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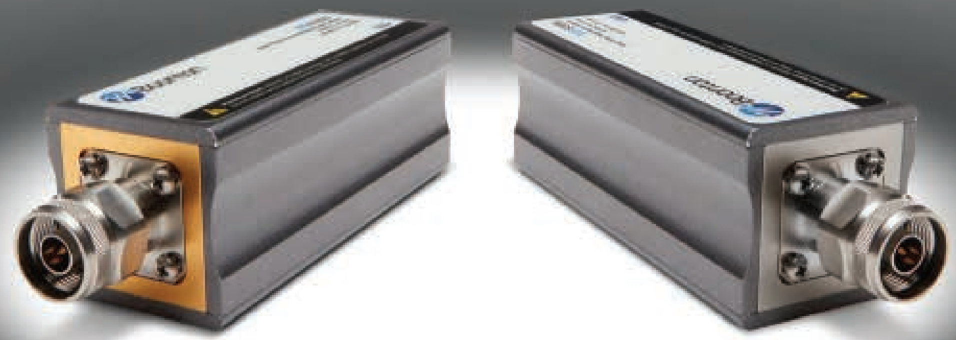


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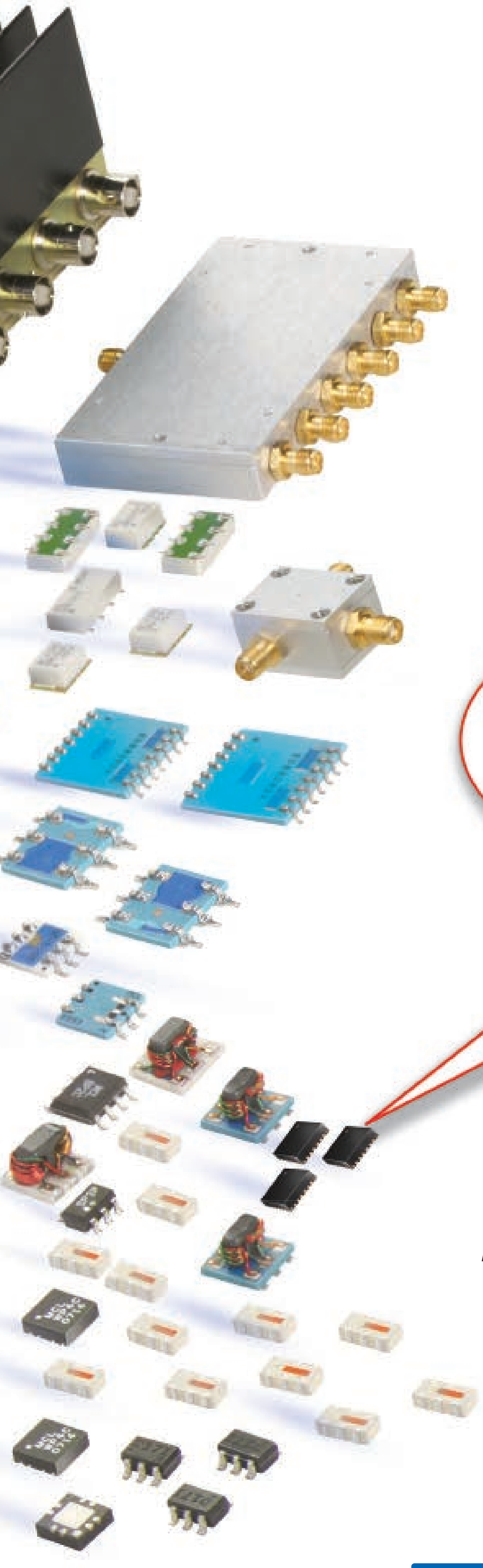

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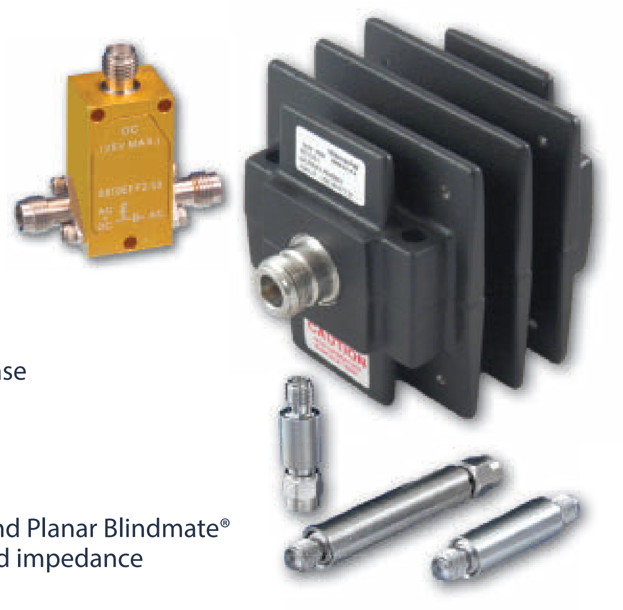

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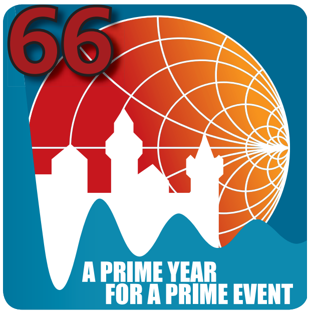

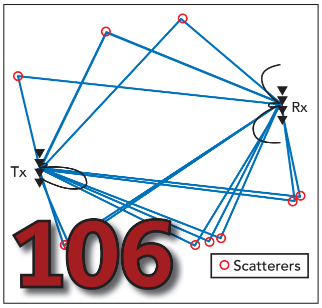

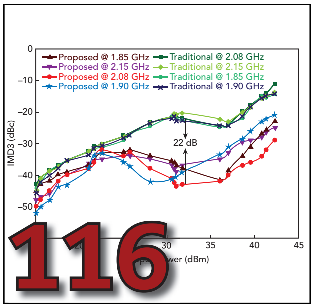

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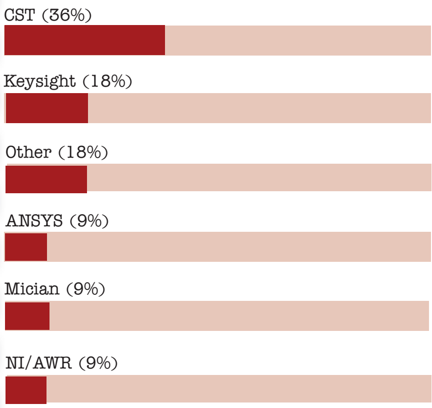

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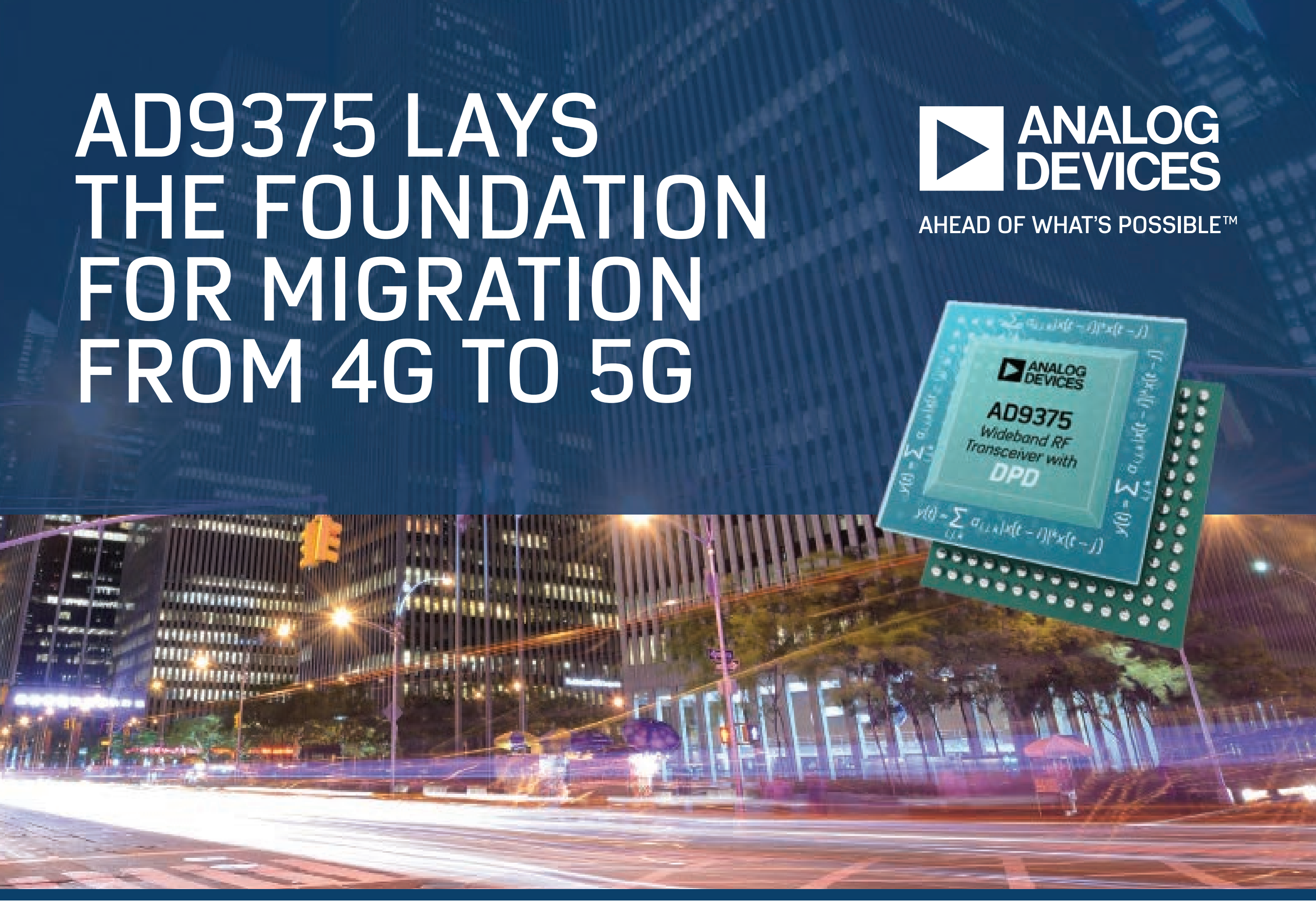
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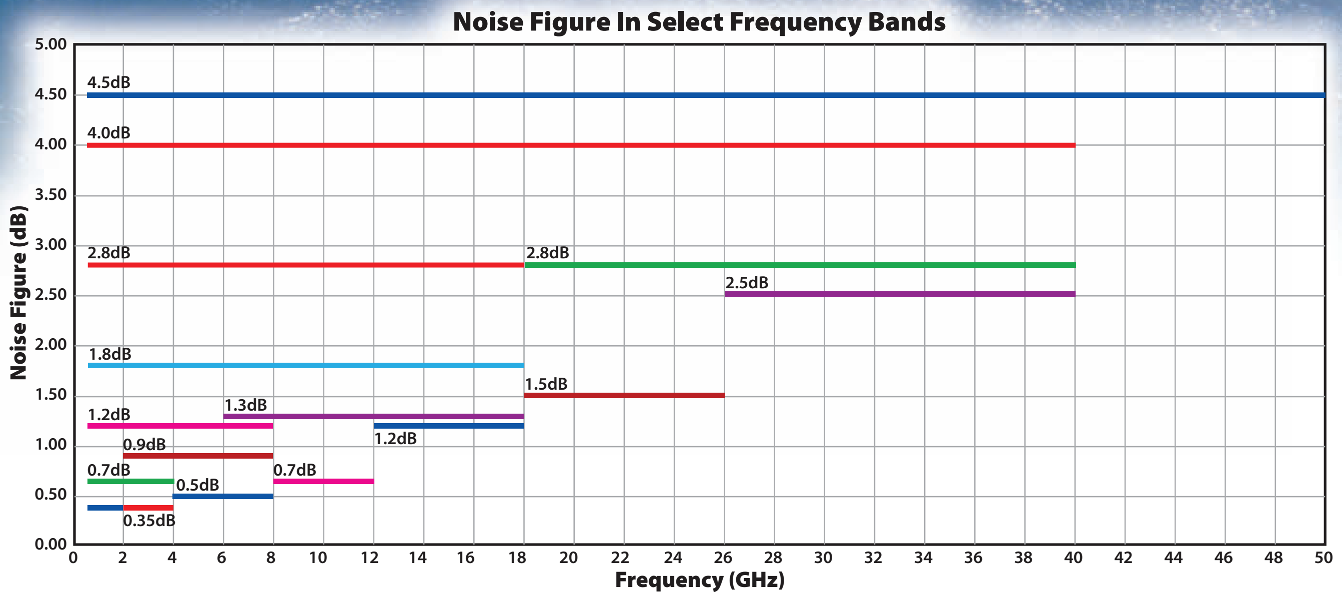


