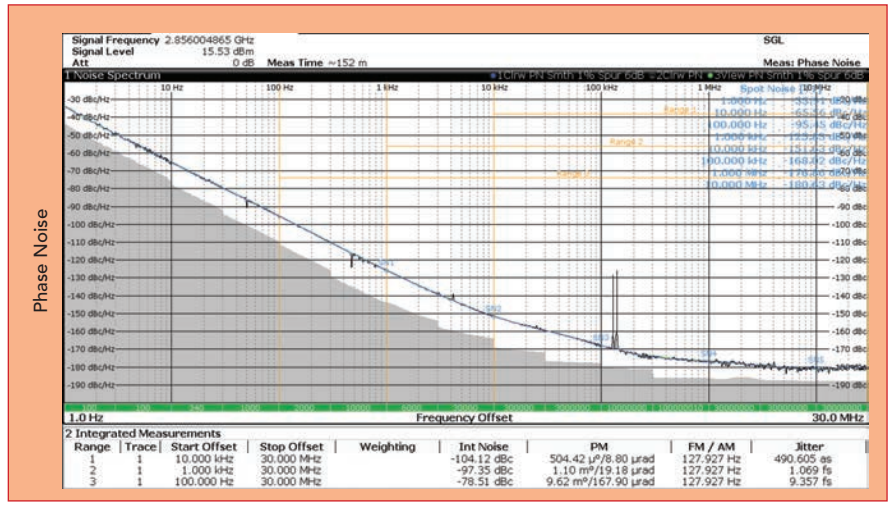

Fig. 13 **Measurement of the 2.856 GHz DRO using R&S test setup with about 2.5 h measurement time.**

in measurement time by a factor of 10.

Measurement Results

With the development of the 2.856 GHz DRO, it soon became apparent that the sensitivity of the then used phase noise test set[21] was insufficient. ***Figure 12*** shows a measurement, taken with the maximum number of correlations (and minimum offset start frequency), extending over 36 hours. Yet, the plot still shows insufficient sensitivity between 10 kHz and 1 MHz, as well as artefacts around 30 kHz.

Also development work on the DROs was tedious, as phase noise measurements took at least 20 minutes in order to come up with a useable value at 1 kHz offset. Since the DRO's -125 dBc/Hz at that offset are just 10 dB below the test set's synthesizer noise, a manageable number of correlations yields an acceptable result (compare to Figure 10).

The situation much improved with the availability of a phase noise measurement system with much lower noise internal reference sources. ***Figure 13*** shows a measurement of the 2.856 GHz DRO with this instrument taken over about 2.5 h of measurement time, showing excellent accuracy. ***Figure 14*** shows 20 dB less phase noise (purple trace)

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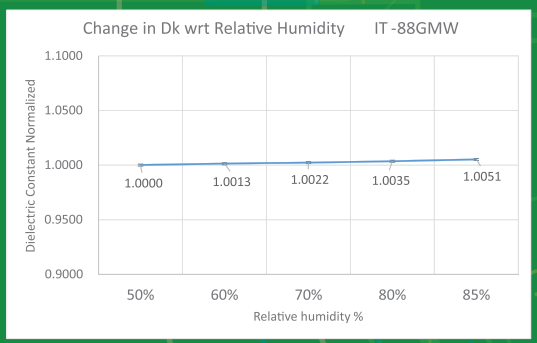

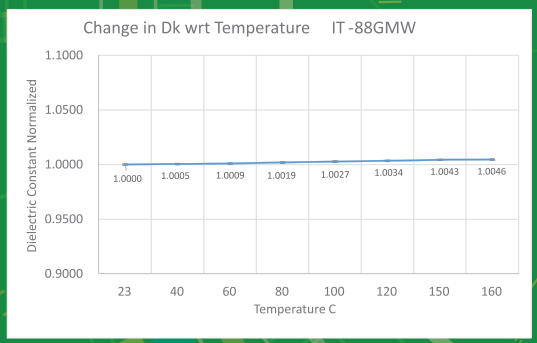

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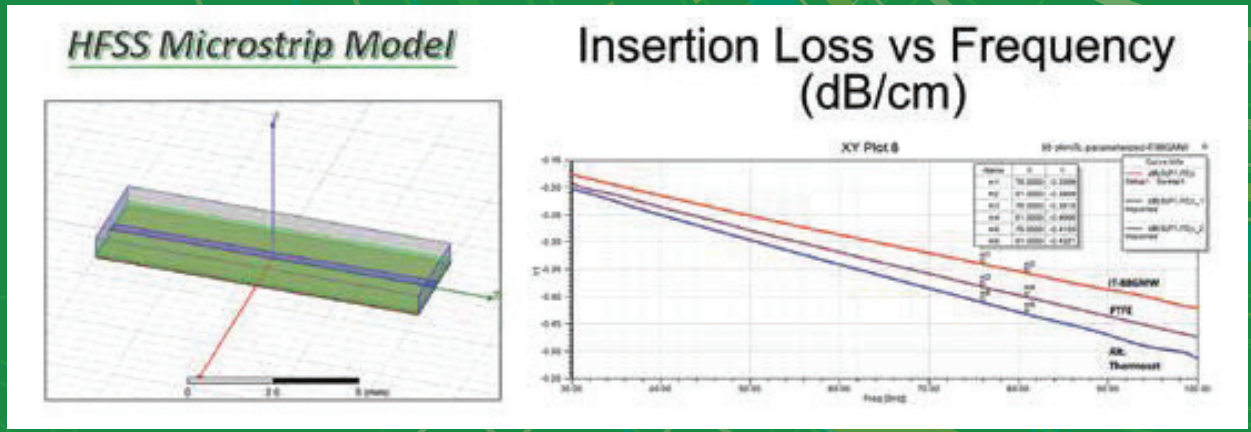

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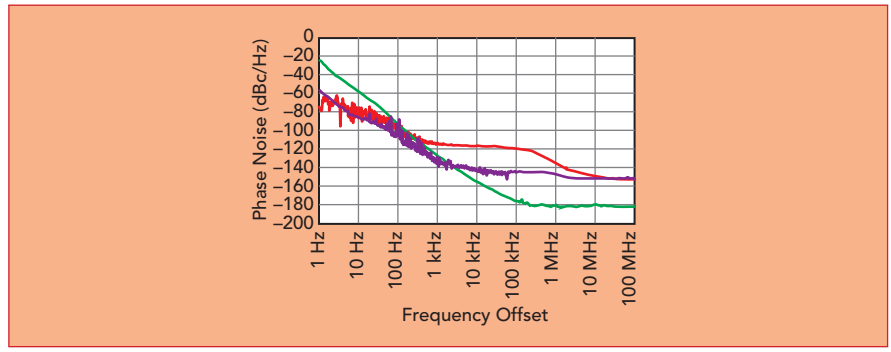

Fig. 14 Comparison of various test setup phase noise compared to 3.9 GHz DRO.

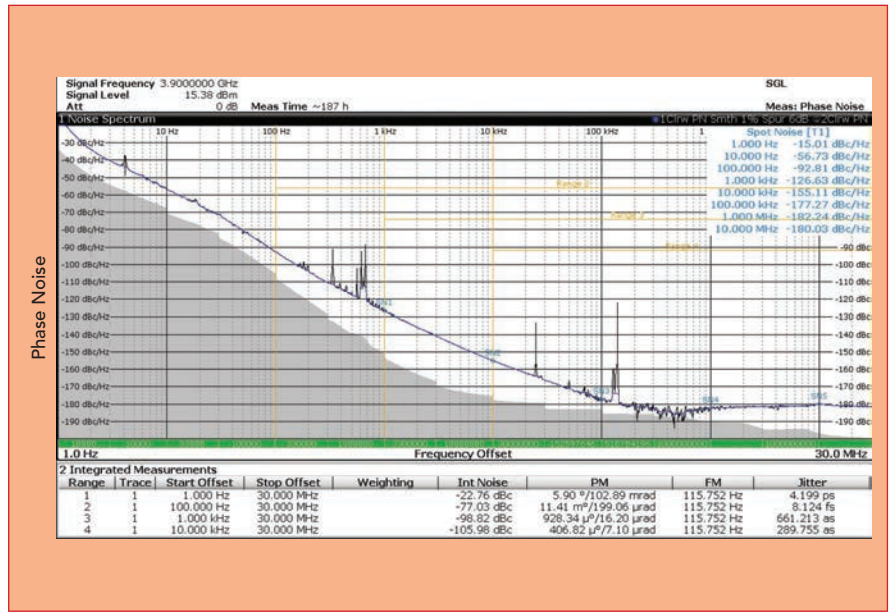

Fig. 15 Measurement results for the 3.9 GHz DRO.

over the offset frequency range from 1 kHz to 100 kHz, compared to another instrument (red trace). Recalling that the cross correlation technique reduces test set noise by 5 dB for every 10-fold lengthening of measurement time, the 20 dB reduction in synthesizer phase noise translates to a potential gain in measurement speed of four decades.

Going back to Figure 13, the alert designer will notice that the phase noise of this DRO does not decay with 20 dB to 30 dB/decade into the noise floor, as theory demands. The measurement therefore hints at extra noise polluting the signal for offsets above 10 kHz, suggesting potential for improvement, not evident from Figure 12. Further investigations revealed a number of simple to implement changes that were incorporated into the next design of the 3.9 GHz DRO. Additional performance was gained by tweaking the design through phase noise optimizations, enabled by the measurement speed of the system that makes useable phase noise data at 1 kHz/10 kHz offset available in less than 10 seconds, even at those challenging phase noise levels. The measurement results of the 3.9 GHz DRO are shown in ***Figure 15***.

With both designs built around dielectric resonators with a loaded Q of 15,000, phase noise numbers at 3.9 GHz can be expected to be 2.7 dB = $20\log_{10}(3.9/2.856)$ higher than at 2.856 GHz. Instead, for offsets over 1 kHz, the 3.9 GHz design shows even lower phase noise. In terms of jitter, the optimizations yielded a 40 percent reduction, bringing jitter down to 0.66 fs (integrating phase noise over 1 kHz to 30 MHz) and 0.29 fs (10 kHz to 30 MHz).

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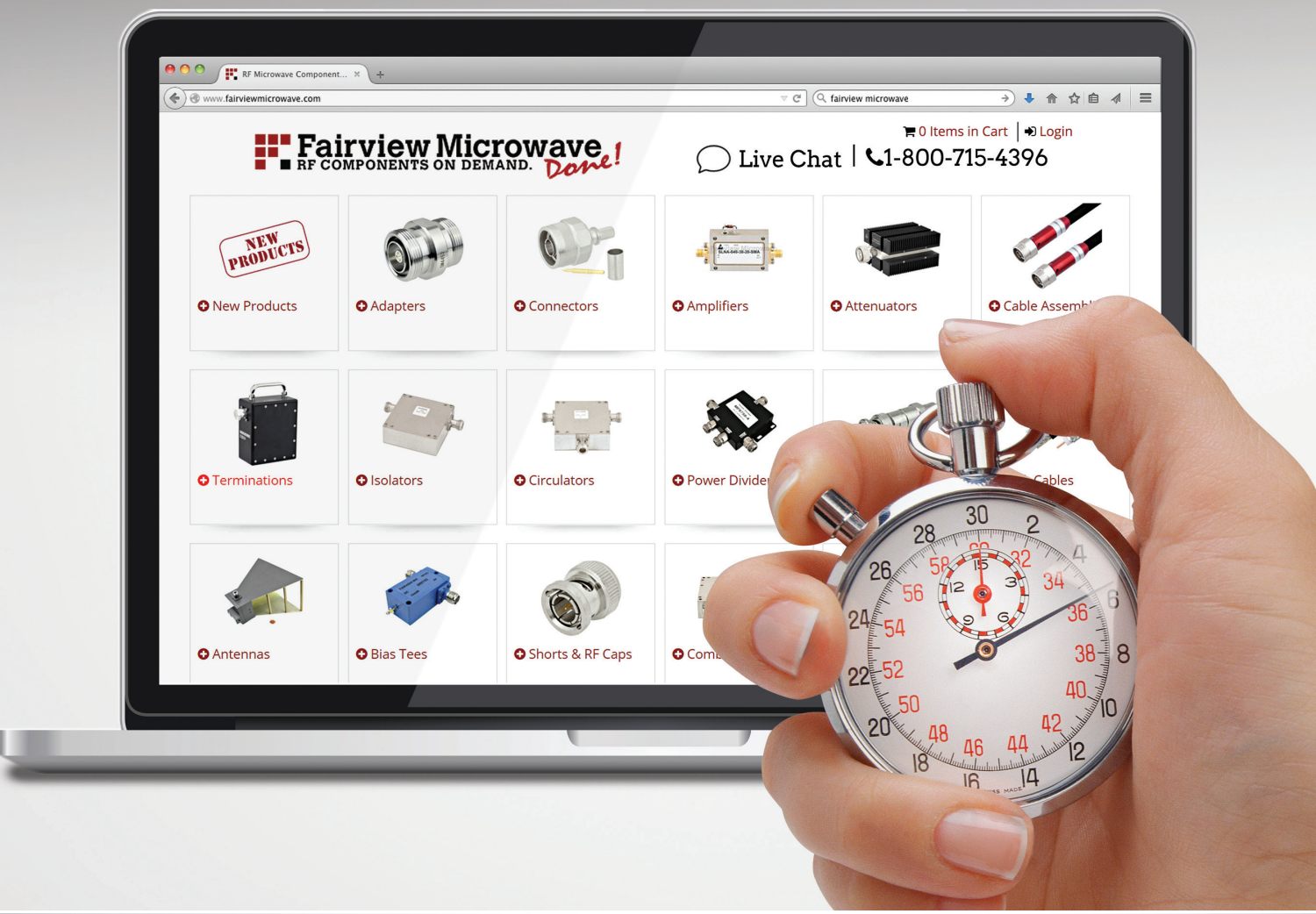

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CONCLUSION

Sub-femtosecond jitter microwave sources were developed for two of the relevant frequencies in X-FEL electron beam accelerators. None of the critical design decisions taken are novel, but rather adhere to long known principles. Use of modern, low noise components and techniques, as well as careful optimization of all building blocks was key to the achieved performance.

It should be pointed out that the resulting designs are stable and reproducible commercial products, with typical noise data not differing by more than a few dB. With the phase noise of the realized oscillators being, at most offsets, decades below the intrinsic noise of most measurement systems, such low noise sources can only be measured using cross-correlation techniques. Yet, the required sources to compare the DRO against must be as low noise as possible, to not overburden the cross-correlation capabilities, bearing in mind that every 5 dB of necessary test set noise reduction require a 10-fold measurement time.■

ACKNOWLEDGMENT

The preceding work would not have taken place without my sales partner Bernd Rupp, putting me in touch with a number of supportive people and drumming up enough interest in a commercial product. Also, I am indebted to Jesse Searls (formerly with Poseidon Scientific Instruments) for encouraging me, to try my hand on these types of ultra-low noise sources. I am very thankful for the support of Frank Lin of Skyworks in finding the optimum resonators and Takahashi Okawa of Daiken Chemical Co. for valuable discussion.