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Invited Paper

From MIMO to Massive MIMO

Paul Harris, Mark Beach and Simon Armour
University of Bristol (U.K.)

Ian Mings
British Telecom (BT)

As we move towards a fifth generation (5G) of wireless networks, the growth in smartphone subscriptions and new wireless applications has resulted in predicted capacity requirements of 100x beyond Long Term Evolution (LTE)–4G.[1] These predictions are now being whittled down into requirements by the 3rd Generation Partnership Project (3GPP) and standardization is well underway.[2] A new physical layer technology that has received a lot of attention in recent years is Massive multiple-input, multiple-output (MIMO), with its ability to dramatically ramp up spectral efficiency figures to unprecedented levels.

In a time where usable spectrum is scarce and expensive, this is a highly attractive solution for operators to increase the capacity possible within the sub-6 GHz bands, and an early form of the technology known as Full-Dimension (FD) MIMO was already considered as early as LTE Release 13.[3] Whilst much progress has been made, Massive MIMO is far from a mature solution. It is still an active research and development area for academia and industry alike, as engineers try to achieve the theoretical gains with commercially deployable solutions.

From an operator perspective, Massive MIMO is able to assist in solving two of the key challenges in the Radio Access Network (RAN)—capacity and coverage. Spectrum remains a scarce and relatively expensive resource for mobile operators, but is a key driver of RAN capacity and headline speed. This is particularly the case in many cities where base station spacing is driven by capacity rather than coverage, which requires a dense cell deployment incurring additional costs for the base stations and site acquisition. The high spectral efficiency delivered by Massive MIMO spatial multiplexing offers an opportunity to deliver capacity increases using existing sites. In areas where cell deployment is driven by coverage rather than capacity, there are also opportunities to use Massive MIMO array gain to increase the range of the base station—particularly when using spectrum between 2 and 6 GHz.

MASSIVE MIMO CONCEPT

Massive MIMO is an evolution of the Multi-User (MU) MIMO multi-antenna technique that exploits multipath scattering to increase system capacity.[4] The generic MU-MIMO model is shown in ***Figure 1***, where an M antenna base station (BS) serves up to K single-antenna user terminals on the same time-frequency resource.

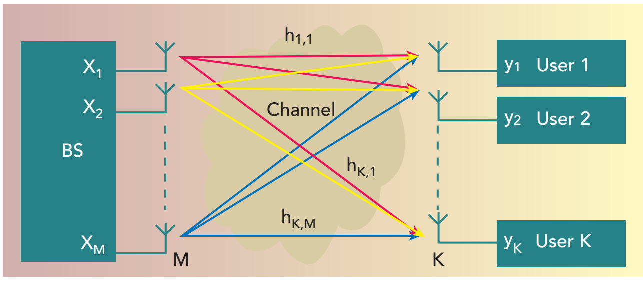


Fig. 1 MU-MIMO model.

M is greater than or equal to K and, strictly speaking, the terminals can each have multiple antennas, but as this is not a requirement, it has been omitted for simplicity. All BS antennas have full RF chains with digitization behind them and the signal processing associated with Massive MIMO is uniquely applied to each signal path from the RF head.

With sufficient spacing between the BS antennas and well dispersed user terminals, independent multipath channels between each BS antenna and user terminal are formed, providing additional degrees of freedom in space. By appropriately precoding the symbols for each user terminal onto the BS antennas using channel knowledge, these spatial degrees of freedom can be harnessed to simultaneously serve multiple user terminals within the same frequency band—a process known as spatial multiplexing. MU-MIMO is already present within both LTE Advanced and the 802.11ac Wi-Fi standard.

In a Massive MIMO system, the number of BS antennas is increased significantly to far outweigh the number of user terminals served, typically by a factor of 10. This increase in degrees of freedom serves to better guarantee spatial orthogonality between users, reducing inter-user interference (IUI) and providing for a more stable, deterministic spatial multiplexing gain when using MU-MIMO. A large amount of array gain is possible, which permits low-power RF chains for the same range, and the law of large numbers also comes into play to average out the effects of noise, fast-fading and hardware impairments.

Furthermore, the natural orthogonality gained in the spatial dimension permits low-complexity linear decoding and precoding at the BS, reducing computational overheads and latency. An overview of the common linear techniques is given in ***Table 1***. The user terminal itself does not need to do anything other than transmit its training signal—the BS does the rest. Massive MIMO does not encompass all systems with a large array of antennas, some of which often perform more conventional beam steering, but specifically those systems that use many tens or hundreds of digital RF chains to conduct robust spatial multiplexing.

TABLE 1

AN OVERVIEW OF LINEAR DECODING/PRECODING TECHNIQUES

Linear Decoder/Precoder	*Description*
Matched Filtering (MF)	Also known as maximal ratio combining/transmission (MRC/MRT). Applies the conjugate frequency domain channel vector and thus does not consider IUI. Typically best for low-SNR regimes.
Zero-forcing (ZF)	Uses degrees of freedom to null IUI. Amplifies noise. Outperforms MF in most practical cases when SNR is high.
Regularised ZF (RZF)	ZF that considers the impact of noise to enhance performance (MMSE).

It should also be noted that whilst using millimeter wave frequencies may seem attractive from an array size perspective, there are several issues with this: high path-loss, prohibitively expensive Full Massive MIMO processing (see Table 1) across GHz bandwidths and rapid multipath channel decoherence. For these reasons, millimeter wave systems with large arrays tend to apply a hybrid approach, with analogue beam steering to compensate for link budget, followed by a reduced level of digital MIMO operation within the analogue beams.

As the number of antennas on the BS side increases, so too does the number of channels that require training. To avoid infeasible training overheads and reach maximum capacity, Massive MIMO must operate in time-division duplex (TDD) mode and exploit channel reciprocity. In doing so the number of orthogonal training signals required is no longer

dependent upon M but solely the number of user terminals present. However, frequency-division duplex (FDD) Massive MIMO solutions are being explored as a large percentage of the world's 4G networks currently operate in this mode.

Fig. 2 Lund 100-antenna Massive MIMO testbed.[13]

Fig. 3 Bristol 128-antenna Massive MIMO testbed, which is managed by Bristol Is Open (BIO), a joint venture between the University of Bristol and the Bristol City Council.

IMPLEMENTING MASSIVE MIMO

The momentum for making Massive MIMO happen has built tremendously in the past year. ZTE has released a Pre5G Massive MIMO BS,[5] demonstrating a 4 to 6x improvement in spectral efficiency through various trials, and Nokia, jointly with Sprint, demonstrated a Massive MIMO solution at Mobile World Congress 2017.[6] Facebook has constructed a Massive MIMO prototype for long-range rural access[7] and even Intel has joined the party to provide its own processing solution for large-scale MIMO systems.[8]

Going back a few years prior to these developments, Lund University in Sweden partnered with the Advanced Wireless Research Group at National Instruments in 2014 to construct the world's first Massive MIMO testbed.[9] The University of Bristol joined the collaboration in 2015 to contribute to the ongoing software development having constructed a Massive MIMO platform of its own using the same hardware. These two systems are shown in ***Figure 2*** and ***Figure 3***, respectively. These systems were constructed entirely from commercial-off-the-shelf (COTS) hardware components all linked together using Gen-2 PCIe. An overview of the specifications can be found in ***Table 2***.

In implementing the systems, there

TABLE 2
SYSTEM SPECIFICATIONS

No. of Antennas	100 (Lund), 128 (Bristol)
No. of Terminals (Spatially Multiplexed)	12
Max Tx Power per Chain	15 dBm
Carrier Frequency Range	1.2 to 6 GHz (3.51 GHz used at Bristol)
Bandwidth	20 MHz
Waveform	LTE Spec OFDM (1200 15 kHz subcarriers)
Modulation	QPSK, 16-QAM, 64-QAM, 256-QAM
Duplexing	TDD (0.5 ms switching period)
MIMO Decoding/Precoding	ZF, regularised ZF and matched filtering (MF)

were two key challenges: data handling and processing latency. For a single 20 MHz LTE band, each RF chain is producing and consuming 30.72 MS/s, which equates to 122.9 MB/s/chain when using 4 bytes/sample. For a 128-antenna system, this sums up to a bidirectional rate of 15.7 GB/s. Not only is this a lot of data to process, but a fast TDD switching period of 0.5 ms is required to ensure channel validity for the downlink and this brings with it a strict requirement for processing latency. The schedule shown in ***Figure 4*** illustrates the orthogonal frequency-division multiplexing (OFDM) symbol layout across one full 10 ms radio frame and specifically the seven OFDM symbols within one 0.5 ms slot. Following reception of the UL Pilot symbol, the precoding matrices for all frequency domain resource blocks must be available and samples ready for transmission just three OFDM symbols (214 μs) later.

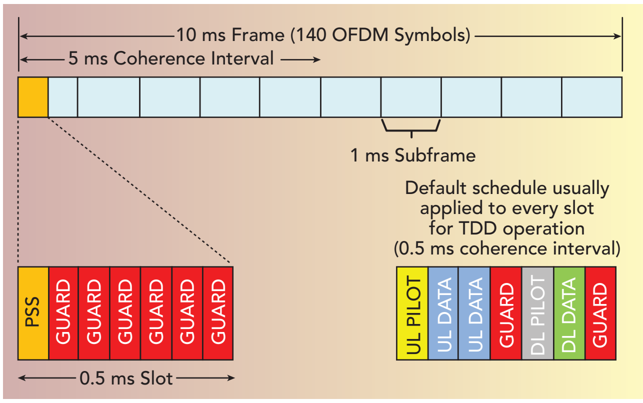
The per chain data rate was reduced by performing OFDM modulation and demodulation at the RF front-end utilizing Kintex 7 FPGAs present on the software-defined radios (SDR). At subcarrier rate with 3 bytes per complex sample, each chain has a bidirectional throughput of 50.4 MB/s. Sixteen antenna subsystems were then formed with careful sample routing to provide eight bidirectional links of 806.4 MB/s back to the central MIMO co-processors—a sum bidirectional rate of just under 6.5 GB/s. At the heart of the system, a further four Kintex 7 FPGAs perform 128 × 12 (M × K) MIMO processing on a quarter of the bandwidth each (300 subcarriers).

The maximum peer-to-peer link rate of each co-processor across PCIe is 2.4 GB/s, which means three co-processors would have satisfied the throughput requirement; however, four were chosen to further lower the burden on low-latency design. Each co-processor must perform channel estimation and form linear decoding and precoding matrices for its portion of bandwidth. The linear decoding and precoding options included in the design were matched filtering (MF), zero-forcing (ZF) and regularized ZF, the latter two of which require matrix inversions.

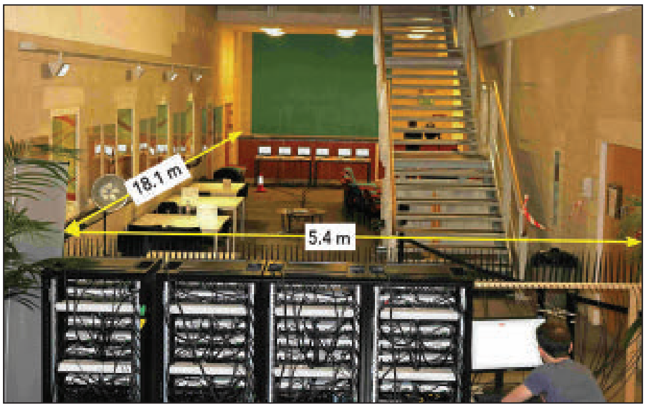
Using a QR decomposition for matrix inversion implemented through a modified Gram-Schmidt process with a partially parallel systolic array,[10] these four FPGA card co-processors clocked at 200 MHz met the throughput requirement of 1.4 million matrices/s. Clearly, implementing a fully digital Massive MIMO solution is far from trivial, but these systems went on to demonstrate just how huge the spectral efficiency gain can be.[11,12]

EXTREME SPECTRAL EFFICIENCY

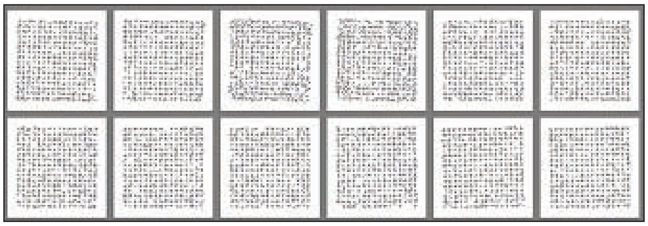
Through enhanced MU-MIMO spatial multiplexing, Massive MIMO provides the opportunity to ramp-up spectral efficiencies to unprecedented levels by serving multiple user terminals on the same time-



▲ Fig. 4 TD LTE-like PHY frame schedule.



▲ Fig. 5 Indoor trial one: University of Bristol lower atrium.[14]

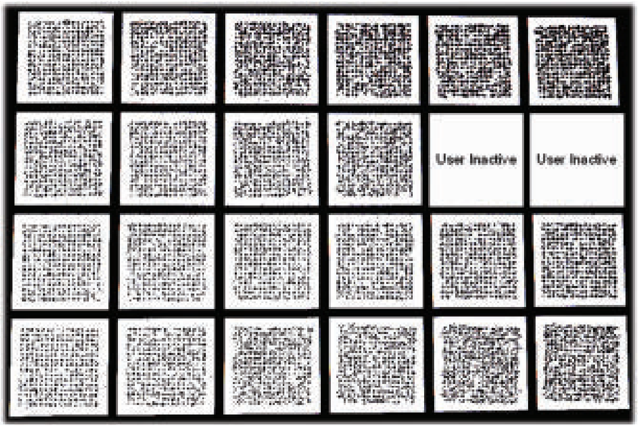


▲ Fig. 6 UL Constellations from each user terminal in indoor scenario 1 after ZF decoding.[14]

frequency resource. The theoretical results were promising, but until recently there had been little in the way of publicized demonstration of real implementations achieving such gains.

In early 2016, with newly implemented real-time systems, the University of Bristol and Lund University ventured out of the lab for the first time to see what was possible. Within an indoor atrium environment at the University of Bristol, a 5.4 m long linear array of 112 dipole antennas was used to serve 12 user terminals at a distance of 18 m (see ***Figure 5***). The user terminals were closely spaced (2.5 to 6 λ) and configured for uplink only transmission using 256-QAM. In this scenario, a record breaking spectral efficiency of nearly 80 bits/s/Hz was achieved with a rate of 132 Mb/s from each user terminal; a sum rate of 1.59 Gb/s in 20 MHz of bandwidth. The clarity of the received constellations in ***Figure 6*** illustrates just how well the system mitigated IUI with linear decoding alone (ZF).

▲ Fig. 7 Indoor trial two: University of Bristol upper atrium.[15]



▲ Fig. 8 Uplink constellations for 22 users following ZF decoding in indoor trial 2.[15]

Two months after this first trial, armed with a new 128-element patch array, a second indoor trial was conducted in the upper atrium of the same building. This time, modifications were made to enable up to 24 user terminals to be served, and the aim was to see how far it could really be pushed. At a distance of nearly 25 m, the BS and user terminals were placed at opposite ends of the atrium as shown in ***Figure 7***. The BS array had a 4 × 32 configuration with alternating H&V polarizations, thus still exhibiting dominance in the azimuth, and the user terminals were bunched in a straight line with the same 2.5 to 6λ spacing as the first trial.

Once again transmitting with 256-QAM in the uplink, it was possible to spatially multiplex up to 22 user terminals and infer an achievable spectral efficiency of nearly 146 bits/s/Hz through post-emulation (nearly 3 Gb/s in only 20 MHz of bandwidth). The received constellations are shown in ***Figure 8*** and once again illustrate the excellent IUI mitigation achieved with ZF. In this scenario, adding a 23rd user caused a significant reduction in the SINR.[14,15]

To gain perspective and insight from a network operator, the two universities and National Instruments subsequently conducted trials in early 2017 jointly with British Telecom (BT) at BT Labs in Adastral Park, Suffolk, U.K.[16] Within an exhibition hall environment using the


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Fig. 9 Bristol Massive MIMO testbed receiving 64–QAM from 24 user clients at Adastral Park (BT R&D).

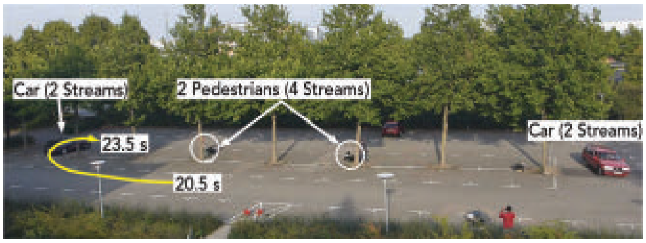
Fig. 10 Bristol Massive MIMO testbed demonstrating spatially multiplexed HD video transmission from 10 users.

128-antenna system, 24 user terminals were served with over-the-air (OTA) synchronization and up to 64-QAM modulation, inferring a spectral efficiency of over 100 bits/s/Hz (see ***Figure 9***). Also, spatially multiplexed HD video transmission from 10 user terminals was demonstrated (see ***Figure 10***). When compared to the second indoor trial conducted at the University of Bristol, this shows how the spatial multiplexing performance can vary within different environments. Whilst these results served to indicate the staggering gains possible with Massive MIMO, the next step was to consider outdoor environments and user terminal mobility.

MOBILITY

It has been expected that mobility will pose problems for Massive MIMO due to the impact of channel ageing upon decoding and precoding. With a linear technique such as zero-forcing, deeper nulls are placed upon interfering users with far greater precision in Massive MIMO, but this leaves less margin for error. The system is more sensitive to steep rises in IUI from terminal movement. Increasing the channel resounding interval may help to overcome this, but it ultimately eats into the coherence interval and limits the number of user terminals that can be served.

In the summer of 2016, Lund University and the University of Bristol conducted the world's first publicized demonstration of a real-time Massive MIMO system operating with mobile channel conditions. The 100-antenna Lund BS operating at 3.7 GHz was placed upon a third story rooftop and served multiple cars travelling at up to 50 km/h within a car park 30 to 50 m away. The scenario was predominantly line-of-sight (LOS) and a 4 × 25 azimuth dominated BS array configuration was used with alternating H&V polarizations. Configured as a mixture of bicycle carts and cars, up to eight user terminals were spatially multiplexed with both uplink and downlink transmission, and each terminal transmitting at a fixed power of 0 dBm.