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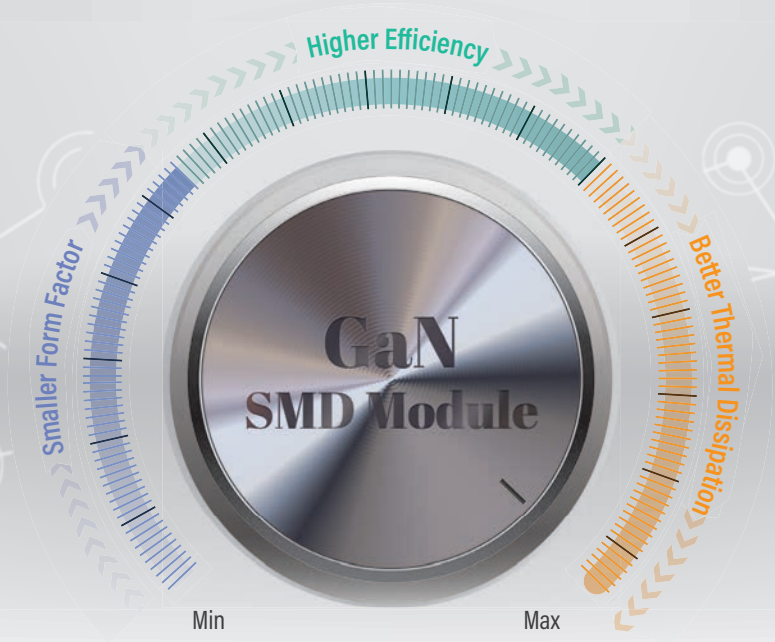

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INVITED PAPER

Design of Highly Linear FET Resistive Mixers

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Steve E. Avery and Richard Barber
Cobham Advanced Electronics Solutions, San Jose, Calif.

Mixers are essential RF front-end elements as they are responsible for translating a signal to a different frequency. They do this by beating (heterodyning) the signal of interest with another signal to produce an intermediate frequency. An ideal mixer produces the desired output signal with a clean spectrum, however practical mixers produce many unwanted spurious signals as well. Additionally, circuit parasitics and device nonlinearities generate further mixing spurs that limit system performance. Mixers can utilize various types of devices including diodes, FETs and BJTs, each with its own strengths and weaknesses.

Tradeoffs in conversion loss, LO drive, port-isolations, noise, VSWR and linearity are among the many aspects of mixer design. These parameters have a predominant influence on overall system performance, especially dynamic range. In particular, a highly linear mixer with low conversion loss and low distortion characteristics is a key desire for most system designs. This is where FET-based mixers have an advantage.

A FET-based mixer can be designed to operate in either an active or passive manner. In the active mode, the FET is typically DC biased as an amplifier, but with the gate near pinch-off. The LO and RF signals feed the gate, or gates if a dual-gate device is used, and the IF signal is coupled off the drain. This configuration provides gain, but at the cost of input compression and higher levels of intermodulation products. Passive resistive FET mixers, on the other hand, have conversion loss, but display outstanding input compression and intermodulation characteristics. This article focuses on the passive resistive FET mixer, covering its basic operation and design, concluding with measurements on a GaAs-based mmWave MMIC.

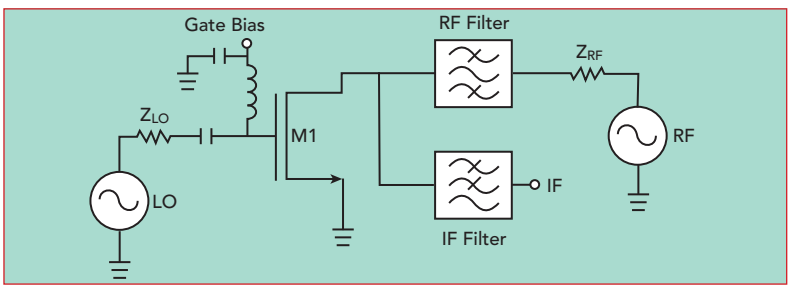

Fig. 1 **FET resistive mixer.**

BASIC FET RESISTIVE MIXER OPERATION

A FET resistive mixer utilizes the resistive channel between the drain and source of a "cold FET" or "unbiased FET" to achieve frequency translation. The RF input signal is applied across the drain-source channel of the FET, while the LO signal is applied to the gate. The IF output signal then appears across the drain. This configuration is shown in ***Figure 1***, where a diplexer is needed to separate the RF and IF signals present at the drain.

It works by modulating the channel resistance at the rate of the applied LO signal, which produces the mixing action with the RF signal. During the positive cycle of the LO, the RF sees the linear resistance of the channel, as seen in ***Figure 2a***, enabling it to achieve low intermodulation distortion levels. ***Figure 2b*** shows the operation of the mixer over time for a series of conductance pulses at the rate the LO is presented to the RF.

MATCHING

In ***Figure 3***, Z_{LO} represents the LO source impedance, to which is matched the gate

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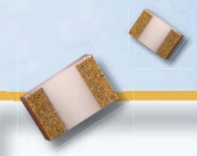

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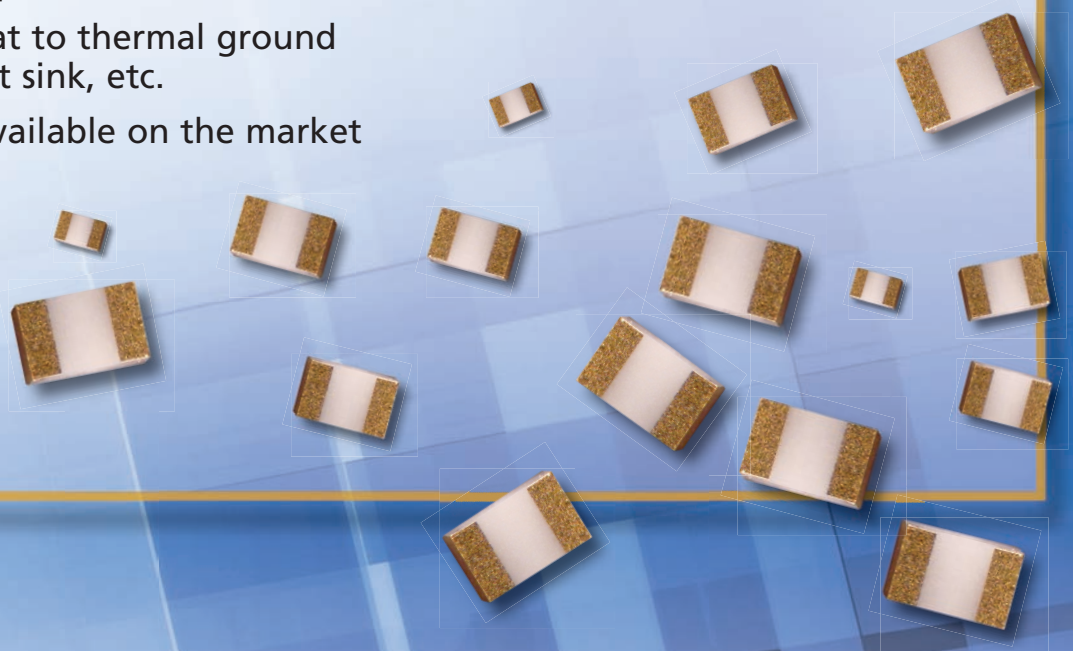

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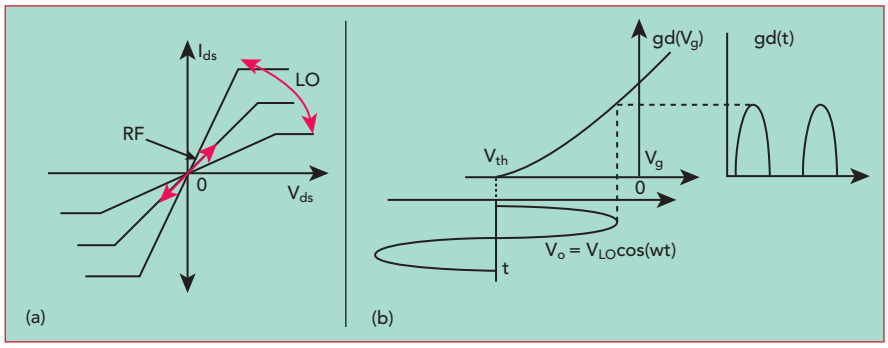

Fig. 2 **FET DC IV curves as the LO and RF swing about the linear region (a) and FET channel conductance modulation waveform (b).[1]**

impedance in order to maximize the voltage across capacitor C_{gs}. This can be done by considering the equivalent small signal model in Figure 3a. The LO input impedance depends mainly on the RC circuitry and can be reduced to the equivalent circuit shown in Figure 3b.[2] The small signal RF and IF impedances are determined in a similar fashion, with the channel conductance replaced by the time-averaged value of the on-off variation over the LO cycle. Further refined estimates can be made by including the gate terminated by the gate impedance evaluated at the RF and IF frequencies. The simplification shown in Figure 3c is sufficient if the reactance of C_{gd} is large compared to the resistances of R_g and R_s.[3]

To prevent LO leakage from pumping the drain conductance through C_{gd}, the RF and IF matching circuit should ideally be designed to short-circuit the drain at the LO frequency (see Figure 3a). Also, the gate should be short-circuited at the RF frequency to prevent the RF voltage from varying the channel conductance.[4]

TOPOLOGIES

Although the focus is on a single-ended FET mixer thus far, FET resistive mixers can be used in balanced topologies as well to further improve isolation and reduce intermodulation distortion (IMD). ***Figure 4a*** shows a single balanced topology with the LO applied to the gates through a balun and the RF applied to the drains in phase. Because the LO drives the two gates in a balanced (180 degree) fashion, the IF signals appearing at the drains are 180 degrees out of phase. These are filtered through a diplexer and recombined using an output balun. A key difference between the single balanced

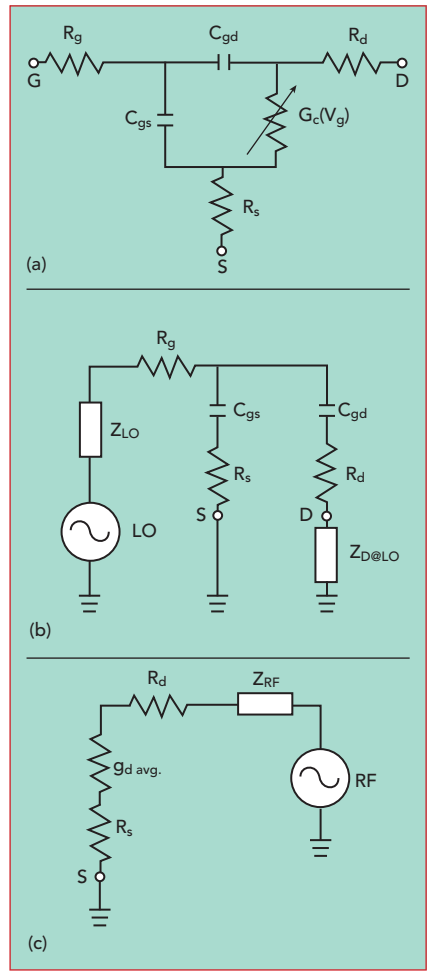

Fig. 3 **Nonlinear equivalent circuit with no drain bias (a), simplified equivalent LO circuit (b) and simplified equivalent RF/IF circuit (c).[2]**

FET mixer and a single balanced diode mixer is the additional balun

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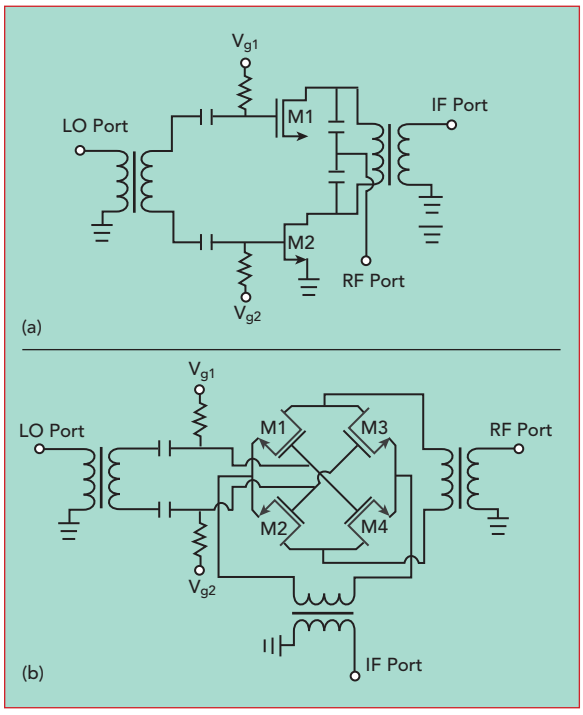

Fig. 4 **Balanced FET resistive mixer topologies: single balanced (a), double balanced (b).**

in the FET mixer; the extra balun is required to recombine the IF since, unlike diodes, the FETs cannot be operated in reverse. Single balanced configurations can achieve similar conversion losses as their single-ended FET mixer counterparts, but with a 3 dB improvement in odd-order IMD performance because of the RF power splitting between the two devices. The single balanced topology also has an inherent rejection of even-order IMD products due to the drains being shorted by the IF blocking caps. Depending on the quality of the balance, even order improvements of 20 dB or more can be achieved.[4] Note that either the LO or RF can be applied out of phase, but generally the LO is chosen to be balanced, for in this configuration, the drains are a virtual ground to the LO, thus reducing the LO's ability to pump the drain and cause further distortion.

Figure 4b shows a double balanced version in a ring structure; note that the extra balun is still required in contrast to a double balanced diode mixer. All four corners of the ring are virtual grounds for the LO and the IF connection points are virtual grounds for the RF. Both RF connections are made at virtual ground points with respect to the LO and IF. Thus, the RF, LO and IF are inherently isolated from each other in this configuration. This mixer also has the same IM rejection properties as a diode ring mixer; that is, all even order IM products are canceled out.[5] Isolations and even order IM distortion products are both dependent on the quality of circuit balance maintained throughout the mixer.