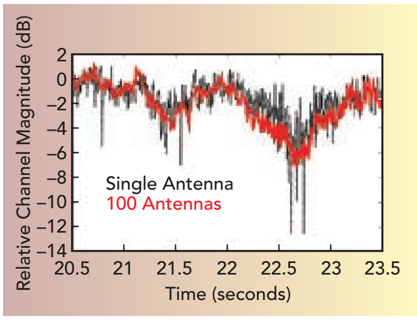


▲ Fig. 11 Fading scenario as viewed from the BS.[13]

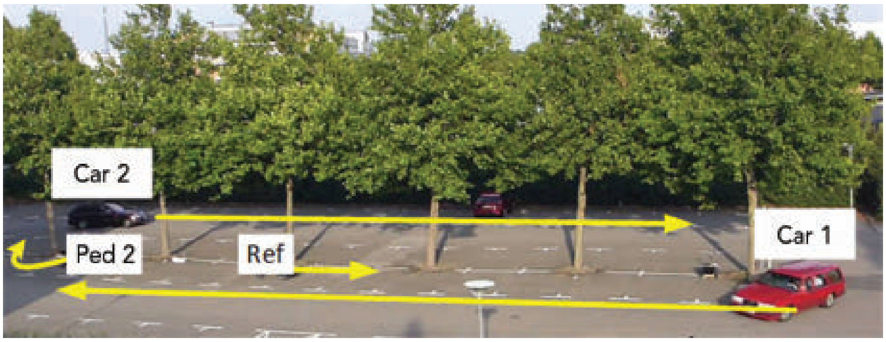
The 80th percentile real-time bit error rate (BER) achieved for all eight users in this scenario was 1 percent on the uplink and 10 percent on the downlink when using QPSK with no power control, user grouping or coding. A video of the demonstration can be found at: www.youtube.com/watch?v=wPPMrr4rHmo.

Some of the key insights from this measurement trial came from analyzing the temporal aspects of the measured channel data. By ensuring the uplink pilot symbols were captured at or above the Nyquist spatial rate (λ/2 sample spacing) for the periods of interest, an accurate picture of the channel behavior over time could be formed. ***Figure 11*** illustrates one portion of a scenario where the composite channel magnitude between the BS and one car user terminal was observed. This is the view from the BS array and the path of the car of interest over the three seconds is illustrated by a yellow arrow.

In ***Figure 12***, the normalized composite channel magnitude for the full 100 antennas is compared with that of a single BS antenna over the same three second period. The Massive MIMO case smooths out the Rician-like fading experienced by one antenna due to the huge gain in spatial diversity. In fact, inspecting the power correlation over time for this same period indicated that power control update



▲ Fig. 12 Comparison of channel magnitude over time: 100 antennas vs. single antenna.[13]



▲ **Fig. 13 Temporal correlation scenario for Car 2.[13]**

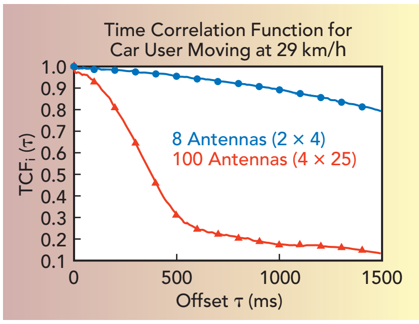
rates could be reduced by 5x for the 100-antenna case.

As previously mentioned, the critical aspect for Massive MIMO when it comes to mobility is the increased rate of channel decorrelation. To gain some insight into what the impact could be, a second scenario was established as pictured in ***Figure 13***. The user object of interest is Car 2, which moves across the car park in the direction of the arrow at a speed of 29 km/h—at this speed, the Nyquist rate is satisfied for the 5 ms channel capture rate used. Time-shifted correlations of the channel vector for this user were then performed, the results for which are shown in ***Figure 14***. By comparing the 100-antenna results to those from an 8-antenna configuration, the significant increase in decorrelation rate can be clearly seen.

Here, the 100-antenna system experiences a rate of decorrelation 7x greater than the 8-antenna system. The 90 pecent coherence time of 125 ms is still relatively large, but an outdoor LOS scenario with minimal scattering represents a best case for channel coherence. In addition to these results, which were recently published,[13] other measurements have begun to indicate just how severe the situation can be for non-line-of-sight (NLOS) scenarios, with a reported 90 percent coherence time of 500 ms with only 0.1 km/h of mobility.[17]

LOOKING TO THE FUTURE

Massive MIMO has set the stage for an unprecedented level of spectral efficiency, and will without a doubt feature in 5G wireless communication systems. Despite the advance of millimeter wave, the propagation characteristics of sub-6 GHz technology are more desirable for



▲ **Fig. 14 Comparison of channel decorrelation: 100 antennas vs. 8 antennas.[13]**

many scenarios, and Massive MIMO is therefore crucial for squeezing more out of the lower bands.

At first glance, it appears high-mobility could cause some difficulties for Massive MIMO deployments, but this may or may not be a problem depending upon the applications and environments it targets. In outdoor—LOS scenarios over greater range—the channel decoherence rates with typical vehicular speeds could potentially be tolerated with little training overhead. On the other hand, NLOS, dense-urban environments with rich multipath scattering will provide more rapid channel decoherence, but this may be tolerable with pedestrian level speeds.

One exciting possibility is to entirely change the way we view the channel and modulate signals, and an emerging wireless modulation technology called Orthogonal Time Frequency and Space (OTFS) is doing just that.[18] Rather than take snapshots of the frequency domain channel, OTFS formulates a 2D representation of the wireless channel in the Delay-Doppler domain (see ***Figure 15***). By choosing suitable time and bandwidth observation intervals, this essentially provides a complete representation of the wireless channel by indicating the delay and Doppler shift of each multipath component, just like a radar. Since the environment and Doppler trajectories change relatively slowly compared to the time-varying multipath channel, the Delay-Doppler coherence time is greater than that of the frequency domain.

This means OTFS could enable closed-loop Massive MIMO operation in conditions that OFDM cannot. By performing modulation in the Delay-Doppler domain using 2D basis vectors, the energy of each symbol is spread across time and frequency, utilizing the full diversity of the wireless channel. The result is a static channel response and stable SNR. Early results have shown that OTFS not only outperforms OFDM, but can operate using 64-QAM at 500 km/h, whilst OFDM must drop down to 16-QAM at this speed for a suitable Block Error Rate (BLER).

However, despite all the above, there are many challenges that need to be solved before Massive MIMO becomes mainstream for operators. These include:

- Potentially higher costs associated with maintaining Massive MIMO implementations that are based on Active Antenna Units (AAU), where the radio electronics are integrated with the antennas and installed at the top of the radio towers. These can only be maintained by skilled rigging teams. While this issue could be partially mitigated by the fact that a single element failure may

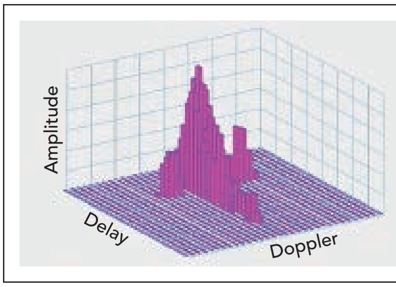


Fig. 15 OTFS Delay-Doppler domain.[18]

not greatly impact overall performance, further study is required.

- The impact of Massive MIMO systems on radiated power limits. The potential antenna gain from these systems may have a significant impact on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) compliance.
- The availability of tools to perform Massive MIMO radio planning.

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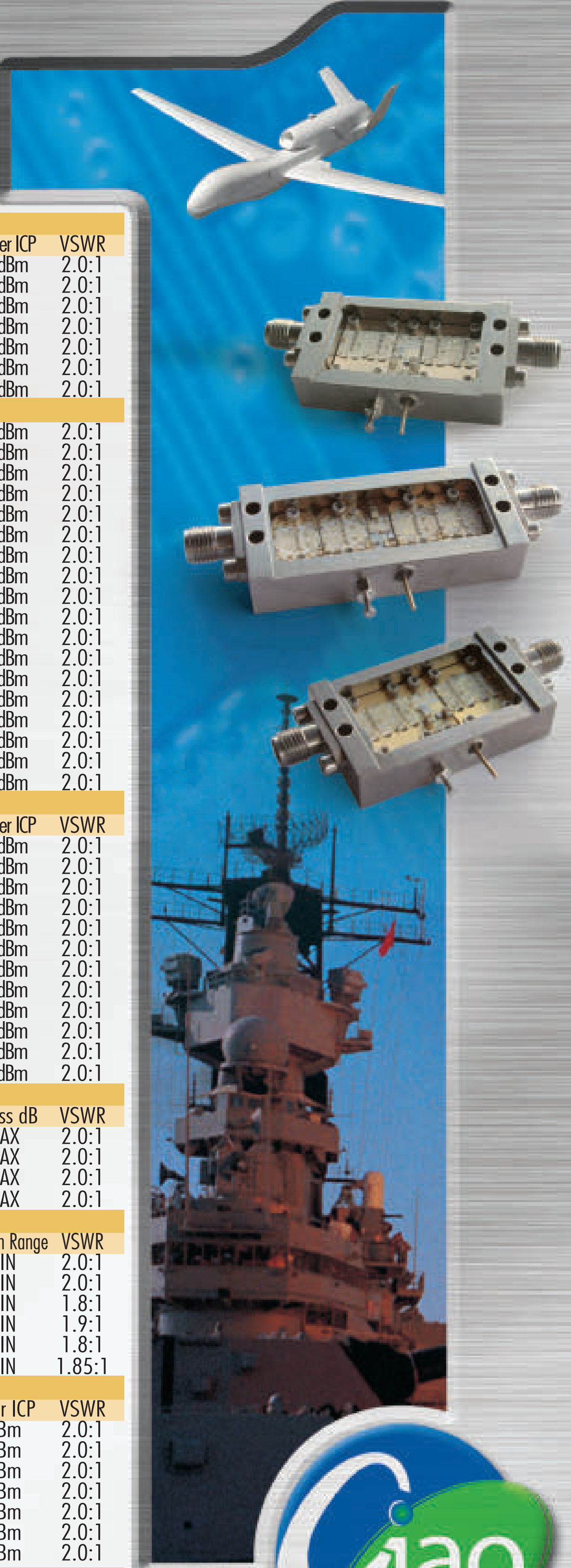

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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LM Invests $350M in State-of-the-Art Satellite Production Facility

Preliminary construction is underway on a new, $350 million Lockheed Martin (LM) facility that will produce next-generation satellites. The new facility, located on the company's Waterton Canyon campus near Denver, is the latest step in an ongoing transformation infused with innovation to provide future missions at reduced cost and cycle time.

The new Gateway Center, slated for completion in 2020, includes a state-of-the-art high bay clean room capable of simultaneously building a spectrum of satellites from micro to macro. The facility's paperless, digitally-enabled production environment incorporates rapidly-reconfigurable production lines and advanced test capability. It includes an expansive thermal vacuum chamber to simulate the harsh environment of space, an anechoic chamber for highly perceptive testing of sensors and communications systems and an advanced test operations and analysis center. The Gateway Center will be certified to security standards required to support vital national security missions.