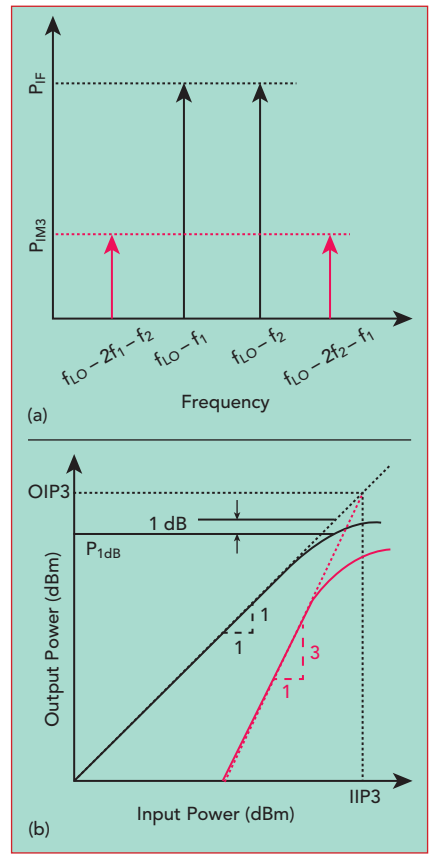

Fig. 5 **Mixer's two-tone output spectrum at IF (a) and fundamental and IM3 levels vs. two-tone input power (b).**

LINEARITY

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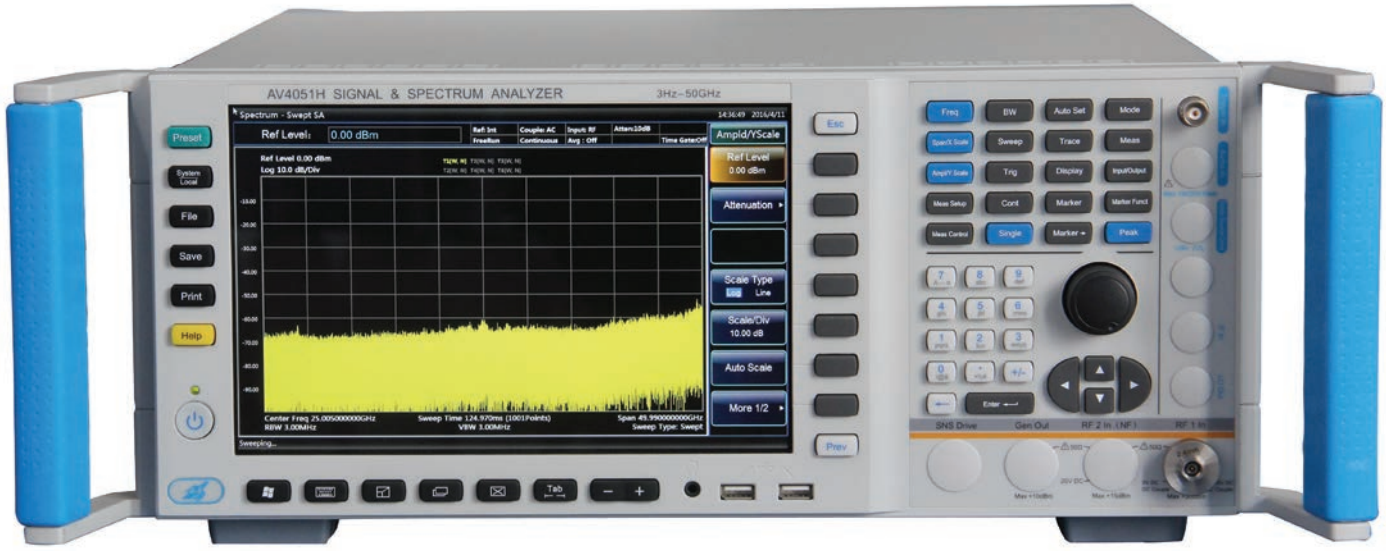

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ing harmonics of the RF and LO. For instance, an input signal consisting of two distinct tones incident at the mixer results in IF products of various orders according to:

$$f_{IM} = \pm mw_{LO} \pm n_1 w_{RF1} \pm n_2 w_{RF2} \quad (1)$$

These products are generated by the nonlinearities in the device, similar to those of an amplifier. The key difference is that mixers have an additional signal, the LO which converts the intermodulation products to the IF frequency as seen in ***Figure 5a*** for the down-converting case. Figure 5a shows the two tones along with the close in third-order ($n_1 + n_2 = 3$) intermodulation products (IM3). Note that this occurs with all other harmonics of the LO present within the mixer as well, which are not shown. The extrapolated intercept of the fundamental and IM3 products when the RF input power is swept is shown in ***Figure 5b*** is called the output third-order intercept point (OIP3). The input third-order intercept (IIP3) is simply related to the OIP3 by the gain as OIP3 = IIP3 + gain. Achieving the highest possible IIP3 implies that the close-in IM3 are very small relative to the fundamental.

In addition to distortion, gain compression is also an important characteristic when assessing a mixer's linearity. Assuming the mixer is not saturated by the RF tones, as the RF power increases, the levels of the IM products rise at a rate equivalent to their mixing order. For instance, the third-order products (IM3) will change 3 dB for every 1 dB change in input level of both input tones, as seen in Figure 5b. Once the mixer starts to saturate, however, the fundamental output power begins to compress. When compressed 1 dB below the extrapolated output power it has reached its 1 dB compression point.

For low distortion in a FET resistive mixer, the LO should be the only influence on the channel's conductivity. Also, to operate in a clean on-off fashion, the device should spend as little time as possible in the transition region between fully off and fully on. Thus, with the device biased around its pinch-off voltage, a high LO drive is desired to switch the device as fast as possible. If, however, too much LO voltage is applied, and the peak gate voltage exceeds the nominal gate turn-on voltage, then LO current leaks into the channel. This current may interfere with the modulation process and increase distortion. The remedy is to bias the device further below its pinch-off voltage to allow for higher levels of LO drive. This results in shorter conductance pulses, and has the effect of increasing RF and IF output impedances.[5] To aid in maintaining reasonable impedances, a FET with a larger gate width can be used. Caution must be used, for a larger device requires more LO power, and the device's capacitive parasitics increase. It is best to use the largest device possible based on the frequency of operation and available LO power.

In practice, a small amount of LO current does leak from the gate to the drain via the gate-drain capacitance (C_{gd}). To address this, simply

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resonating out C_{gd} with a parallel inductor is straightforward, although it is a narrowband solution. Another byproduct of the leakage of power is the possibility of inducing low level drain current rectification. This can be minimized by DC grounding the drain.

Another aspect to linearizing a FET resistive mixer involves the use of drain bias, for it has been observed that by adding a small positive drain bias, the intermodulation levels of the mixer fall quite drastically.[6] With too much drain bias, however, the FET will no longer remain within its linear region of operation; instead, it will be closer to saturation, and the desired resistive operation utilizing the linear channel resistance will no longer be the case.

Modeling the drain conductance in terms of applied gate and drain voltages can be done with a Taylor series expansion as shown below, to observe how the second- and third-order drain conductances vary.

$$i_{ds}\left(V_{gs}, V_{ds} + v_{ds}\right) \quad (2)$$
$$= G_{ds}\left(V_{gs}, V_{ds}\right)v_{ds} +$$
$$\frac{1}{2}\frac{\partial G_{ds}\left(V_{gs}, V_{ds}\right)}{\partial V_{ds}}{v_{ds}}^2 +$$
$$\frac{1}{6}\frac{\partial^3 G_{ds}\left(V_{gs}, V_{ds}\right)}{\partial {V_{ds}}^3}{v_{ds}}^3$$

$$= G_{d1}\left(V_{gs}, V_{ds}\right)v_{ds} +$$
$$G_{d2}\left(V_{gs}, V_{ds}\right){v_{ds}}^2 +$$
$$G_{d3}\left(V_{gs}, V_{ds}\right){v_{ds}}^3$$

The goal is to minimize third-order distortion products since they are close to the IF, thus we want to reduce the third-order drain conductance term (G_{d3}) as much as possible over the gate swing. Using a 4 × 25 µm FET from Qorvo's 0.15 µm PHEMT process, the measured third-order drain conductance (G_{d3}) over both the applied gate and drain bias is shown in ***Figure 6***. There is a sweet spot for these devices to achieve the lowest G_{d3}. Thus, with a little drain bias applied, this sweet spot should yield the lowest possible intermodulation levels achievable within the FET.

MMIC DESIGN

To demonstrate G_{d3} minimization, a MMIC mixer is designed and fabricated (see ***Figure 7a***). A single balanced resistive FET mixer topology with balanced LO and RF is chosen for its small size and ability

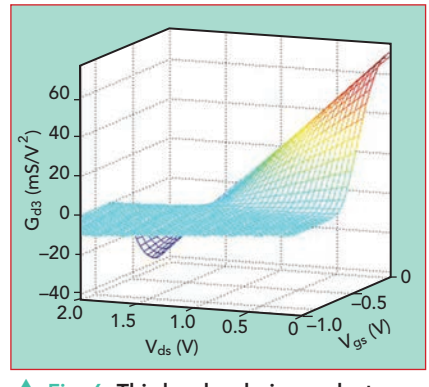

Fig. 6 **Third-order drain conductance of a GaAs PHEMT vs. V_{ds} and V_{gs}.**

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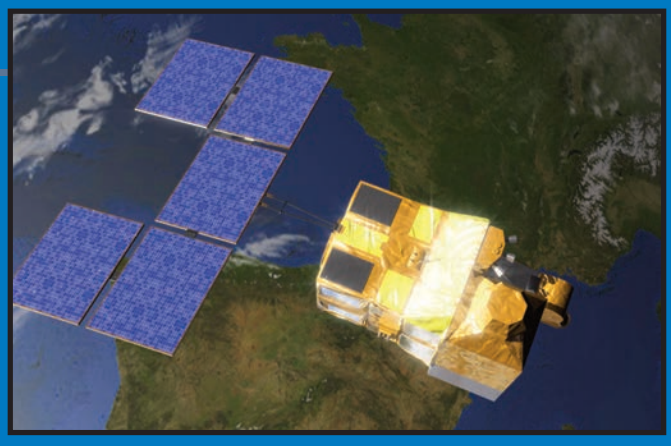

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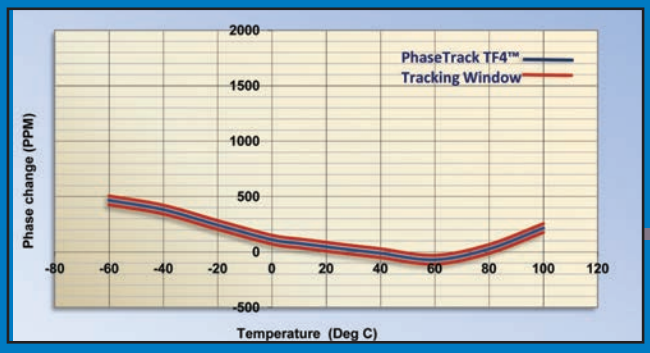

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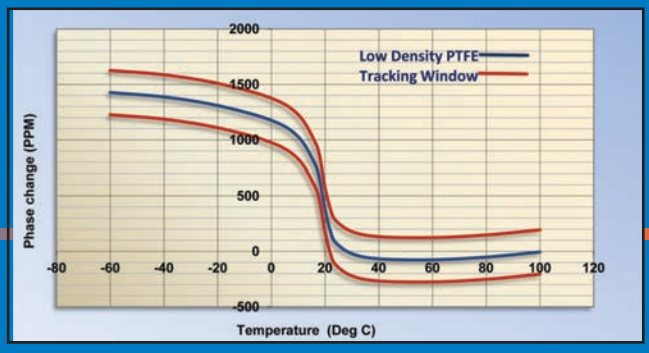

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to fit on a chip. This configuration does not provide for rejection of even-order intermodulation products, but it does improve the inherent LO-IF and RF-IF port isolations. The MMIC is fabricated using Qorvo's 0.15 µm GaAs PHEMT process. The mixer core uses a pair of 4 × 25 µm FETs. The gates are biased through N^+ doped GaAs resistors, and the drains are biased through an off-chip bias-T.

The LO and RF baluns utilize a spiral Marchand structure with capacitive compensation to improve amplitude and phase balance. This type of balun allows the mixer to work well over a multi-octave bandwidth, but requires that all the matching networks between the baluns and the FETs operate over a similar bandwidth as well. This type of balun does not inherently provide an optimal termination to the leakage that passes through C_{gd}, but it is an acceptable design tradeoff in terms of operating bandwidth. The RF balun is designed to allow the IF to pass through unaffected.

MMIC MEASUREMENT RESULTS

The MMIC is packaged in a fixture with 2.92 mm K connectors. Testing is done with a two-tone signal at -5 dBm per tone, separated by 10 MHz centered around 27 GHz. The LO is fixed at 28 GHz and is swept in power to ensure the mix-

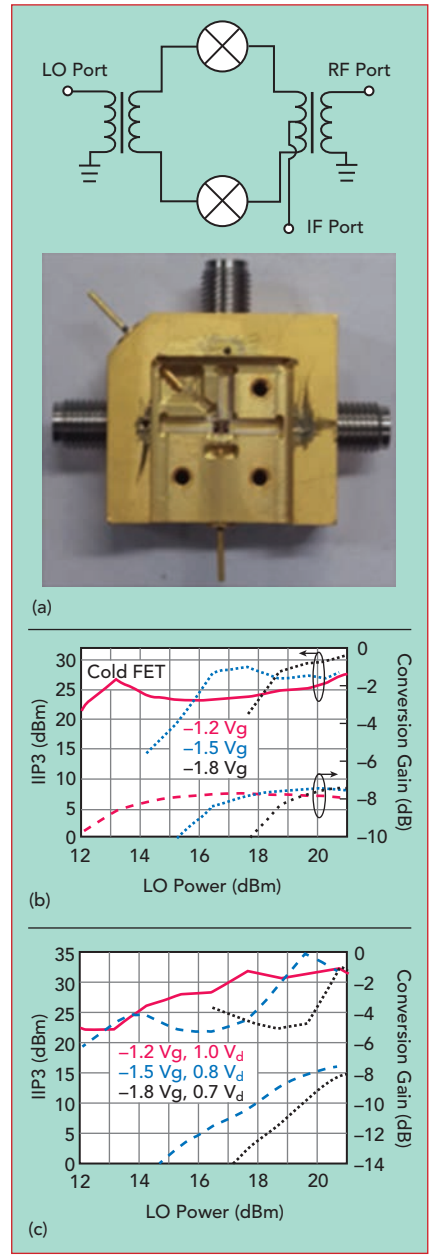

Fig. 7 MMIC schematic and prototype (a), IIP3 and conversion gain vs. LO power with the drains DC grounded (b) and with drain bias applied (pinch-off = –1.2 V) (c).

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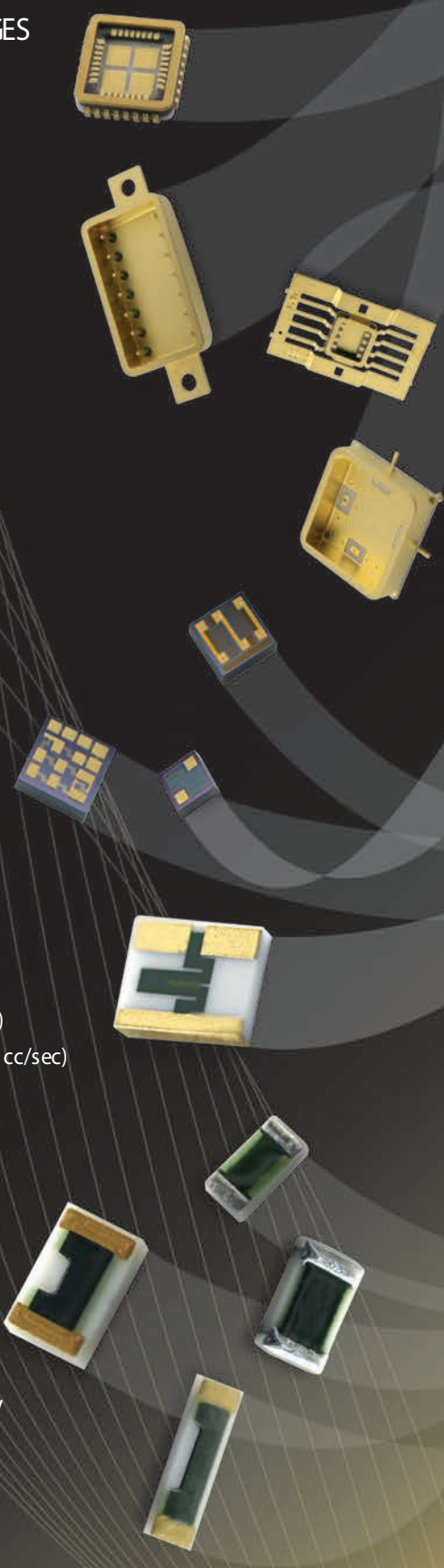

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er is driven sufficiently at selected gate bias points.