266,000 sq. ft. "Factory of the Future" will Speed Production and Lower Costs

"This is our factory of the future: agile, efficient and packed with innovations. We'll be able to build satellites that communicate with front-line troops, explore other planets and support unique missions," said Rick Ambrose, executive vice president of Lockheed Martin Space Systems. "You could fit the Space Shuttle in the high bay with room to spare. That kind of size and versatility means we'll be able to maximize economies of scale, and with all of our test chambers under one roof, we can streamline and speed production."

LM expects the construction effort to employ a total of 1,500 contractors during the three-year construction phase. LM has added more than 750 jobs to its Colorado workforce since 2014, and currently has about 350 job openings in the Denver area alone. State and local officials in Colorado have helped strengthen the aerospace industry and foster an environment that helps aerospace companies thrive and grow.

LM's Waterton Canyon campus has been a hub of space innovation since the 1950s, with more than 4,000 employees and a wide range of industry-leading design, manufacturing and test facilities on site. Spacecraft currently in production at the site include the Air Force's GPS III satellites, NASA's InSight Mars lander, NOAA's GOES-R Series weather satellites and commercial communications satellites.

Companies selected by LM for the project include Hensel Phelps as the general contractor, Matrix PDM Engineering and Dynavac for thermal vacuum chamber design and construction and ETS-Lindgren for anechoic chamber design and construction.

STO Outlines Vision for "Mosaic Warfare"

DARPA's Strategic Technology Office (STO) recently unveiled its updated approach to winning or deterring future conflicts during Sync with STO Day, held in Arlington, Va. The foundation of STO's new strategy rests on the recognition that traditional U.S. asymmetric technology advantage today offer a reduced strategic value because of growing global access to comparable high-tech systems and components, many of which are now commercially available. Additionally, the high cost and sometimes decades-long development timelines for new military systems cannot compete with the fast refresh rate of electronics component technology on the commercial market, which can make new military systems obsolete before they are delivered.

STO's updated strategy seeks a new asymmetric advantage—one that imposes complexity on adversaries by harnessing the power of dynamic, coordinated and highly autonomous composable systems. "We've developed a technology-based vision that would enable highly complex, strategic moves by composing multiple contributing systems to enable what might be thought of as 'mosaic warfare,' in which individual components can respond to needs in real-time to create desired outcomes," said Tom Burns, director of STO. "The goal is to fight as a network to create a chain of effects—or, more accurately because these effects are not linear, 'effects webs'—to deter and defeat adversaries across multiple scales of conflict intensity. This could be anything from conventional force-on-force battles to more nebulous 'Gray Zone' conflicts, which don't reach the threshold of traditional military engagements but can be equally disruptive and subversive."

U.S. military power has traditionally relied upon monolithic military systems where one type of aircraft, for example, is designed to provide a single end-to-end capability tailored to a very specific warfighting context—and be a significant loss if shot down. In contrast, the composable effects webs concept seeks a mosaic-like flexibility in designing effects for any threat scenario. By using less expensive systems brought together on demand as the conflict unfolds, these effects webs would enable diverse, agile applications—from a kinetic engagement in a remote desert setting, to multiple small strike teams operating in a bustling megacity or an information operation to counter an adversary spreading false information in a population threatening friendly forces and strategic objectives. Mosiacs can rapidly be tailored to accommodate available resources, adapt to dynamic threats and

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be resilient to losses and attrition.

"Applying the great flexibility of the mosaic concept to warfare, lower-cost, less complex systems may be linked together in a vast number of ways to create desired, interwoven effects tailored to any scenario," said Dan Patt, deputy director of STO. "The individual parts of a mosaic are attritable, but together are invaluable for how they contribute to the whole. This means that even if an adversary can neutralize a number of pieces of the mosaic, the collective can instantly respond as needed to still achieve the desired, overall effect."

The mosaic warfare concept is more highly evolved than previous approaches that envisioned a monolithic "system of systems." These were intractably complex, designed as a static configuration by a single system integrator. Attempts to make these systems of systems more flexible sought to accommodate a more diverse selection of constituent components by enforcing a particular architecture. Such constructs typically require adherence to a particular standard, or sometimes used a proprietary "universal translator" to make a limited family of systems work together. "While an open standard may offer interoperability for a period of time, developing them is time-consuming, expensive and requires compromise. And inevitably, as soon as a standard is agreed upon, someone comes up with a new idea not considered during the standards-development process and is either locked out or the whole process must start over again. Ultimately, this approach just does not scale well," Patt said.

"The mosaic warfighting concept moves beyond any one organization, military service or company's system designs and the requisite interoperability standards, which are inherently inhibiting and unscalable," Patt said. "We're focused on developing processes and tools that would focus on trusted connections between known entities, enabling easy backwards compatibility and just-in-time, custom creation of any needed connections to enable rapid, intelligent, strategic assembly and disassembly of diverse systems. This construct opens a virtually limitless possibility for creating effects webs at the tactical, operational and campaign levels."

STO's strategy stands to enhance the effectiveness of existing military capabilities across all domains—maritime, ground, air, space and cyberspace, as well as enable new, low-cost unmanned systems that the Services, DARPA and companies anticipate building in the future. The mosaic strategy is also anticipated to change the way the military thinks about designing and buying future systems. Instead of spending years or even decades building monolithic systems to rigid requirements, future acquisition programs would be able to buy mosaic "tiles" at a rapid, continuous pace. The true power of the new capabilities will come from the composite mosaic effects.

Network to Link U.K. Universities to Test 5G Technology

Experts from leading 5G research institutions at the Universities of Surrey and Bristol and King's College London, have been awarded £16 million to develop the cutting-edge 5G test network, which will see academic expertise and commercial leadership brought together to trial the technology and make sure people and businesses can enjoy the benefits sooner.

The universities will work together to create three small-scale mobile networks, which together will form the test network. Each network will have a number of the elements expected in a commercial 5G network—including mobile signal receivers and transmitters and the technology to handle 5G signals—to support trials of its many potential uses.

The University of Surrey's 5G Innovation Centre (5GIC) will lead the project and develop 5G radio technologies and a fully virtualised mobile core network at 3.5 GHz and 700 MHz frequency bands for enhanced Mobile Broadband (eMBB) and Ultra Reliable Low Latency Communications (URLLC).

> "...end-to-end 5G service delivery..."

Bristol University will deploy 5G capability in the extensive Smart City and Smart Campus test beds in the city, targeting full 5G and fibre infrastructure convergence. Bristol will also contribute to the key Software Defined Network technologies for end-to-end 5G service delivery. Public demonstrators will be the focus of delivery, targeting media, gaming and transport applications.

King's College London is driving the vision for ultra-low latency 5G tactile internet developments with Internet of Skills applications. Through its 5G Tactile Internet Lab, King's is also pioneering several important 5G co-design approaches with various industries, including smart cities, smart transport, performing arts and health.

£100 Million Boost for U.K. Space Sector

The U.K. Government has announced a £100 million investment in the country's space industry. The package includes £99 million of Industrial Strategy Challenge Fund investment to create a National Satellite Testing Facility (NSTF) on the Harwell Campus in Oxfordshire, alongside a £4 million investment for a new National Space Propulsion Facility at Wescott Venture Park in Buckinghamshire.

Due to open in early 2020, the new NSTF will be a world-class facility for the assembly, integration and testing of space instruments and satellites, positioning the U.K. to capitalise on the estimated 3,500 to 10,000 satellites that are due to be launched by 2025. It will also facilitate the build of bigger and more technologically advanced satellites and remove the need for U.K. companies to use test facilities located abroad.

> "...a world-class facility..."

Part of the government's Industrial Strategy, the significant funding boost will enable U.K. industry to competitively bid for more national and international contracts and ensure the country remains a world-leader for space technologies for decades to come.

Visiting the U.K. Space Gateway on the Harwell Campus, where the NSTF will be based, U.K. Universities and Science Minister Jo Johnson said: "From Cornwall to the Highlands and islands of Scotland, the U.K. space sector underpins industries worth more than £250 billion to the U.K. economy, and through our Industrial Strategy we will unlock the sector's potential to grow further.

He added, "Located in a cluster known for research excellence, these new facilities will help U.K. companies be more competitive in the global market for space technology and support our ambition to capture 10 percent of the global space market by 2030."

Nokia Bell Labs Leads NGPaaS Project for 5G Era

Nokia Bell Labs is to lead a consortium of industry vendors, operators, IT companies, small and medium-sized enterprises and European academic institutions to build the Next Generation Platform-as-a-Service (NGPaaS) for the 5G era. The consortium is part of the 5G Infrastructure Public-Private Partnership (5G-PPP), launched in 2014 as an initiative between the European Union and telecom concerns.

5G standard is emerging at a particular time in technology history when the cloud is deeply transforming many industries and services. As such, innovations have to be cloud-native in order to be successful and this means adopting a model beyond the current telco Infrastructure-as-a-Service (IaaS) model: a Platform-as-a-service (PaaS) model. Such a platform does not exist today. With NGPaaS, the consortium's goal is to realise the vision of adopting the PaaS model to optimally support cloud-native 5G systems.

For More Information

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Bessem Sayadi, consortium project leader and research manager for Nokia Bell Labs, said: "The consortium's ambition for developing a next generation PaaS is to enable developers to collaborate within the 5G ecosystem (operator, vendor and third party) in order to ignite new businesses; thereby increasing market scale and improving market economics."

Industry and academia players making up the consortium include: Nokia Bell Labs France (FR), Nokia (IL), ATOS (ES), BT (U.K.), Orange (FR), Virtual Open Systems (FR), Vertical M2M (FR), B-COM (FR) and ONAPP (U.K.), along with the University of Milano-Bicocca (IT), Danmarks Tekniske Universitet (DTU) and IMEC (BE).

ITU Releases 2017 Global ICT Facts and Figures

The annual release of the *International Telecommunication Union's Information and Communication Technologies (ICT) Facts and Figures 2017* shows a significant increase in broadband access and subscriptions, with China leading the way.

"*ITU's ICT Facts and Figures 2017* shows that great strides are being made in expanding Internet access through the increased availability of broadband networks. Digital connectivity plays a critical role in bettering lives, as it opens the door to unprecedented knowledge, employment and financial opportunities for billions of people worldwide," said ITU Secretary-General Houlin Zhao.

The data reveals that mobile broadband subscriptions have grown more than 20 percent annually in the last five years and are expected to reach 4.3 billion globally by the end of 2017. Between 2012 and 2017, least developed countries (LDC) saw the highest growth-rate of mobile broadband subscriptions. Despite this, the number of mobile subscriptions per 100 inhabitants in LDCs is the lowest globally at 23 percent.