Figure 7b shows the measured conversion gain and IIP3 with the drains grounded (cold FET), while ***Figure 7c*** shows them with drain bias applied. In the cold FET case, as the devices are biased further below pinch-off and the LO drive level is increased both the IIP3 and conversion gain steadily improve. With drain bias applied, the conversion gain increases slightly, but the large improvement in IIP3 is a good tradeoff.

Large signal testing is conducted as well; ***Figure 8*** shows the measured conversion gain of each mixer as a single tone 27 GHz RF signal is swept in power from 0 to 21 dBm, with a fixed 28 GHz LO. In cold FET operation, the mixer achieves an input 1 dB compression point (P_{1dB}) of 16.5 dBm, only 0.4 dB below the LO drive level. This is one of the merits of using FETs; the RF and LO are applied to different parts of the mixer, whereas in a diode mixer both the LO and RF directly control the diode conductance. With drain bias applied the mixer achieves a P_{1dB} of 21.7 dBm, 2 dB above the LO drive. This can be attributed to the reduction of C_{gd} via the application of drain bias.

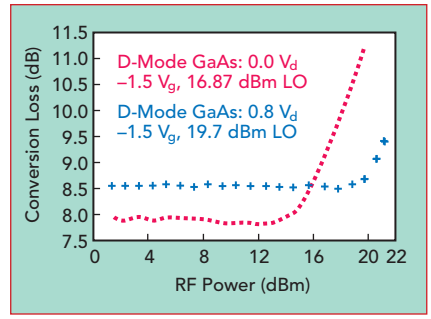

Fig. 8 Measured conversion loss at 27 GHz vs. RF input power, tested in both cold FET and optimized drain bias modes.

CONCLUSION

Maximizing a mixer's IIP3 can vastly improve the dynamic range of a system and result in overall higher system performance. The design process for producing highly linear FET resistive mixers is reviewed, and a GaAs MMIC is designed and built using the linearization techniques discussed. An IIP3 of 35 dBm is achieved in a mmWave mixer.■

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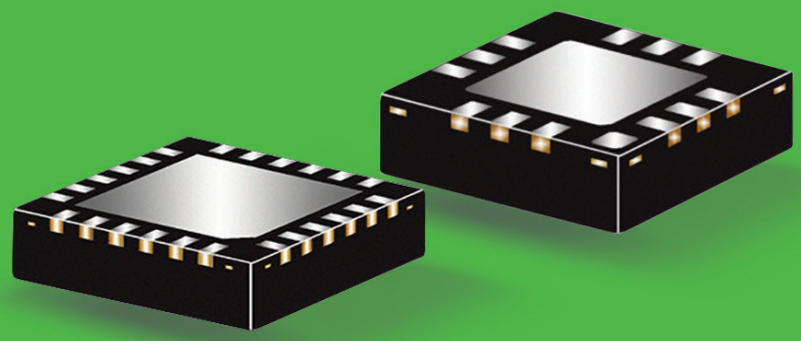
6. J. A. Garcia, J. C. Pedro, M. L. De la Fuente, N. B. Carvalho, A. Mediavilla and A. Tazon, "Resistive FET Mixer Conversion Loss and IMD Optimization by Selective Drain Bias," *IEEE MTT-S International Microwave Symposium Digest*, Vol. 2, June 1999, pp. 803–806.

MMIC MIXERS & MULTIPLIERS



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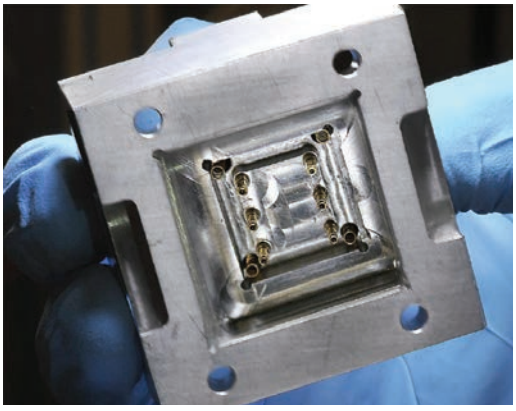
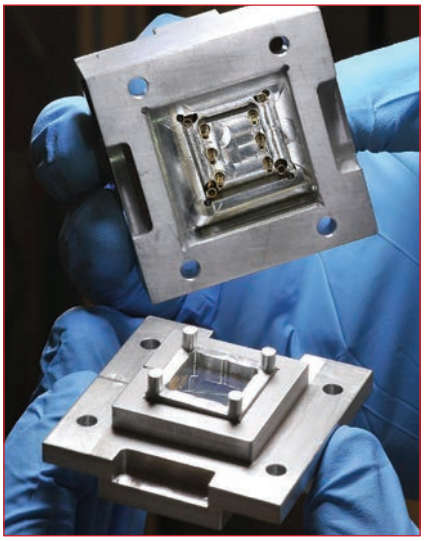


RF Probe for Ultra-Low Temperature Applications

INGUN USA Inc.
Lake Wylie, S.C.

Quantum computing architectures have been transferred from the laboratory environment to full-scale introduction to the market for universal quantum computers. INGUN has helped to develop an interconnect solution which replaces traditional bond wiring. This has paved the way for scalability at the Institute of Quantum Computing in Waterloo, ON, Canada.

Explained simply, quantum computing can process much more data than traditional computing systems, which is vital for IT forensics, security and cryptology, for example, making it effective for real world applications and not just in the laboratory. In a binary system, each bit is either a 0 or a 1, and it can never be both 0 and 1, but quantum bits (qubits) allow for a superposition of both states at the same time, which means that more computations can be done when compared to regular binary systems.



▲ Fig. 1 The HFS-847 301 038 A 1200 M-S-Y probe resonator chuck.

A quantum socket, consisting of several resonators is the device under test (DUT) for this application. The RF probes stay permanently in the chuck, but only make contact with the resonator if the chuck is compressed. This is all done at very low temperatures—for this application, an apparatus that cools down the temperature to just slightly above absolute zero (0°K or -273.15°C) is used. This is done in several stages. The chuck can be seen in ***Figure 1***.

Around this temperature, the resonators become super-conductive. It goes without saying that regular spring probes and contacts would not work at all in such an environment. However, INGUN has come up with a modified coaxial probe version—the HFS-847 301 038 A 1200 M-S-Y 100 mil probe—that uses special beryllium-copper springs and other proprietary materials so that the probe is usable in that temperature range. For this setup, the probes also have to be strictly non-magnetic.

Usually, a thin nickel layer is used beneath the gold plating. This is done because nickel works as a carrier or adhesive for the gold, which ensures a long life and prevents the gold from chipping off from the base material. It acts as a diffusion stopper. Nickel, however, is ferromagnetic, thereby attracted by magnets, so the plating process has to ensure that not even a slightest amount of nickel is present when the parts are electroplated. After plating a Gaussian chamber is utilized to verify that no nickel residue is

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PMI Model No.	FREQ Range (GHz)	Insertion Loss (dB)	VSWR	Maximum Input Power	Leakage Power (dBm)	Recovery Time	Size (Inches) / Connectors
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LM-100M20G-18-10W-SFF http://www.pmi-rf.com/Products/limiters/LM-100M20G-18-10W-SFF.htm	0.1 - 20	2	2.0:1	1 W CW 10 W Pulsed (10% Duty Cycle,100 µs Pulse Width)	18.5	115 ns	0.50 x 0.50 x 0.22 SMA (F)
LM-1G18G-15-25W-SMF http://www.pmi-rf.com/Products/limiters/LM-1G18G-15-25W-SMF.htm	1.0 - 18	2.5	2.0:1	10 W CW 100 W Peak (10% Duty Cycle & 40 µs Pulse Width)	15	100 ns	1.00 x 1.00 x 0.40 SMA (F)
LM-18G40G-18-1W-292FF http://www.pmi-rf.com/Products/limiters/LM-18G40G-18-1W-292FF.htm	18 - 40	4	2.1:1	1 W CW	18	10 ns	0.5 x 0.5 x 0.22 2.92mm (F)

LM-500M8G-2-33DBM-12V

LM-2G18G-2D8-33DBM-12V

LM-8G18G-7-33DBM-12V

LM-1G2G-N15-33DBM-12V

ACTIVE LIMITERS

PMI Model No.	FREQ Range (GHz)	Insertion Loss (dB)	VSWR	Maximum Input Power	Leakage Power (dBm)	DC Supply Voltage	Size (Inches) / Connectors
LM-500M8G-2-33DBM-12V http://www.pmi-rf.com/Products/limiters/LM-500M8G-2-33DBM-12V.htm	0.5 - 6	2	2.0:1	+33 dBm CW	2.3	+12 VDC @ 180 mA	1.08 x 0.71 x 0.29 SMA (F)
LM-2G18G-2D8-33DBM-12V http://www.pmi-rf.com/Products/limiters/LM-2G18G-2D8-33DBM-12V.htm	2.0 - 18	2	2.0:1	+33 dBm CW	2.8	+12 VDC @ 180 mA	1.08 x 0.71 x 0.29 SMA (F)
LM-8G18G-7-33DBM-12V http://www.pmi-rf.com/Products/limiters/LM-8G18G-7-33DBM-12V.htm	8.0 - 18	2	2.0:1	+33 dBm CW	7.1	+12 VDC @ 100 mA	1.08 x 0.71 x 0.29 SMA (F)
LM-1G2G-N15-33DBM-12V http://www.pmi-rf.com/Products/limiters/LM-1G2G-N15-33DBM-12V.htm	1.0 - 2	2	2.0:1	+33 dBm CW	-15	+12 VDC @ 250 mA	1.92 x 0.78 x 0.36 SMA (F)

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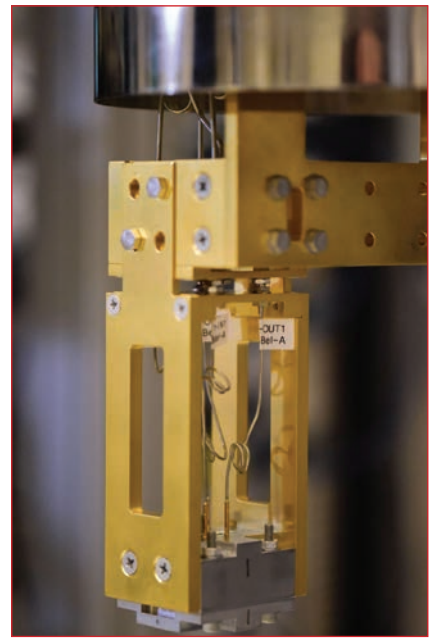
present on the probes.

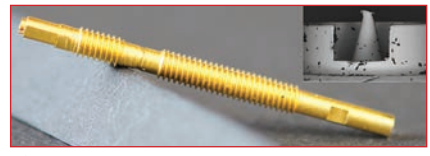
The probes operate from DC to beyond 10 GHz with excellent S-parameter characteristics and can be used for grids down to 100 mil (2.54 mm). The tail end of the probe can be connected to 0.047 in. diameter type coaxial cables through the use of a special snap-in connector type.

The special springs were tested and characterized for their compression at room temperature, in liquid nitrogen (i.e., at a temperature of T ≃ 77°K) and in liquid helium (T ≃ 4.2°K). No noticeable difference was found when comparing the cold springs to springs operating at room temperature. The final configuration with the chuck and the coaxial probes and assemblies which gets used in the freezer is shown in ***Figure 2***.

What started as a research project has evolved into the development of a probe that can be used for various industries such as automotive, military, space and aviation. In all these industry segments parts have to be cycled with large temperature swings. Also, the use of 100 percent non-magnetic base materials and the use of an "ecobrass" material makes the HFS-847 301 038 A 1200 M-S-Y very interesting for the medical industry. See ***Figure 3*** for a close-up of this probe.



▲ Fig. 2 The chuck and coaxial cables.



▲ Fig. 3 Close up of the HFS-847 301 038 A 1200 M-S-Y probe tip and body.

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ACKNOWLEDGMENT

INGUN would like to thank Professor Matteo Mariantoni, Jeremy Bejanin, Thomas McConkey and the whole team at the Institute of Quantum Computing in Waterloo, ON, Canada for their studies with the probe. For anyone interested in the research, the article is titled, "Three-Dimensional Wiring for Extensible Quantum Computing: The Quantum Socket," and was published in *Physical Review Applied*, October 2016.

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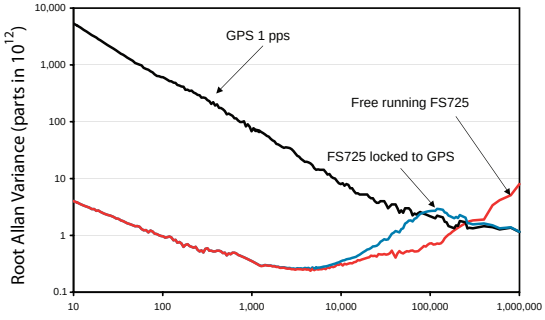

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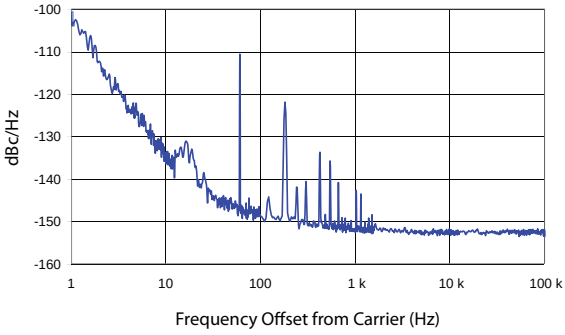

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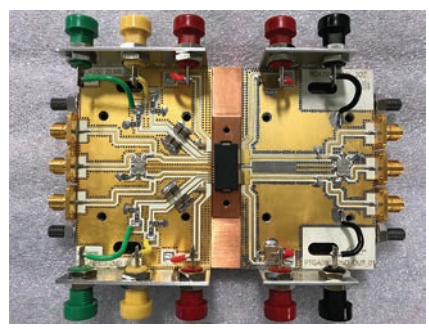
Responding to ever-increasing demands for higher data rates, wireless infrastructure providers are moving to more broadband systems. The newly-released 600 MHz spectrum (band 71) will help address these bandwidth needs. To take advantage of this spectrum, cellular base station operators need to provision amplifiers that operate from 600 MHz to 1 GHz. A wideband driver that covers all the individual bands, plus broadband applications below 1 GHz, with flat RF performance is desired for base station amplifier lineups, to achieve faster cycle time, ease of use and compact designs. To meet this market requirement, Infineon Technologies has developed a two-stage, 50 V, LDMOS RF integrated circuit (PTGA090304MD) that operates from 575 to 960 MHz.

LDMOS technology has long been the most cost-effective solution for base station power amplifiers (PA). Even though GaN has made significant progress in recent years, LDMOS is still the leading technology for commercial base station PAs below 1 GHz, due to its competitive RF performance and cost advantage. Unlike the traditional LDMOS process that uses a 28 V drain supply, Infineon's 50 V LDMOS technology is optimized for 50 V, offering higher power density and competitive RF performance to meet market needs for more compact base station PAs.

DESIGN AND PERFORMANCE

The PTGA090304MD is a two-stage design based on Infineon's 50 V LDMOS technology that operates from 575 to 960 MHz. By integrating two gain stages onto one IC, assembled in the low-cost TO270-14 overmolded plastic package, the device produces more than 30 dB gain and eliminates the need to use three discrete driver devices to meet the gain requirement of the lineup. The input is internally matched to 50 Ω, so



▲ **Fig. 1 LDMOS driver IC in the broadband fixture.**

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TABLE 1

BROADBAND WCDMA PERFORMANCE
(36 dBm AVERAGE P_{OUT}, 10 dB BACK-OFF FROM PEAK POWER, BROADBAND FIXTURE)

Frequency (MHz)	Input Return Loss (dB)	Gain (dB)	Efficiency (%)	PAR (dB)	ACPR (dBc)
575	-22.6	28.5	18.0	9.2	-38.3
590	-22.7	29.6	18.1	9.2	-40.5
660	-18.7	31.9	18.4	9.3	-46.2
746	-18.8	30.8	17.3	9.4	-47.0
860	-20.3	30.1	16.0	9.4	-46.2
960	-21.1	30.2	15.1	9.2	-45.1

TABLE 2

WCDMA PERFORMANCE IN THE 728 TO 768 MHz NARROWBAND FIXTURE

	PTGA090304MD			Current Market Performance		
Frequency (MHz)	Gain (dB)	Power-Added Efficiency (%)	ACPR (dBc)	Gain (dB)	Power-Added Efficiency (%)	ACPR (dBc)
728	33.0	19.7	-46.4	30.9	19.6	-44.7
748	32.8	19.7	-46.7	31.1	19.5	-45.5
768	32.5	19.5	-46.6	31.2	19.3	-46.2

TABLE 3

WCDMA PERFORMANCE IN THE 920 TO 960 MHz NARROWBAND FIXTURE

	PTGA090304MD			Current Market Performance		
Frequency (MHz)	Gain (dB)	Power-Added Efficiency (%)	ACPR (dBc)	Gain (dB)	Power-Added Efficiency (%)	ACPR (dBc)
920	33.4	19.6	-46.4	34.4	19.9	-45.0
940	33.3	19.3	-46.3	34.5	20.0	-44.6
960	33.2	19.1	-46.0	34.3	19.8	-44.3

no input matching is needed on the PCB. The DC blocking capacitor at the input is also integrated on the IC die.

The PTGA090304MD covers 575 to 960 MHz, which corresponds to 50 percent fractional RF bandwidth, with one broadband impedance match on the PCB. ***Figure 1*** shows the broadband RF fixture, and ***Table 1*** summarizes the performance in the fixture with a single-carrier, 10 dB peak-to-average ratio (PAR), WCDMA waveform at 10 dB back-off from the peak power of 40 W. The device has flat output power, greater than 15 percent efficiency and 30 dB gain. The PTGA090304MD delivers competitive narrowband performance in the two major cellular bands under 1 GHz. ***Tables 2*** and ***3*** show the RF performance at 10 dB output power back-off in the 728 to 768 and 920 to 960 MHz bands, respectively. The driver has 33 dB gain, 19 percent efficiency and excellent raw linearity of -46 dBc adjacent channel power ratio (ACPR) in both bands.

The PTGA090304MD's output match uses a simple matching topology that is easy to implement on the PCB, making impedance tuning straightforward and convenient to implement in production. The same PCB layout (see Figure 1) is used for the broadband and two narrowband fixtures, as the output match for the different frequency bands only requires changing two surface-mount capacitors. This provides the flexibility of using one device and one board layout to cover multiple bands, minimizing manufacturing complexity.

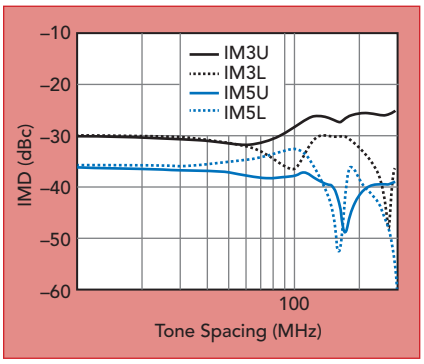


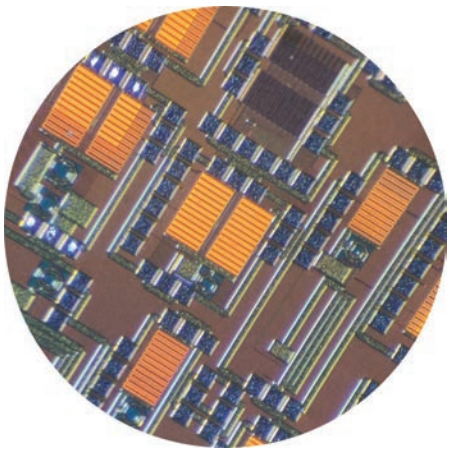
Fig. 2 Two-tone IMD vs. tone spacing, with the driver in the broadband fixture.

Being a dual-path device, the PTGA090304MD can be used in different amplifier architectures. The circuit in Figure 1 shows the device operating in class AB, with both paths split and combined with a 3 dB hybrid coupler on the input and output, respectively. To achieve higher efficiency, the two devices can be configured as carrier and peaking amplifiers in a broadband Doherty configuration.

Excellent raw linearity at the device level helps to reduce the complexity and cost of external linearization or to increase the output power and efficiency. ***Figure 2*** shows the two-tone IMD performance versus tone spacing. Linearization of the device was characterized using an Optichron digital predistortion (DPD) system. With DPD, the ACPR of the circuit was reduced to the noise floor of -54 dBc, using a two carrier LTE signal with 7.9 dB PAR and 40 MHz signal bandwidth, showing no RF performance degradation at 7 dB back-off from the peak power.

The PTGA090304MD wideband IC provides state-of-the-art performance below 1 GHz and meets the requirements of base station PAs. Scheduled for production in the third quarter of 2018, it will have the widest bandwidth of any 1 GHz RFIC on the market—while offering competitive narrowband performance. Infineon plans future two-stage ICs using 50 V LDMOS, for different power levels.

Infineon RF
Morgan Hill, Calif.
www.infineon.com/rfpower



95 dBm IIP3 Switch Boosts LTE ULCA Performance

RF Innovation
Starnberg, Germany

LTE uplink carrier aggregation (ULCA) puts new, significant linearity challenges on RF front-end components. The switches need to be ultra-linear to achieve the best receive sensitivity, with an input third-order intercept point (IIP3) greater than 90 dBm required to achieve uncompromised performance.

RF Innovation has developed a technology—SwIP®—that improves third-order intermodulation (IM3) performance of FET-based switches by greater than 20 dB (see ***Figure 1***), which boosts switch linearity to levels of 95 dBm IIP3. While this technology can be used in many applications where ultra-linear switches are required, LTE ULCA is probably the most prominent since the benefits are dramatic. Many concepts have been developed that try to overcome the shortcomings of limited IM3 performance in RF front-ends, but all of them require extra effort and cost, such as separate antennas for the two uplink carriers. Now, SwIP technology allows an easier, smaller and more cost-effective solution for RF front-ends.

LTE ULCA CHALLENGES

LTE carrier aggregation (CA) has almost unlimited possibilities to combine available spectrum. The uplink case puts tough linearity requirements on the RF front-end components, requiring unprecedented IIP3 levels. While LTE without uplink CA requires approximately 72 dBm IP3, adding uplink CA increases this to greater than 90 dBm, because mixing products can fall into the receive bands and reduce receive sensitivity (see ***Figure 2***). For example, for uplink inter-band CA of bands 1 and 3, the intermodulation products of the two transmit (Tx) carriers fall into the band 1 receive (Rx) and GPS spectrum, respectively. A similar issue occurs for uplink CA of bands 2 and 4, where the upper IM3

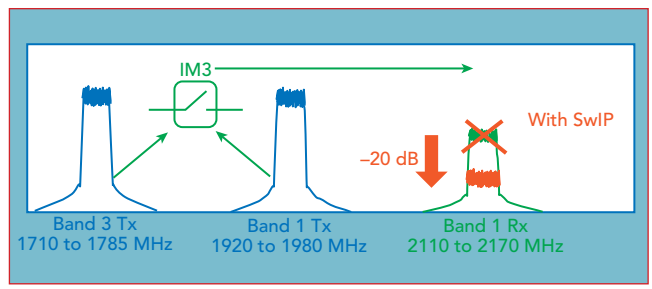


Fig. 1 SwIP reduces IM3 products, boosting LTE carrier aggregation performance.

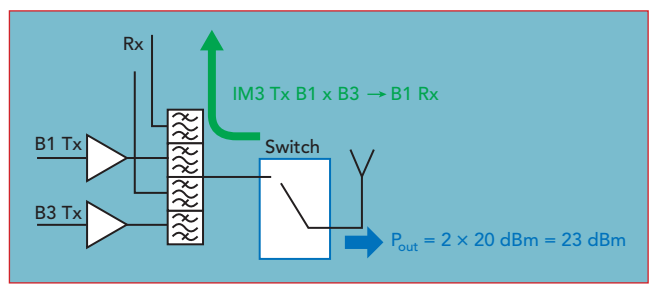


Fig. 2 With uplink carrier aggregation, antenna switch creates unwanted IM3 products that fall into band receive frequencies.

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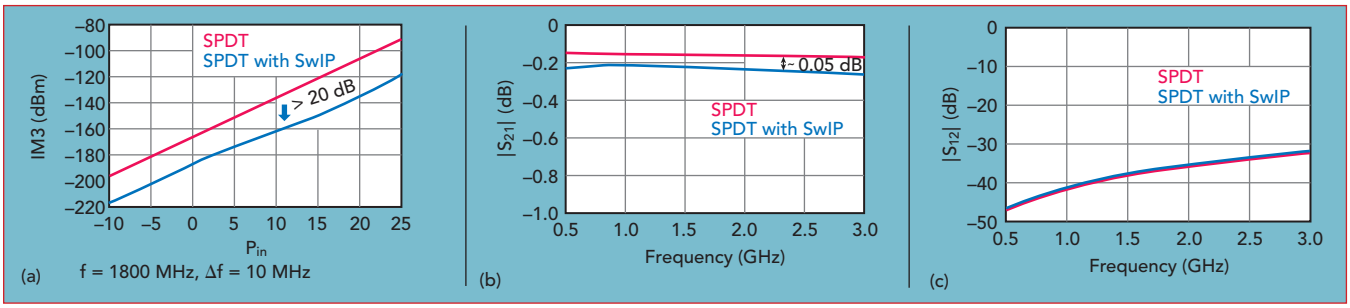

Fig. 3 **SPDT IM3 (a), insertion loss (b) and isolation (c) using SwIP technology.**

product falls into the band 2 Rx spectrum. 3GPP specifications acknowledge the technical challenge and allow maximum sensitivity degradation (MSD) up to 25 dB.

SwIP TECHNOLOGY

Most of this loss of sensitivity can be regained using SwIP technology. SwIP has been developed by RF Innovation to help meet these requirements and uses existing semiconductor processes. The main features and benefits of SwIP are:

- Up to 20 dB improvement in IMD3, boosting IP3 to 95 dBm
- Process agnostic: applicable for bulk CMOS, SOI and GaAs PHEMT
- Power agnostic: applicable for any power level
- No impact on isolation
- Approximately 0.1 mm² die area
- Approximately 0.05 dB added insertion loss.

Figure 3 shows the performance improvement SwIP technology adds to a standard SPDT switch implemented in SOI. A SOI-based SPDT has an inherent IP3 of 83 dBm, the performance that commercially-available, high IP3 switches offer today. Using SwIP, IM3 products are 20 to 25 dB lower, increasing IP3 by 12 dB to an absolute level of 95 dBm.

The price paid for this IM3 improvement is a minor insertion loss increase of approximately 0.05 dB and approximately 0.1 mm² additional die area compared to the baseline SPDT. The isolation is identical to that of the baseline SPDT. A sensitivity analysis simulating production, voltage, temperature and load VSWR swings shows robust behavior.

The benefits of SwIP technology were verified with demonstration hardware fabbed on a 180 nm SOI process. Compared to a SPDT switch without SwIP, the first tape-out hardware achieved:

- IMD3 improvement of 15 to 20 dB
- Approximately 0.1 dB additional insertion loss
- Identical isolation.

APPLICATIONS

LTE ULCA is one of the targeted applications for SwIP technology, as it enables highly linear RF front-ends with IIP3 up to 95 dBm. However, its usage is not limited to mobile phone switches; it covers any RF switch application requiring extraordinary high linearity with power levels up to tens of Watts. SPDT, DPDT and more complex configurations with multiple inputs and outputs can be supported.

The technology has been proven with SOI hardware and has been successfully evaluated for GaAs PHEMT and bulk CMOS processes.

RF Innovation is offering SwIP intellectual property rights to interested parties for licensing or acquisition.