The number of fixed-broadband subscriptions has increased by nine percent annually in the last five years with up to 330 million subscriptions added. Also, there has been an increase in high-speed fixed broadband subscriptions parallel to the growth in the number of fibre connections. Most of the increase in high-speed fixed broadband subscriptions in developing countries can be attributed to China, which accounts for 80 percent of all fixed-broadband subscriptions at 10 Mbit/s or above in the developing world.

Which RF Transmitter Technologies Will Take Advantage of Radar Opportunity?

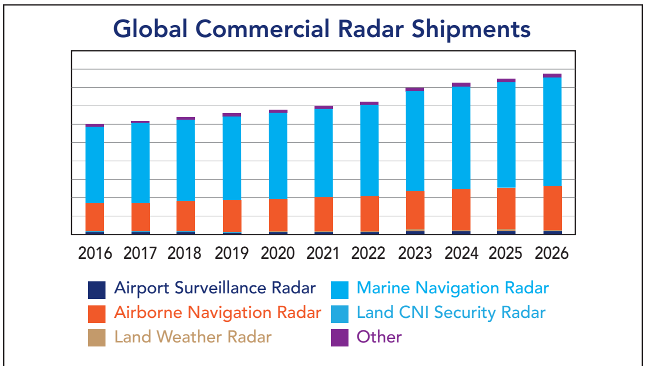
The global commercial radar market will grow at a 4.5 percent CAGR, increasing across traditional platforms and opportunities to address emerging threats. Strategy Analytics predicts the total number of commercial radar shipments will reach 17,516 units in 2026.

For airports, driving factors include new development projects and upgrades to existing facilities, fueled by continued growth in air traffic, which also drives demand for airborne radars. For land and maritime domains, these include International Maritime Organization requirements for vessels operating compliant radar systems, perimeter security and intrusion detection needs for combating asymmetric threats and robust counter-drone strategies.

"Technology advancements around Doppler processing, electronic digital beamforming, solid-state transceivers, signal processing algorithms and 3D displays are adding impetus to radar spending globally through upgrades on existing systems and new radar procurements," according to Eric Higham, North American director for ADS.

The adoption of solid-state semiconductors RF transmitters in longer range, higher power air traffic control primary radars is still at an early stage, with Hensoldt's ASR-NG system one example of a GaN-based system available now. While companies such as Blighter Surveillance Systems and Kelvin Hughes, have replaced vacuum tube RF transmitters with GaAs and GaN respectively for perimeter protection, counter-drone, marine radar and other commercial radar systems that require an optimal balance between performance and cost.

"Industry will need to understand which segments of the commercial radar market will drive growth, what technologies will underpin the high-power RF requirements and which strategies, whether it be mergers, acquisitions or partnerships, will provide the best return on investment," notes Asif Anwar, ADS director at Strategy Analytics.



Source: Advanced Defense Systems (ADS)

5G Reshaping RF Technology Landscape with Opportunities for RF Power Devices

The RF power market will boom. "The revolutionary transition toward 5G implementation in the next five years is dramatically reshaping the RF technology landscape," according to Zhen Zong, technology and market analyst for Yole Développement. This is true not only for smartphone applications but also for RF telecommunication infrastructure applications above 3 W; and 5G is offering enormous business opportunities for compound semiconductors.

Yole expects an increasing demand for telecom base station upgrades and small cell implementations. Overall market revenue could increase 75 percent between 2016 and 2022, posting a 9.8 percent CAGR and a change from US$1.5 billion in 2016 to more than US$2.5 billion in 2022. While there is still much to be settled and established, one thing is certain: the new radio network will require more devices and higher frequencies. Chip providers therefore have a tremendous opportunity, especially RF power semiconductor sellers.

In the meantime, defense applications are also providing opportunities for RF power devices, as there is a trend of replacing old vacuum tube designs with solid-state technologies exploiting GaAs and GaN. These provide better performance, reduced size as well as robustness in various use cases. This market segment's revenue will increase around 20 percent by 2022 with a 4.3 percent CAGR between 2016 and 2022.

Manufacturing Organizations IoT Solutions Deployment to Nearly Double

In a recent survey of 455 U.S.-based companies across nine vertical markets, ABI Research found that 67 percent of manufacturing respondents do not currently have IoT solutions in operation. Of those, 74 percent are either investigating, assessing or planning to deploy such solutions in the next year. Results show that while a lot of the activity in non-connectivity categories are relatively simplistic deployments, industrial IoT (IIoT) applications share a common propensity for automation enablement.

"These companies are looking to connect their HMI, SCADA and control networks to higher level enterprise systems as well as the cloud," says Ryan Martin, principal analyst at ABI Research. "Exposing data to enterprise-level systems provides better support for analytics and the management of people, processes and systems."

At the onset, the IIoT ecosystem was predominantly anchored by proprietary M2M applications with limited interoperability between internal operational data and external systems/processes. Today, it is becoming

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more open as focus shifts from simplistic to more complex applications. In fact, 35 percent of respondents in manufacturing are now assessing artificial intelligence, and 47 percent have either deployed or plan to deploy robotics solutions in the next 12 months.

"The value of leaner systems, processes and procedures is greater than the sum of its parts for players in industrial end markets," concludes Martin. "These are generally large organizations with a set of well understood needs and slim margins, though the ability for IIoT technologies to serve as an infrastructure amplification engine is unbounded."

Autonomous Vehicles, Drones Usage to Rise in U.S. Transportation Industry

In a recent survey of 455 U.S.-based companies across nine verticals, ABI Research found that 30 percent of transportation industry respondents plan to introduce robotics into their operations within the next year, with another 22 percent actively assessing the technology. Despite notable near-term progress in robotics deployments to support e-commerce and delivery growth, lack of familiarity with nascent technologies such as 5G, autonomous vehicles and the related ecosystem is impacting potential adoption.

"Providers may view intelligent transportation technologies as solutions to evolve their existing operations versus opportunities for developing new revenue streams and business models," says Susan Beardslee, senior analyst at ABI Research.

Respondents find that intelligent transportation technology benefits are frequently linked to promoting workforce collaboration, centralized IT, operations frameworks and workforce mobility. Primary barriers to adoption include data security and privacy concerns, alignment with existing legacy framework and associated costs of adoption. Respondents also expect limited impact of delivery drones over the next two years; 40 percent do not see a role for this in their businesses within that timeframe.

"The results deliver validation that notable challenges remain to digitize, automate and transform the transportation industry," concludes Beardslee. "Support of emerging technologies draws mixed reactions, with OTA building awareness. But respondents still see other compelling technologies as nascent to the transportation industry. We expect to see this increase soon to effectively link vehicles and assets to operations."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

ANSYS announced that it has acquired **Computational Engineering International Inc. (CEI)**, the developer of a suite of products that help engineers and scientists analyze, visualize and communicate simulation data. Terms of the deal, which closed earlier this month, were not disclosed.

COLLABORATIONS

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

NEW STARTS

SemiGen Inc. announced the exciting purchase of the former Micrometrics/Metelics fabrication facility in Londonderry, N.H. Moreover, SemiGen will be relocating operations to this location. The recently acquired facility boasts over 20,000 square feet of lab and cleanroom space, and accounts for a $2.5 million dollar facility and capability upgrade for SemiGen. This acquisition will enable SemiGen to offer complete RF/microwave services and component solutions to their customers.

ACHIEVEMENTS

Keysight is now AS9100D certified. The certification was performed by DEKRA Certification Inc., and is in addition to its existing certificates for ISO9001:2015, ISO17025:2005 and ISO14001:2004. AS9100D is the most recent, internationally recognized quality management system standard specific to the aerospace, aviation and defense market segments. AS9100 builds on the ISO9001 standard, which establishes the business management system that aerospace, aviation and defense customers mandate to improve supply chain quality.

Anritsu Co. announced that it is the first test company to earn GCF approval for more than 80 percent of Cat-M1 RF conformance test cases for frequencies used in Japan, North America and Europe. The test cases can be integrated into the LTE-Advanced RF Conformance Test System ME7873LA and re-affirm Anritsu's LTE test leadership by creating a solution to verify that Low-Power-Wide-Area (LPWA) devices and systems used in IoT applications are compliant with global standards. The Cat-M1 RF conformance test cases are software tools specifically written for the industry-leading LTE-Advanced RF Conformance Test System ME7873LA.

CONTRACTS

Oshkosh Defense LLC, an Oshkosh Corp. company, announced that the **U.S. Army** has placed another order for the Joint Light Tactical Vehicle (JLTV) program including 748 vehicles and 2,359 installed and packaged kits. The order valued at more than $195 million, is the fifth order for JLTVs since the contract was awarded in August 2015. The JLTV program is currently in Low Rate Initial Production (LRIP) and remains on-schedule, on-budget and is completing reliability and performance test activities as well as logistics supportability evaluations around the country.

BWX Technologies Inc. announced that its **BWXT Nuclear Energy Inc.** subsidiary has been awarded an $18.8 million contract from **NASA** to initiate conceptual designs for a nuclear thermal propulsion reactor in support of a possible future manned mission to Mars. The scope of the contract includes initial reactor conceptual design, initial fuel and core fabrication development, licensing support for initial ground testing and engine test program development. Work under the contract is expected to continue through 2019, subject to annual congressional appropriations and options exercised at customer discretion.

Teledyne Labtech, a U.K.-based business unit of **Teledyne Microwave Solutions**, announced that it has secured a new supply contract worth over £11 million as part of an agreement with international aerospace, defence and security company **Leonardo**. The award spans over eight years for the manufacture, assembly and testing of high performance RF/microwave PCB for leading-edge active electronically scanned array (AESA) radar systems.

Envistacom announced it was awarded a $10 million, five-year contract by **U.S. Army Contracting Command-Aberdeen Proving Ground (ACC-APG)** to provide mission-critical communications and operations support to the U.S. Army 2nd Theater Signal Brigade and 102nd Strategic Signal Battalion. The contract was issued as a delivery order via the Global Tactical Advanced Communications Systems and Support (GTACS) contract vehicle by Ft. Huachuca contracting activity. Under this contract, Envistacom will deliver strategic communications systems support for the Enterprise Satellite Communications (SATCOM) Gateway Facility located at Landstuhl (ESG-L) Germany, with systems support including: Satellite Communications System (DSCS), Standardized Tactical Entry Point (STEP), Teleport and Regional Hub Node (RHN).