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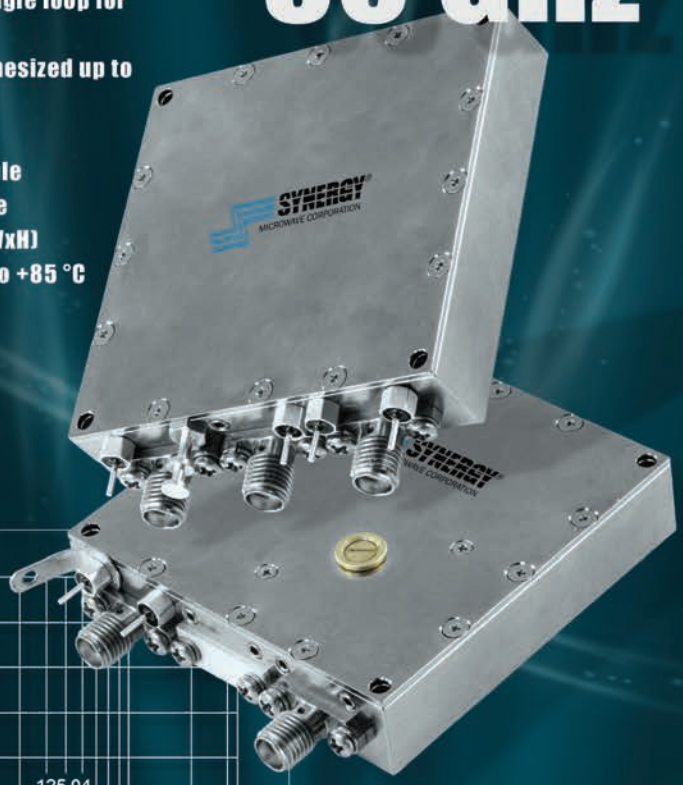
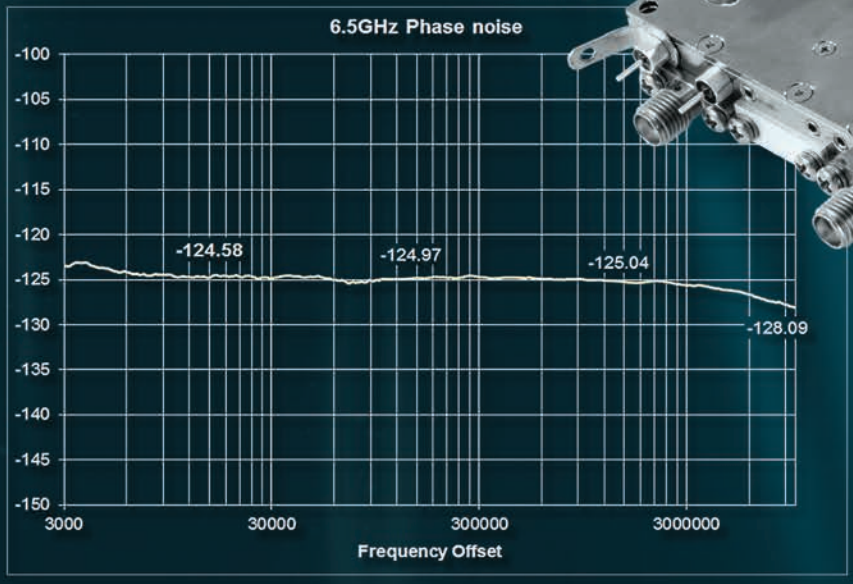


Applications:

- SATCOM, RADAR, MICROWAVE RADIO

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



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High Performance, Cost-Effective VNA Test Cables

Offering a cost-effective alternative to original equipment manufacturer VNA cable solutions, the new TestPro VNA test cables have been specially designed to withstand the rigors of test laboratory use and production testing for 50 Ω communications systems. The test cables are available as single cable or phase-matched pairs and are delivered in three standard lengths of 25, 38 and 48 in.

Available in 40, 50 and 67 GHz options, the TestPro VNA test cables have a guaranteed maximum phase and loss change. This is significant and essential because amplitude and phase variation following VNA calibration causes inaccurate S-parameter measurements. These phase-stable cables are available in both male and female versions and either 2.92 mm, 2.4 mm or 1.85 mm diameters.

To endure the rigorous treatment and harsh environments that test cables are often subjected to in the laboratory and in production, the TestPro VNA series is designed to be robust: the braided stainless steel armoring surrounding the coax provides a rugged, self-locking, flexible cable with a flex life exceeding 50,000 cycles. While robust, the TestPro VNA cable assemblies are still able to offer precise phase and amplitude stability when flexed and provide good accuracy and long-lasting intervals between recalibration.

As they provide accurate measurements with phase and amplitude stability, offer long calibration intervals, a high degree of flexibility with no spring-back and are long-lasting, the TestPro VNA series is particularly applicable for VNAs, testing in laboratory environments and critical measurements.

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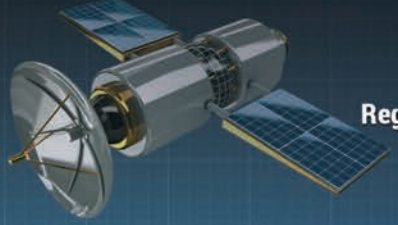

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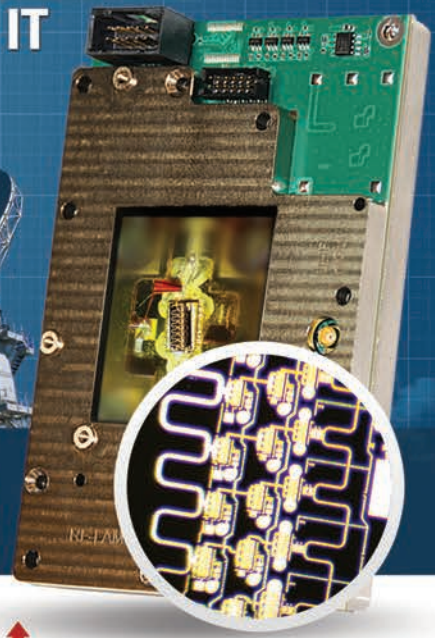

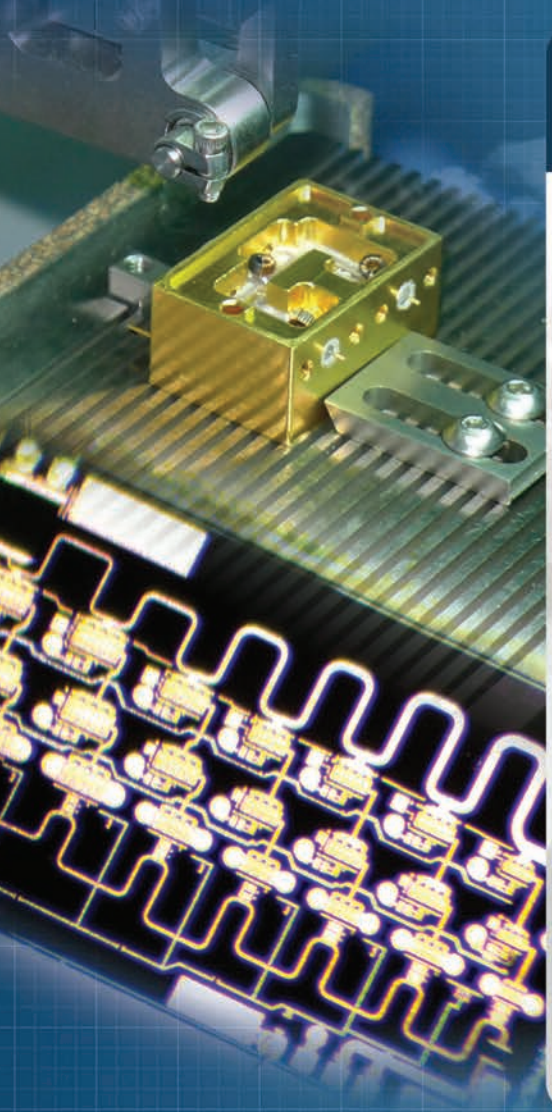

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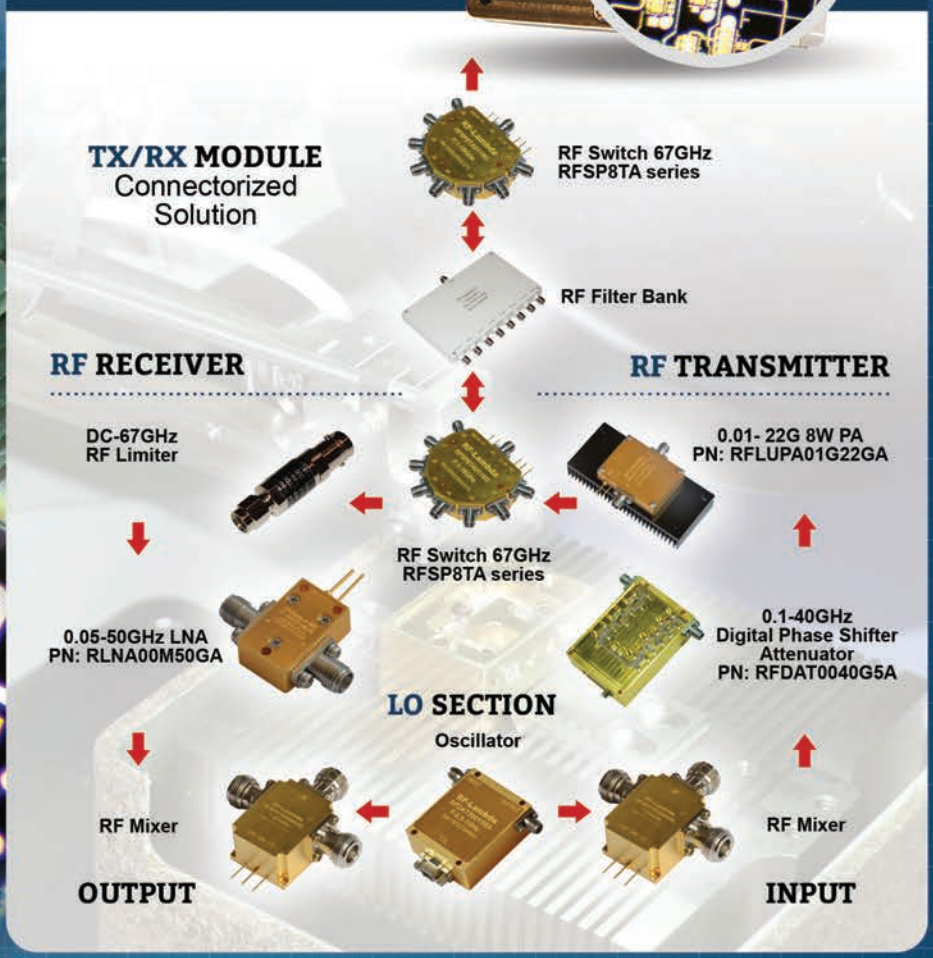

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GaAs PHEMT Amplifiers Optimized for Mixers

Marki Microwave recently introduced two GaAs PHEMT distributed amplifiers optimized for mixer and low phase noise applications.

The ADM-5974CH covers DC to 35 GHz with 14 dB small-signal gain, +22 dBm saturated output power, 6 dB noise figure, −153 dBc/Hz phase noise at 10 kHz offset and 16 dB return loss. This amplifier provides an efficient and optimized LO drive for Marki's mixers and is well-suited for electronic warfare, clock distribution and test and measurement applications.

The second amplifier, the ADM-5931CH, covers DC to 28 GHz and provides 11 dB small-signal gain and +18 dBm saturated output power, drawing less than 85 mA DC bias current. The amplifier's noise figure is 6 dB, phase noise is −153 dBc/Hz at 10 kHz offset, and the return loss is 16 dB. An efficient and low power solution, this amplifier is well-suited for use as a preamp or LO driver.

With a negative gate bias voltage, Marki Microwave's GaAs PHEMT amplifiers are optimized to provide high even-harmonic suppression while generating high odd harmonics, to emulate a square wave with low rise and fall times. Marki's mixers are designed to uniquely take advantage of this design approach. Fabricated with a low noise PHEMT process, Marki amplifiers work well in low phase noise applications.

The ADM-5974CH and ADM-5931CH are available as bare die, with enhanced moisture resistance to improve reliability. Marki also offers a selection of amplifiers in surface-mount, 3 mm x 3 mm and 4 mm x 4 mm QFN packages or multi-chip connectorized modules.

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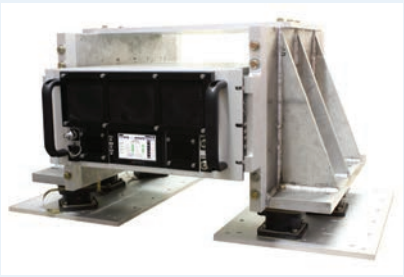
COTS PA Design Passes MIL-STD-810



A commercial off-the-shelf (COTS) power amplifier (PA) design developed by Empower RF Systems passed MIL-STD-810 testing, an endorsement of the ruggedness of the company's products. Adding a dust filter was the only adaptation for testing.

Mounted in a test fixture, Empower's Model SKU 2126 was subjected to 40 G shock while operating uninterrupted at full rated output power. The amplifier system was tested to MIL-STD-810E, Method 514.4, with 40 G peak vibration and operated for 270 minutes on each axis. The unit also passed a three-axis shock test to MIL-STD-810F, Method 516.5, with 18, 40 G peak pulses per direction, using an 11 ms sawtooth pulse.

Empower's tested and field-proven design is common across the company's "Next Generation" family of amplifiers. The amplifiers incorporate a patented architecture and reflect design goals to minimize RF power losses along the internal signal path, simplify manufacturing and enable ease of servicing. The design includes RF and digital printed circuit board signal routing that eliminates virtually every internal connector, RF cable and electrical harness. This makes the amplifier fundamentally rugged and reliable, while improving the RF efficiency.

Understanding that connecting external metering hardware will reduce the reliability of the overall PA platform, Empower's engineers incorporated the external power sensors, meter and data converters into the amplifier. This improves reliability; eliminates RF power losses associated with the external connector, cable and coupler; and lowers system cost, eliminating the need to purchase external metering equipment.

The consequence of this compact, electro-mechanical structural design with added instrumentation is a COTS amplifier that is inherently durable. Even if the application does not require military "shake and bake" certification, the ruggedness protects the amplifier when it is shipped—often many times during its lifetime—and, let's face it, accidents do happen.

VENDORVIEW

Empower RF Systems
Inglewood, Calif.
www.EmpowerRF.com

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Head of Connectivity, SCL, Facebook

"AT&T Perspectives on 5G Services"
David Lu
Vice President, AT&T

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- Test-bed Services for 5G

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ATC Product Selection Guide

ATC's Product Selection Guide is a time saving tool that guides the designer to a selection of RF Passive Products, suitable for the application frequency of interest. It is organized by popular frequency range segments that are associated with distinct application categories. These categories include 0 to 30 MHz for HF, 30 to 800 MHz for Public Safety Radio, 800 to 3500 MHz for UHF and cellular and 3500 MHz to 100 GHz for microwave and mmWave. Each range has a unique color-code that makes the selection process user-friendly.

American Technical Ceramics (ATC)
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EM Simulation for Automotive Applications

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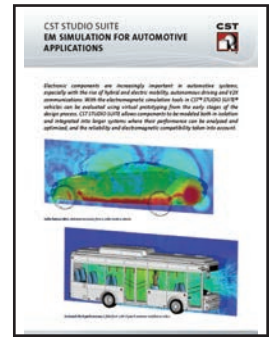

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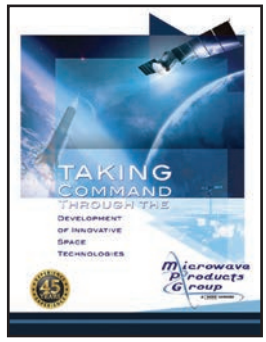
New Catalog Update



Dow-Key® Microwave is the oldest continuously operating switch manufacturer in the U.S. Today, the company is part of the Microwave Products Group, a subsidiary of Dover Corporation. Space business experts stress the most critical aspect of supplier selection is heritage. Just released is the MPG Space Brochure which highlights and unifies the heritage, product leadership and innovation of four world-class brands to enable superior space reliability under demanding conditions.