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

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Around the **Circuit**

Comtech Xicom Technology received a $7.5 million follow-on order for GaN solid-state power amplifiers (SSPA) that will be used for commercial airborne, in-flight connectivity. Comtech's GaN SSPAs will help to enable high speed satellite connectivity for both airlines and travelers around the world. The order will be shipped during the company's fiscal 2018 year (August 2017 through July 2018). Comtech Xicom Technology, based in Santa Clara, Calif., is a subsidiary of Comtech Telecommunications Corp. and part of Comtech's Commercial Solutions segment.

LGS Innovations announced it has been awarded a four-year, $7.5 million cost-plus-fixed-fee contract by the **Defense Advanced Research Projects Agency (DARPA)** under the Dispersed Computing (DCOMP) program. Dispersed computing is an approach that uses the collective computing power of dissimilar, dispersed edge devices, such as smartphones, sensors and microclouds, when backhauling data to large data centers creates unacceptable latency or is not a viable option in the field. Under the terms of the contract, for the first phase of the program, LGS will develop algorithms and protocols for identifying, connecting and tasking dispersed computing assets for simultaneous users with competing demands at different priority levels in a dynamic network environment.

Harris Corp. has received a delivery order to supply its multi-channel Falcon III® HMS (handheld, manpack and small form-fit) manpack radios to support two major **U.S. Army** test events. The order was received during the first quarter of Harris' fiscal 2018. The Harris AN/PRC-158 multi-channel radio—both dismounted and mounted manpack configurations—is one of three radios the Army selected for evaluation during Field-based Risk Reduction (FBRR) and Operational Test (OT). The order also includes vehicle installation kits, ancillaries, training and field service representative support. The first radios are expected to be delivered in the spring of 2018.

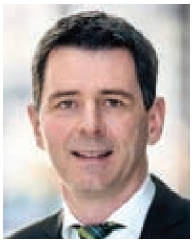
Antenna Systems Solutions S.L. (Celestia Technologies Group) announced that it has won a contract to supply a turnkey indoor far-field antenna measurement system to the **Aalto University** in Helsinki, Finland. The range will be operational from 2 up to 60 GHz and measures 8.5 m in length.

PEOPLE

▲ *Satish Dhanasekaran*

Keysight Technologies announced that **Satish Dhanasekaran** will succeed Mike Gasparian as president of the Communications Solutions Group, effective immediately. Gasparian, who is retiring, will remain an advisor until the end of the year, assisting with the transition. Dhanasekaran was previously the vice president and general manager of the Wireless Devices and Operators unit within the Communi-

cations Solutions Group. He joined the Americas sales organization of Agilent Technologies in 2006, and subsequently served as the Microwave and Communications Division marketing manager and general manager of the Mobile Broadband organization. Dhanasekaran started his career with Motorola, designing and leading the development of first-generation smartphone devices.


▲ *Andreas Pauly*

Andreas Pauly has taken over as executive vice president of the Test and Measurement Division at **Rohde & Schwarz**. Consequently, he was also appointed to the board of directors. Pauly succeeds Roland Steffen, who will retire at the end of 2017. Pauly joined Rohde & Schwarz in 1996 as a software engineer. In 2003, he assumed his first managerial position in the company and in 2015 he was appointed vice president of Signal Generators, Audio Analyzers and Power Meters. Pauly advanced the expansion of the microwave product portfolio and continued his business unit's success story.


▲ *Dan Schettler*

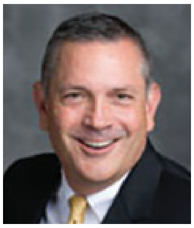
Insulated Wire Inc. announced that **Dan Schettler** has joined the company as director of Business Development. Schettler has more than 25 years of experience in the RF and microwave community in management and engineering positions. He will provide product and process development solutions, as well as, business development and marketing expertise. Schettler holds an MBA from Villanova University and an MSEE from Johns Hopkins University. Prior to joining IW, Schettler worked for Micro-Coax Inc. and Weinschel Engineering in a variety of design & development, process & applications engineering, marketing and management roles.


▲ *David Burgess*

David Burgess, formerly a senior staff engineer at L3 Technologies, Aviation Communication and Surveillance Systems, has been named CTO for **Aethercomm Inc.** As a premier leader in RF design and manufacturing of high-power solid state amplifiers, Burgess will oversee advanced and emerging technologies in an effort to continue Aethercomm's growth strategies. Burgess has over three decades' experience in RF design leadership in both the commercial and DoD Market sectors, as well as several RF publications.

Isola Group has named industry veteran **Michael White** to the newly created position of chief revenue officer. White has over 30 years of global high-tech industry experience. Prior to joining Isola, he was SVP Sales and Marketing at Transphorm, a leader in the high-power, high-efficiency semiconductor market where he will

Around the **Circuit**



▲ *Michael White*

continue his position as a board member. He also spent over 20 years at National Semiconductor, where he held positions including VP/GM of Power Management, VP of Strategic Planning and VP of North American Sales.

▲ *Dr. Ian Gresham*

Anokiwave announced **Dr. Ian Gresham**, Anokiwave Technology Fellow, presented at the 2nd annual Global Technology Congress held on July 19-21, 2017 in Shanghai, China. Dr. Gresham participated in the 5G Ecosystem panel during day one of the session and presented during day two of the New Network Architecture session.

▲ *Keith Bargroff and Sumit Tomar*

Peregrine Semiconductor Corp., founder of RF SOI (silicon on insulator) and pioneer of advanced RF solutions, announces two new executives. **Keith Bargroff** was promoted to serve as the vice president of engineering, and **Sumit Tomar** was hired as the vice president of product marketing. Since the Murata acquisition in 2014, Peregrine has experienced tremendous growth—both in employee headcount and in new market opportunities. As the team and product portfolio expanded, Peregrine created two new senior leadership positions. Semiconductor-industry veterans Keith Bargroff and Sumit Tomar have been selected to bring their knowledge and expertise to Peregrine's growing team.

REP APPOINTMENT

Melcom Electronics Ltd. has announced an agreement to serve as the sales representative and a distributor in the U.K. and Ireland for **Cree's Wolfspeed RF Products**, a global leader in wide bandgap semiconductor technology and the provider of the industry's most field-tested SiC power and GaN-on-SiC RF solutions.

PLACES

RFMW Ltd. announced the opening of a direct sales office in Milan, Italy. The new sales organization will support customers in Italy, Spain, Portugal, Greece and Cyprus. RFMW is a specialized distributor with a focused distribution of RF/microwave components as well as customer specific component engineering support.

Welcome to European Microwave Week 2017

Arne Jacob, *General Chairman of EuMW 2017*
Ivar Bazzy, *President, Horizon House Publications*

For complete coverage of the EuMW conference, event news, exhibitor product information and special reports from the editors of *Microwave Journal*, visit our online show daily at www.mwjournal.com/eumw2017

Grüß Gott and welcome to Nuremberg! The medieval city is at the heart of Franconia in Northern Bavaria and, from Sunday the 8th to Friday the 13th of October, it will open its heart and the doors of the Nürnberg Convention Center (NCC) to the RF and microwave community as it plays host to the 20th European Microwave Week. The lifeblood of the event is three conferences: the 47th European Microwave Conference (EuMC), the 12th European Microwave Integrated Circuits Conference (EuMIC) and the 14th European Radar Conference (EuRAD), not forgetting the European Microwave Exhibition and complementary workshops, short courses and seminars.

The motto for the Week is "A Prime Year for a Prime Event," and due to its active and productive industry, geographical location and robust economy, Germany is a prime destination for EuMW. A specific aim this year is to capitalise on the strength of international, national and local industry and academia with the introduction of the new Session Keynotes format, which is designed to boost industrial participation and intensify the interaction between industry and academia. For this, internationally recognised experts from the industry will open selected sessions with presentations on challenges and state-of-the-art achievements in their field.

The depth and quality of the conference programme is demonstrated by the three Focused Sessions that cover subjects from conformal antennas for defence, security and space applications, to advanced materials, through to the latest developments in vacuum electronics. EuMW is truly global—attracting visitors worldwide alongside international exhibitors and conference contributors. For instance, four of the six special sessions highlight research activities in Central Europe, the Asia Pacific Region and in Latin America.

The fifth Special Session considers the latest research on stochastic approaches in Electromagnetic Compatibility, while the sixth illustrates the increasing importance of funding as representatives from U.S., European and German agencies promote international funding opportunities. More information on the content of EuMC, EuMIC and EuRAD can be found in Attending EuMW 2017 on page 72.

Germany is at the forefront of automotive development, with RF and microwave technology playing a vital role in the industry's advancement. That effort is being recog-

nised and demonstrated to a greater extent than ever before at EuMW 2017, where the focus is on: Advanced Driver Assistance Systems (ADAS) on its way to Highly Automated Driving (HAD) in the future, with four workshops and three sessions within EuRAD discussing the subject. Also, within the entrance hall of the Nuremberg Messe at NCC OST there will be a special exhibition of technology demonstrators and test cars from Mercedes-Benz, Bosch, Hella and Valeo, which can be viewed during normal exhibition hours.

The Defence, Security & Space Forum continues to go where no forum has gone before, as it ventures into "The Internet of Space—Technologies and Applications." The Forum will examine how a new class of satellite communication can be developed utilising state-of-the-art microwave and millimetre wave technologies. The Forum encompasses the EuRAD Opening Session and concludes with the Executive Forum. More information can be found on page 88.

EuMW promotes inclusivity, epitomised by the Women in Microwave Engineering event, sponsored by IEEE MTT-S, which will consider "Communications: Past, Present and Future," and conclude with a visit to the 'Rundfunkmuseum Fürth' for a demonstration of the Nuremberg metropolitan area's historical role of the RF industry.

As well as delving into history, EuMW 2017 will also look to the future through events specifically tailored to the younger generation, including the very successful Student Challenge. The Student Design Competition comprises two tasks that should be prepared in advance, and also features a design task to be carried out on-site. Designed to address the needs of PhD students, the topic of the second European Microwave Doctoral School will be "RFIC Design Cycle and Emerging Topics." Additionally, the School offers talks on soft skills and social events. EuMW 2017 will also see the second European Microwave Student School for bachelor and master students from all over Europe, which will address the topic of "Radar Techniques and Technologies." Last but not least, The Career Platform will continue the successful format of previous years.

An integral and vital constituent of EuMW is the European Microwave Exhibition, which this year will take up 8,000 square metres of gross space and has, at the time of writing, attracted 349 exhibiting companies. The exhibition hall will not only be a focal point for innovation, where companies from around the globe will showcase and demonstrate their products and services, but it will also be a platform for interaction.