Dow-Key Microwave
www.dowkey.com

Updated Online Catalog

VENDORVIEW

Exodus Advanced Communications has updated its website's online catalog to reflect the new products they have developed in recent months. The updated search function can be used to find the best match for your needs. Should you have a custom product request, you can submit your requirement on the company's website at any time or via email at sales@exoduscomm.com. The company's engineering service group provides full design support starting from the conceptual phase to prototype verification and full production capability.

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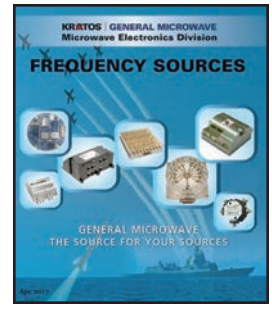

General Microwave Corporation has designed and manufactured cutting edge microwave frequency sources since 1987. This Short Form Catalog includes sources ranging from free running voltage and digitally controlled oscillators to fast (1 usec) indirect synthesizers, company profile and a wideband frequency modulation applications and techniques tutorial. Specially featured is the Series SM60 family of fast indirect synthesizers capable of analog and digital frequency modulation while center frequency remains in the pure locked mode.

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Hot New Products

VENDORVIEW

This new 20 page product guide provides a complete survey of Mini-Circuits' latest product releases from the second quarter of 2017. Highlights include everything from ultra-wideband coaxial LNAs, multi-channel programmable attenuation systems, high-power stripline 90° hybrids, ultra-wideband splitters up to 40 GHz and more. Mini-Circuits is continuously innovating new products to meet your needs, and this informative product line update will help you stay up to date with our latest, coolest new model releases.

Mini-Circuits
www.minicircuits.com

2018 Product Catalog

Passive Plus Inc. (PPI) has released its new 2018 Product Catalog showcasing several new additions to their 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 their website. PPI manufactures high quality, high-power passive components using state-of-the-art manufacturing techniques. 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

High-Power Component Catalog

RLC Electronics' catalog includes mechanical footprints and electrical specifications for their high-power component capabilities. RLC's high-power capabilities include high-power SP2T and multi-position switches, high-power filters (lowpass, bandpass and band-reject) and high-power couplers, all up to 40 GHz. Units have been tested and proven to withstand the most severe environmental conditions. RLC can also provide customized designs to meet specific customer requirements not shown in the catalog.

RLC Electronics
www.rlcelectronics.com

New 2018 Main Catalog

VENDORVIEW

SAGE Millimeter's 2018 Main Catalog features 10 product families to offer total component and subassembly solutions for system integrations and applications. The 10 product families include antennas, amplifiers, frequency converters, control devices, ferrite devices, oscillators, modules and subsystems, test equipment and waveguide passive components. Custom designed products are also available by contacting the sales department. Request a copy of their catalog at www.sagemillimeter.com.

SAGE Millimeter
www.sagemillimeter.com

New 2018 Catalog

VENDORVIEW

Spectrum Instrumentation is a world-leading manufacturer of digitizers and AWGs, offering a perfect fit solution for every customer at a fair price and available from stock. How is this possible? Find out in the new 2018 catalog, which shows and explains all the benefits of Spectrum's unique, modular product design and their unique, five-year warranty that makes them the solution of choice for leading companies and research institutes. The catalog is available as print or PDF at: www.spectrum-instrumentation.com/en/contact-us.

Spectrum Instrumentation
www.spectrum-instrumentation.com

Enhanced Product Catalog

SV Microwave just released their latest Product Catalog which combines all of their most popular series (Coaxial Contacts, 2.92 mm, 2.4 mm, 1.85 mm, SMA, SMP, SMPM and SMPS) into one catalog. The company has also added their cable assemblies. Each part number in the latest version can be easily purchased through distribution. Additionally, the digital edition includes part number hyperlinks that connect to their respective website landing page. Each part number landing page shows stock availability and technical specs, allows the user to download the data drawing, request a quote and more.

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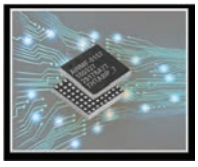
The Second Generation IC Family

VENDORVIEW



Anokiwave announced the next product in a new family of second generation 5G silicon quad core ICs that enable 3GPP compliant base stations with the worldwide release of the 28 GHz AWMF-0157 IC. The second generation IC family is part of Anokiwave's on-going strategy to enable the commercialization of 5G mmWave systems with silicon ICs. The AWMF-0157 operates at 26.5 to 29.5 GHz, supports four radiating elements and includes gain and phase controls for analog RF beam steering.
Anokiwave
www.anokiwave.com

High Voltage Coupled Inductors

The LPD8035V provides 1500 Vrms, one-minute isolation (high potential) between windings from a package that measures just 7.92 × 6.4 × 3.5 mm, providing users with significant size and cost reductions over conventional bobbin-wound alternatives. It is ideal for Flyback, SEPIC and isolated-buck converter designs. The LPD8035V Series is currently offered in six inductance values ranging from 4.7 to 150 µH. It provides peak current ratings up to 2.7 Amps, which represents a 40 percent increase over previous generation products. It also has a tight coupling coefficient (≥ 0.97).
Coilcraft
www.coilcraft.com

High Cycle Switches

Dow-Key Microwave introduces high cycle switches. The SPDT (401U- and 521U-series) and the transfer (411CU-series) switches offer the high-reliability expected from Dow-Key with the improvement of 5× the life. This is achieved through Dow-Key's precise design and tight manufacturing specifications. Primarily used in the commercial market, these switches have many applications including commercial, wireless and SATCOM, on board communication systems, antennas, Automatic Test Equipment (ATE) and many other diverse applications.
Dow-Key Microwave
www.dowkey.com

WZ-Series Filters

VENDORVIEW

Exceed Microwave's WZ-Series bandpass filters utilize super high Q resonators, providing very low insertion loss while maintaining high frequency selectivity. Low insertion loss and the structural design allows for higher power handling than any other waveguide filter. This is ideal for pre-select filters for low NF as well as high-power transmit filters. WZ-Series BPF is available in any frequency up to V-Band.
Exceed Microwave
www.exceedmicrowave.com

Shielded Surface Mount RF Inductors

Gowanda Electronics, a designer and manufacturer of precision electronic components for RF and power applications, announces the expansion of its SML32S series of wirewound, shielded, molded RF surface mount inductors in the "1210" style. This expansion increases the number of individual parts in the series by more than 20 percent and broadens the inductance range by adding values from 120 to 470 µH. The expansion was done in order to address the market need for higher inductance shielded inductors in RF applications.
Gowanda Electronics
www.gowanda.com

1208 MHz Lowpass Filter

KR Electronics part #3337+ is a 1208 MHz lowpass filter. The filter is a selective elliptic type filter. The stopband starts at 1292 MHz and is maintained to > 6 GHz. The filter is

supplied in a miniature surface mount package measuring 0.20 × 0.30 × 0.18 in. Other frequencies are available.
KR Electronics
www.krfilters.com

Two Stage Combiner

The M Wave Design Corp. model #90HPCA1201 is a high-power 0° X-Band 8:1 two stage combiner network that weighs just under 1 lb and will handle eight each 2 Kw peak/100 W+ average inputs. The rated output power is 800 W CW out with an integrated 50 W termination for phase imbalance reflection. The input ports are SMA female and output is WR90 choke flange (MIL-F-3922/59-006).
M Wave Design Corp.
www.mwavedesign.com

Broad Band (0.38 to 6 GHz) Low PIM 10 W Loads

VENDORVIEW

MECA's new compact low PIM (-170 dBc typ.) 10 W loads with extended frequency and power handling capabilities. Feature industry leading PIM verified at 1900 MHz (+40 dBm) at -160 dBc min all while handling full rated power to 85°C. All of the terminations cover 0.38 to 6 GHz frequency bands in Type N, 4.3/10.0 and 7/16 DIN interfaces. With VSWR's of 1.10:1 typ./1.20:1 min (0.698 to 2.70 GHz) and 1.15:1 typ./1.25:1 Max (0.38 to 0.698 and 2.7 to 6 GHz). All in a compact package of 5.25 × 1.25 in. Made in U.S. with 36 month warranty.
MECA Electronics Inc.
www.e-MECA.com

SPDT Switch

VENDORVIEW

Mini-Circuits' MSP2TA Series are ultra-reliable, rugged-duty absorptive fail-safe SP2T switches designed in break-before-make configuration offering an ultra-long switching life. Powered by +12 VDC, the device has a typical switching speed of 20 ms, insertion loss of 0.25 dB and high isolation of 80 dB. The MSP2TA series are suitable for use across a wide range of applications, including switching for automated test equipment and redundancy switching.
Mini-Circuits
www.minicircuits.com

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New**Products**

2-Way Splitter

VENDORVIEW

The MRFSP5725 2-way splitter 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. These units are built lead-free and RoHS compliant. S-parameters are available on request.

MiniRF
www.minirf.com

Surge Protectors

RF Superstore has expanded their product offering to include surge protectors, commonly used on antenna installations to protect sensitive equipment. The initial product line is focused on N-Type surge protectors with wide-band operating frequency ranging from DC to 7 GHz, VSWR of 1.50:1, a maximum impedance of 50 Ohms, with an insertion loss of < 0.5 dB.

RF Superstore
www.RFsuperstore.com

High-Power 18 GHz SPDT Switch

RLC Electronics announces the addition of a high-power 18 GHz SPDT switch with N connectors to its product capabilities. The switch can handle 1000 W at 100 MHz, 200 W at 4 GHz and 125 W at 18 GHz, and provides high-reliability, long life and excellent electrical performance characteristics over the frequency range (including high isolation). Options on the switch include operating mode (failsafe or latching) and coil voltage (12 or 28 VDC), as well as indicator circuitry and a TTL driver.

RLC Electronics
www.rlcelectronics.com

CABLES & CONNECTORS

Coaxial Cable

MHD Cable announces spiral strip shield flexible microwave and mmWave coaxial cable for up to 18, 26.5 and 40 GHz. For the reference, the company enclosed RF, microwave, mmWave cable parts list up to ~18, ~26.5 and ~40 GHz. They also offer RG flexible cable (RG-142, RG-214), semi-flexible hand-formable cable (SF-141), semi-rigid cable (SR-085) based on MIL-C-17 standard and customized special cables, PTFE semi-finished core cables.

MHD Cable
www.mil-c-17.co.kr

Removable End Launch Connectors

VENDORVIEW

Pasternack has released a new line of high speed end launch connectors. These new removable end launch connectors are perfect for signal integrity measurements, coplanar waveguide, chip evaluations, SERDES, substrate characterization, 25 GbE and test fixture applications. Pasternack's new series of high speed end launch connectors is comprised of four models that provide VSWR as low as 1.10:1 and a maximum operating frequency of 40 to 110 GHz. Connector options include 1 mm end launch (110 GHz), 1.85 mm end launch (67 GHz), 2.92 mm end launch (40 GHz) and 2.4 mm end launch (50 GHz).

Pasternack
www.pasternack.com

Connectors

Radiall has expanded its range of RF passive products equipped with an SMP-LOCK® interface for the space market. This innovative connector features an easy and robust locking mechanism which dramatically increases the retention force of the interface, prevents accidental disconnection and saves significant integration time. Radiall's SMP-LOCK® is a high performance interconnect solution at a low cost. This connector is compliant with an SMP interface and includes a unique quick locking system to simplify installation and provide a secure connection.

Radiall
www.radiall.com

AMPLIFIERS

0.7 to 18 GHz Dual Band Amplifiers

VENDORVIEW

AR RF/Microwave put two of their state-of-the-art Class A amplifiers in a single chassis, and now you can go from 0.7 to 18 GHz with the reliability of solid state designs. With up to 60 W in the first 0.7 to 6 GHz band split and up to 40 W output power in the 6 to 18 GHz split, the company put it together for you in one package that costs less, weighs less and takes up less space than two separate amplifiers.

AR RF/Microwave Instrumentation
www.arww-rfmicro.com/html/ps-dual-band-amplifiers.asp

Solid Power Amplifier Module

VENDORVIEW

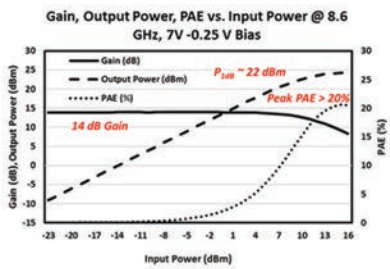
The AMP11108 state power amplifiers covers the entire 1 to 8 GHz frequency range at 40 W minimum and high P1dB output pow-

er rating. Operating off 32 VDC at 8 amp typical and covering three full octaves bandwidth this Class AB linear module features built-in protection circuits and high ruggedness in a small form factor, lightweight housing. The AMP1110A is suitable for CW, pulse and all linear single channel modulation standards and for applications such as TWT replacement, communications and EW.
Exodus Advanced Communications
www.exoduscomm.com

High-Power GaN-on-SiC Transistor

Integra Technologies announces the release of a new full-matched, GaN-on-SiC transistor offering 50 W at 5 to 6 GHz. Designed for pulsed C-Band radar applications, the IGT5359L50 GaN-on-SiC HEMT transistor is full-matched to 50 Ohms and supplies 50 W of peak pulsed output power at 50 V drain bias. This transistor cover the frequency range of 5.2 to 5.9 GHz with instantaneous response, features 14 dB of gain and 43 percent efficiency at 1 ms/15 percent pulse conditions.
Integra Technologies
www.integratech.com

DC to 35 GHz Amplifier



Marki Microwave now offers a versatile DC to 35 GHz amplifier in a bare die package, with 14 dB of gain and +22 dBm saturated output power. The ADM-5974CH provides efficient optimized LO drive to all Marki Microwave mixers, ideal for EW, clock distribution or test and measurement applications. The design allows for single-supply DC biasing for customer convenience or for optional negative bias to increase even harmonic rejection and decrease DC current consumption.
Marki Microwave Inc.
www.markimicrowave.com

Low Noise Amplifier

VENDORVIEW

PMI model #PE2-30-8R018R0-3R5-22-12-SFF is an 8 to 18 GHz, low noise amplifier with a typical gain of 30 dB while maintaining a maximum gain flatness of ±1.5 dB over the operating frequency. The typical noise figure is 3.5 dB and offers a minimum OP1 dB of 20 dBm. The operating voltage is +12 to +15 VDC with a maximum current draw of 325 mA. This model is supplied with removable SMA female connectors in their standard PE2 housing.
Planar Monolithics Industries Inc.
www.pmi-rf.com

Low Noise Amplifier

VENDORVIEW

Model SBL-1834232840-KFKF-E3 is a low noise amplifier with a typical small signal gain of 28 dB and a nominal noise figure of 4 dB across the frequency range of 18 to 42 GHz. The DC power requirement for the amplifier is +12 VDC/240 mA. The input and output port configurations are both female K connectors. Other port configurations are available under different model numbers.

SAGE Millimeter
www.sagemillimeter.com

SUBSYSTEMS

16 x 16 L-Band Distributing Matrix with 20 Outputs

DEV is introducing a new L-Band Distribution Matrix in its product portfolio. The Matrix can be configured with up to 16 input and 20 output channels and fits in a compact 2 RU chassis. The 16² (DEV 1985) provides a high degree of flexibility: the number of input and output channels can be changed; connectors and impedances can be configured even after purchase. In addition to electrical and optical inputs, the 16² supports variable gain and slope. It comes with a local user interface and provides many more helpful features.

DEV Systemtechnik GmbH
www.dev-systemtechnik.com

SYSTEMS

2 to 18 GHz Wideband Transceiver

Norden Millimeter introduces the NUDC2-18/1.3-2.3 wideband microwave transceiver in a low-SWaP 3U module. The NUDC2-18/1.3-2.3 includes internal LOs which provide an instantaneous IF bandwidth of 1 GHz and exceptional noise figure: down-converter NF = 6 dB max, up-converter NF = 15 dB max. Both the RF and IF paths include variable attenuation. The NUDC2-18/1.3-2.3 is digitally controlled by RS-485.

Norden Millimeter
www.nordengroup.com

SOURCES

Calibrated Noise Sources

Fairview Microwave Inc. has introduced a new line of calibrated noise sources most commonly used as a precision reference source to measure system level noise figure. Specific applications may involve increasing the dynamic range of analog to digital converters by dithering and reducing correlated noise, system and component wireless testing, signal simulation, evaluating analog and DOCSYS CATV systems and simulation of RF jamming systems for missile guidance.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Hybrid Voltage Controlled Oscillators

RFE's broadband VCOs are designed to meet the challenges of today's military, industrial and commercial markets. They hybrid designs incorporate silicon bipolar transistors and hyperabrupt varactor tuning diodes to give broad bandwidths, reduced phase noise and low post tuning drift. RFE can offer any possible frequency output from 500 MHz to 20 GHz with octave bandwidths available. The case of reconfiguration allows great control of all VCO parameters to meet your critical design needs.

RFE Inc.
www.RFE-mw.com

High Performance 20 GHz Signal Source

SignalCore's high performance 20 GHz VCO-based synthesized signal source is cost effective, compact and designed for seamless integration. With frequency spanning 100 MHz to 20 GHz (1 Hz resolution), low phase noise of -115 dBc/Hz at 10 kHz offset at 10 GHz carrier and amplitude step resolution of 0.01 dB over a -30 to +15 dBm output range, this product is ideal for R&D, academic, military and commercial applications. Full implementation instructions and GUI included. Available in USB, SPI, RS-232 and PXIe.

SignalCore Inc.
www.signalcore.com

1.5 to 3.2 GHz Low Noise VCO

The DCM0150318-5 is a small, half inch square VCO covering the greater-than-octave tuning band from 1500 to 3200 MHz with a tuning voltage of +0.5 to +20 VDC. With a bias voltage of +5 V at 30 mA, this low noise, voltage tuned oscillator will deliver a minimum buffered output power of +7 dBm. The wide tuning range gives a typical low phase noise of -93 dBc/Hz at an offset frequency of 10 kHz and -153 dBc/Hz at 10 MHz offset is ideally suited for automated assembly.

Synergy Microwave Corp.
www.synergymwave.com

ANTENNAS

Small Form Factor Antenna

VENDORVIEW

RFMW Ltd. announces design and sales support for small form factor antenna from Southwest Antennas. The 1001-202 is a half-wave dipole, omni antenna for 2.1 to 2.5 GHz applications. Measuring only 4.29 in. in height, it offers 2.15 dBi of peak gain. The antenna features a tough, black, G10 fiberglass radome and a black-chrome, TNC(m), non-rotating, RF connector making the antenna ideal for low-visibility or tactical applications such as tactical hand-held radios, body-worn radio systems, unmanned robotics platforms and other applications where size and weight are critical.

RFMW Ltd.
www.rfmw.com

New**Products**

TEST EQUIPMENT

S-Series Multi-Purpose RF Test System

Elite RF is proud to introduce the new and innovative S-Series multi-purpose RF test system. It is a flexible alternative to expensive and bulky RF test equipment and can be used in a multitude of applications/settings, such as an ATE factory application. Independent control of each RF system allows for maximum test flexibility and the system can be connected to a larger monitor for viewing multiple windows at the same time. The S-Series also comes with a two year warranty and is made in the U.S.

Elite RF
www.eliterfllc.com

RF and Microwave Power Sensor

VENDORVIEW

The LB680A is a 50 MHz to 20 GHz RF and microwave power sensor designed for pulse measurements. In addition to average power, the sensor makes triggered pulse measurements and provides a time domain plot of the pulse power profile. The sensor also makes statistical pulse measurements including peak and pulse power. The sensor utilizes a 10 MHz video filter, making it ideal for many applications including radar, IoT, manufacturing test and more.

LadyBug Technologies
www.ladybug-tech.com

Smart Power Sensor

VENDORVIEW

Mini-Circuits' PWR-8P-RC is a compact sensor-head that turns any PC into a high performance power meter for peak and average measurements of CW and pulse modulated signals. The sensor has an 80 dB input dynamic range and wide bandwidth, allowing measurement of RF powers down to -60 dBm over 10 to 8000 MHz. The USB HID interface is "plug and play" compatible, meaning no driver installation is required, while the additional Ethernet interface allows remote power measurements over a network.

Mini-Circuits
www.minicircuits.com

Moveable OTA Test Chamber

VENDORVIEW

The new R&S ATS1000 antenna test chamber from Rohde & Schwarz allows developers and production engineers to perform over-the-air (OTA) measurements for 5G on their antenna modules, transceivers, chipsets and wireless devices. Antenna and transceiver measurements are possible in the frequency range from 18 to 87 GHz. The system therefore supports all mmWave frequency bands currently considered for 5G. The compact test chamber makes it possible to measure mobile devices in the far field.

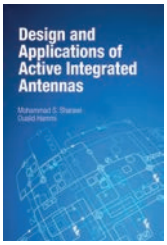
Rohde & Schwarz
www.rohde-schwarz.com

Headless RF Spectrum Analyzer

Signal Hound has announced the SM200A 20 GHz headless RF spectrum analyzer and monitoring receiver for applications ranging from IoT and 5G cellular, to military, aerospace, spectrum management, automotive and radar. Optimized for performance, flexibility, space and cost, the SM200A lowers the cost of entry to high-end spectrum analysis while delivering precisely what is required for the most demanding production-line and spectrum monitoring RF analysis applications.

Signal Hound
www.signalhound.com

MICRO-ADS



Design and Applications of Active Integrated Antennas

Mohammad S. Sharawi and Oualid Hammi

This comprehensive new resource guides professionals in the latest methods used when designing active integrated antennas (AIA) for wireless communication devices for various standards. This book provides complete design procedures for the various elements of AIA, such as the matching network and the amplifier/active element as well as the antenna. This book offers insight into how active integration and co-design between the active components (amplifier, oscillator, mixer, diodes) and the antenna can provide better power transfer, higher gains, increased efficiencies, switched beam patterns and smaller design footprints. It introduces the co-design approach of AIA and its superior performance over conventional methods.

Complete design examples are given of active integrated antenna systems for narrow and wideband applications as well as for MIMO systems. Readers find the latest design methods for narrow and broadband RF matching networks. This book provides a complete listing of performance metrics for active integrated antennas. The book serves as a complete reference and design guide in the area of AIA.

Contents: Impedance Matching Methods; Amplifier Design; Antenna Fundamentals; Active Integrated Antennas; A Co-Design Approach for Designing AIA.

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Fractus Antennas—Making the Virtual Reality

When is an antenna not an antenna? The question may be a riddle but the answer, namely Fractus Antennas' Virtual Antenna™, is a serious phenomenon—a design that challenges the recognized perception of the make-up of antennas used for mobile and IoT applications. However, this technological breakthrough was not developed by an army of boffins in a large laboratory in Silicon Valley but by a focused, dedicated team housed in bright, sunny facilities on a technology park in the hills just outside Barcelona, Spain.

A visit to the facility not only presented the opportunity to see the set-up firsthand but also to meet one of its founders, Dr. Carles Puente. His first research into fractal antennas came as a student and researcher at the Universitat Politècnica de Catalunya (UPC).

In 1999, a fellow student at UPC, Ruben Bonet, was looking to start a company. This not only coincided with Carles' ambition to develop his work commercially but also the evolution of multiband technology. He explained, "We were developing the right technology at the right time, saw the potential for this technology worldwide and so founded the company with help from investors from all over the world."

The company, called Fractus, was active in developing and selling fractal-based antenna products. In 2009, the business was changed into a dual operation with one side selling products, the other selling licenses. However, these licenses were infringed by a number of phone manufacturers, which led to Fractus bringing lawsuits for patent infringement. These were all settled in the company's favor.

Consequently, in July 2015, the company was split into Fractus S.A., dealing with the licensing side, and the formation of a new and independent company called Fractus Antennas SL, in its current form. The whole Fractus Antennas operation is run out of the Barcelona facility with key account managers in Taiwan and India and several worldwide distribution partners, including Richardson RFPD.

While the facility might have a small footprint, the processes and capability for prototyping, testing and validating is extensive, including both chemical and mechanical prototyping labs. Antenna simulation tools such as CST, IE3D and Microwave Office are used, together with Gerber file importation and analysis. There is a full RF lab with the latest VNAs and two anechoic chambers, including a SATIMO Stargate 32, for active testing of smartphones, alongside a BlueTest reverberation chamber.

Armed with these capabilities, Fractus Antennas develops its Virtual Antenna technology that enables the packaging of full multiband mobile antenna performance in a 5 mm by 5 mm chip antenna component, featuring antenna-less technology based on a new generation of tiny components known as antenna boosters.

Being considerably smaller than the operating wavelength, antenna boosters provide full functional multiband wireless connectivity and fit any device form factor and design.

Carles explained, "Fractus Antennas' architecture offers flexibility to accommodate multiple bands, whether it is 4G, 5G or MIMO. Or the same component can be used for mobile, Bluetooth or GPS. It is more like microwave engineering than antenna engineering and gives electronic and microwave engineers the means to migrate into the antenna field and the wireless space more easily.

"Our aim is to deliver tiny, off-the-shelf, standalone components that provide designers with the flexibility to use them in a way not previously possible. This means that chip antenna components can be incorporated on the motherboard like any other component. So the antenna is no longer an outcast!"

As for the future, Carles believes that smartphones will evolve to antenna-less solutions, yet is realistic enough to know that if this technology is going to be pervasive, Fractus Antennas cannot be the only supplier. So, licensing will be the next option and despite past experience, Carles is unfazed, stating, "You can't just be in your cave inventing technology; you need customer feedback and interaction to develop. We need to deliver the message to the industry that we want to share our antenna-less technology with other supply partners and are ready to do so."

www.fractusantennas.com

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- Eg. Track Switch Closures (Assign to Interlock Group)
- Eg. Trigger Alarm Relay (Sends Email Alert)
- Eg. RF Presence Status/Alarm (Safety Feature)
- Eg. Alarm, Activated Switch

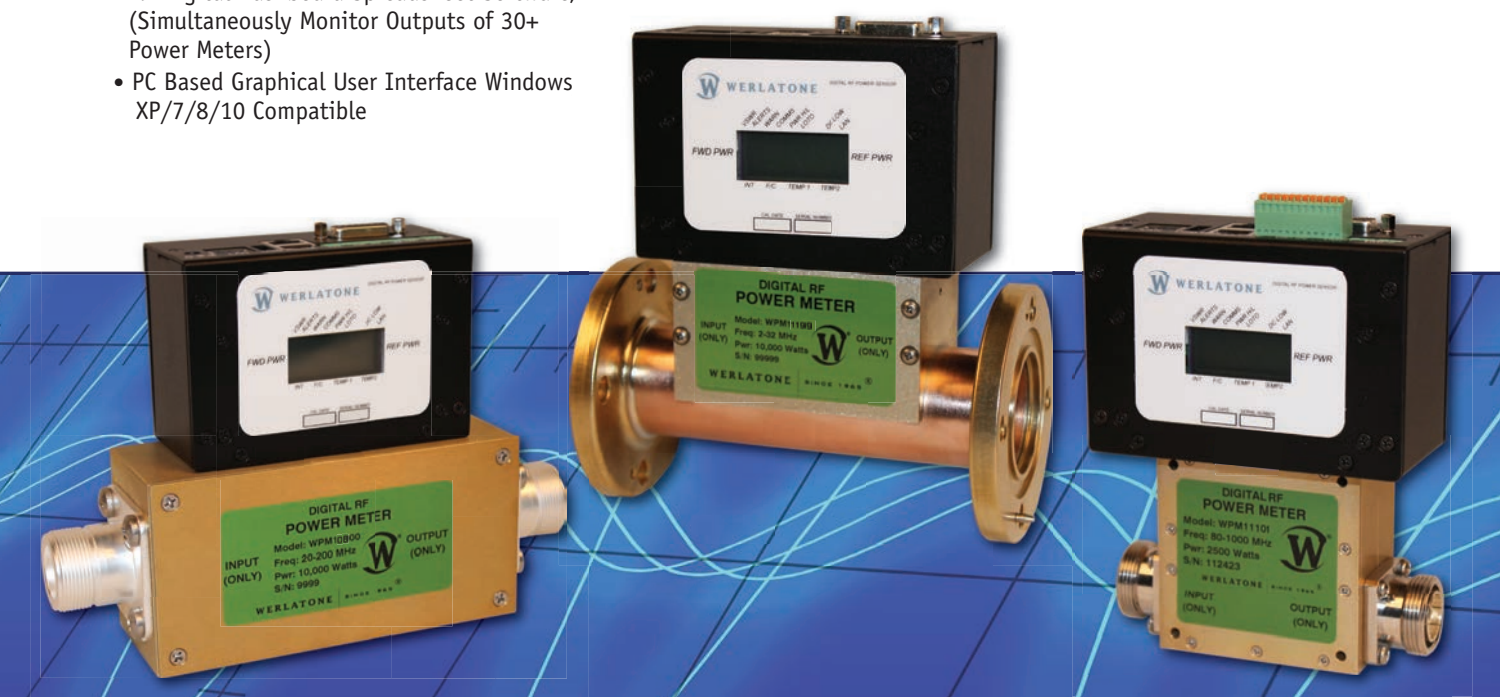
Accessories
- Single Channel and Multi-Channel Displays (1U Rack, Graphical User Interface)
- RF Digital Dashboard Spreadsheet Software, (Simultaneously Monitor Outputs of 30+ Power Meters)
- PC Based Graphical User Interface Windows XP/7/8/10 Compatible

Accuracy
- ± 1% to Customer Calibration Standard, at Preselected Frequencies
- ± 5% over a Multi-Octave Bandwidth
- Werlatone Calibration Traceable to **(NIST) National Institute of Standards and Technology**

Power
- AC Power Adapter (100/240 50-60 Hertz V AC)
- POE (Passive Over Ethernet, Optional POE Injector Kit Available)
- Via RS485 (Via Single Channel or Multi-Channel Displays)

Interface (Via)
- TCP/IP - SNMP and Browser Interface via Local Area Network
- RS232, Serial
- RS485 - Form Addressable Serial Network
- User ID and Password Protected for Access and Control
- Multiple units can be Networked and Simultaneously Monitored On-Site or Remotely (TCP/IP/SNMP/Serial)

✓ RoHS Compliant Design Available
✓ Custom Connector Configurations Available



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