Offering an industry lead focus, the European Microwave Week Microwave Application Seminars (MicroApps) will take place in the

MicroApps Auditorium for the entire three days of the exhibition. Also, this year, Interactive Sessions will see papers displayed on active presentation screens instead of the posters used in previous years. The Sessions will be located in the conference area on Monday and Friday and in the exhibition hall for the three days of the exhibition. CST will facilitate vital access to emails and the web through its sponsorship of Wi-Fi, while the exhibition hall will be the home of the Publisher's Corner and the conference Coffee Breaks, sponsored by Copper Mountain. For the first time, water dispensers, sponsored by Keysight Technologies, will be located on all three conference levels to provide refreshment on-the-go to delegates.

The opportunity to make connections of the networking kind will be provided by the Keysight Technologies sponsored Welcome Reception on Tuesday evening, which is designed to be convivial and encourage interaction between delegates and industry. Other social events include Monday's EuMIC Dinner and the EuRAD Lunch on Friday. In addition, the Free State of Bavaria will host a reception on Wednesday at the 'Kaiserburg,' the imperial castle of Nuremberg.

Another sight worth seeing in Nuremberg is the Frauenkirche in the Main Market Square—a church which features the Männleinlaufen mechanical clock where ornate figures emerge at noon. To make EuMW 2017 run like clockwork has taken a great deal of time and effort. So, on behalf of the Local Organising Committee we would like to thank the Technical Programme Committees of the three conferences, along with some 450 reviewers who worked tirelessly to shape the conference programmes. We would like to acknowledge the EuMA Board for its continued advice and guidance, and thank the Horizon House personnel assigned to EuMW for their indispensable expertise and support in organising this major event. Recognition should also go to the organisers of workshops, special sessions and student events, and we also acknowledge the significant financial and in-kind sponsorship of many industrial companies and organisations.

Nuremberg is primed and ready to host the RF and microwave community, and we are looking forward to welcoming you to EuMW 2017.■

Arne Jacob

Ivar Bazzy

A PRIME YEAR
FOR A PRIME EVENT

Attending European Microwave Week 2017

Compiled by Richard Mumford
Microwave Journal *International Editor*

Nuremberg is steeped in history, and while many of those attending European Microwave Week 2017 will take the opportunity to step back in time to enjoy the medieval spectacle of the city's Old Town, it is the activity of the present and the promise of the future for the RF and microwave industry that will be of prime interest.

That interest should be easily satisfied by an excellent conference programme comprising more than 500 presentations, which is the result of the commitment of some 450 reviewers and the 100 members of the Technical Programme Committee. The regular programme, which is organised in 85 oral and six interactive sessions, is complemented by 38 workshops and five short courses covering a wide range of topics, ranging from millimetre wave circuits to 5G, from power amplifiers to automotive radar and from phased arrays to satellite communications.

Central to the week, the free-to-attend European Microwave Exhibition will be housed in hall 7A of the Nürnberg Convention Center from Tuesday, 10 October to Thursday, 12 October, where 349 exhibiting companies (correct at the time of writing) spread over 8000 square metres (gross) will be primed to showcase and demonstrate their latest introductions.

This year, in excess of 1500 unique conference delegates and around 4500 attendees are expected to descend on the conference and exhibition centre that visitors can also access virtually via the Rohde & Schwarz sponsored EuMW App, which is designed to be a digital companion leading up to and during the week. For the exhibition, it will enable users to navigate the show floor with the interactive map, filter and search for selected exhibitors and contact exhibitors

directly to book a meeting. For the conferences, users can follow and build their own personal agenda, access abstracts, post questions and leave feedback.

Interactive, in the real rather than the virtual sense, the well established EuMW Welcome Reception, sponsored by Keysight Technologies, Horizon House Publications and EuMA, encourages industry and academia to communicate and network. On Tuesday, 10 October, the reception will take place in room Sydney and restaurant Vasco da Gama. The evening will begin with a cocktail reception at 18:30, when guests will be addressed by the 2017 EuMW chairman, Arne Jacob, who will hand over to the 2018 EuMW chairman for Madrid, Magdalena Salazar Palma, followed by an address by Keysight Technologies, after which a three course seated buffet for 1000 people will be served.

From the conference programme, through interactive sessions to new products on display, the main aim is to ensure a productive and informative week for all. To help visitors achieve these aims, the following quick reference guide is designed to complement the Conference Programme and Exhibition Show Guide, where you will find more detailed information.

THE CONFERENCES

Each with their own dedicated time slots throughout the week, there are three focused conferences:

- The 12th European Microwave Integrated Circuits Conference (EuMIC) takes place from Sunday 8 to Tuesday, 10 October
- The 47th European Microwave Conference (EuMC) extends from Sunday 10 to Thursday, 12 October
- The 14th European Radar Conference (EuRAD) ends the week and runs from Wednesday 11 to Friday, 13 October.

The conferences cover a wide range of subject areas, including: microwave, millimetre wave and submillimetre wave systems, antennas and propagation, wireless technologies and telecommunication, encompassing RF, microwave and optical. There is also specific focus on ICs, semiconductor materials and packaging, radar architectures, systems and subsystems, not forgetting sensors and remote systems and test and measurement. Many of these areas will also be covered by the workshops and short courses that start on Sunday, 8 October.

Registration, sponsored by Rohde & Schwarz, opened online on 1 June and remains open up to and during the event, until 13 October. There will be onsite registration from Saturday, 7 October, from 16:00 to 19:00, and from 07:30 each morning from Sunday, 8 October to Friday, 13 October.

The registration area will be located at the entrance to the conference centre as signposted. All those who

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have pre-registered should bring their badge barcode and confirmation to the conference, where they can print out their badge by scanning their barcode at the Fast Track desk onsite. For those who have not pre-registered, there will be onsite registration terminals located within the registration area, where delegates can enter their details and pay immediately by swiping their credit or debit cards through the card readers attached to the terminals. Alternatively, there is the facility to pay at the cashier desk for those who require a printed receipt.

Once in possession of their badge, delegates can collect their delegate bags, sponsored by Hamburg University of Technology (TUHH), which will include a USB stick, sponsored by UMS, containing the conference presentations.

EuMC

In 2017, the EuMC celebrates its 47th anniversary. Forty-seven marks an advanced age, where it is possible to look back on a long and successful tradition, rich scientific experiences and worldwide reputation. The EuMC also recognises that this is a golden age that symbolises the heyday of microwave technology, where wireless technologies in particular impact greatly on daily life, and innovation is evolving at a breathtaking pace.

The 2017 EuMC team has endeavoured to compose

a conference programme to reflect those trends. The result is hundreds of high-quality conference contributions complemented by many topical workshops throughout the week, seven industrial session keynotes, two renowned plenary keynote speakers and eight highly reputed panellists.

The EuMC opening on Tuesday, 10 October, will feature the keynotes of Dr. Bruno Jacobfeuerborn, chief technical officer, Deutsche Telekom AG, and chief executive officer, Deutsche Funkturm GmbH, on "5G: The True Enabler of the Internet of Things," and of Dr. Reinhard Ploss, chief executive officer of Infineon Tech-

nologies AG, on the development "From RF Signals to Smart Sensor Solutions."

Also significant is a special event during the week on "Fully Automated Driving. Enabled by Microwaves. What else?" The EuMC closing session on Thursday, 12 October, will feature eight experts who will share their complementary views on the role of radar, chip technology, optical sensors, navigation, mobile communications, cyber security, test and evaluation and regulation for autonomous driving, arranged in a panel discussion directed by the TV editor and moderator Ulrich Bobinger.

EuMIC

The 12th EuMIC combines the conference's longstanding and appreciated heritage with a range of innovative elements. The composition of the 13 technical sessions and six joint sessions with EuMC reflects the intention to stimulate the scientific discussion among experts from competing and complementary semiconductor technologies addressing the microwave to terahertz frequency regimes, encompassing all aspects from device technologies, modelling and characterisation to the application oriented design of integrated circuits.

The significance of Si-based microwave technologies alongside III-V and other compound semiconductors is reflected by the strong presence of related papers in the technical programme, as well as in the topics of this year's distinguished plenary speakers. As a novel feature to all conferences of the European Microwave Week, EuMIC features four Industrial Session Keynotes from very prominent members of the microwave integrated circuits industry.

Communication in the interactive sessions will be raised by electronic media support, and the scientific programme will be complemented by attractive topical workshops running alongside the conference. The traditional Foundry Session, hosted by the GAAS® Association, together with a new special session on Funding for Research, is further evidence of EuMIC's strong topical diversity.

EuRAD

The 14th EuRAD conference is the major European event covering the present status and future trends in the field of radar technology, system design and applications. It covers a wide variety of topics, ranging from radar components and systems, radar propagation and target modelling, advanced signal processing techniques, up to the most innovative radar architectures and concepts and the latest applications.

In the opening session on Wednesday, two excellent keynote speakers will address important aspects of spaceborne radar and space surveillance. Dr. Paul Rosen, manager NASA Jet Propulsion Laboratory, will present "The Renaissance in Radar Remote Sensing—Our New Vision for Earth and the Planets." In the sec-

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The EuRAD opening session is held in conjunction with the Defence, Security and Space Forum (DSS). In contrast to the opening session, the closing session keynote is focused on consumer and industrial applications. It is entitled "Radar Systems: A New Emerging Market for Consumer and Industrial Applications" and is presented by Dr. Ludger Verweyen, senior director RF Mobile, Infineon Technologies AG.

This year, 151 papers were submitted to the conference and after a rigorous selection process, the 93 accepted papers were organised into 24 oral sessions and two interactive sessions. EuRAD delegates can also attend several sessions shared with EuMC. Two Industrial Session Keynotes will address recent innovation highlights of the radar industry, and attractive topical workshops running alongside the conference round off the EuRAD programme.

THE EXHIBITION

The exhibition hall will feature companies large and small, established and emerging, with the prospect of leading manufacturers utilising the exhibition as a platform to launch new products onto the European and global market. Of course, European companies are to

the fore, with Germany, France and Spain having their own focused national pavilions. As always, the U.S. and Asia are well represented and the Chinese pavilion demonstrates the country's continued and developing presence in the RF and microwave sector and its desire to reach overseas markets.

For the entire three days of the exhibition, the seventh annual European Microwave Week Microwave Application Seminars (MicroApps) will provide instruction with an industry focus. The National Instruments, Rohde & Schwarz and Horizon House sponsored free-to-attend seminars will take place in the MicroApps Auditorium,

located within the main entrance to the exhibition floor. The intent of this open forum is for exhibitors to highlight products and techniques useful to engineers in their day-to-day design work.

Germany is at the forefront of automotive development, with RF and microwave technology playing a vital role in the industry's advancement. That effort is being recognised and demonstrated to a greater extent than ever before at EuMW 2017, where the focus is on Advanced Driver Assistance Systems (ADAS) on its way to Highly Automated Driving (HAD) in the Future, with four workshops and three sessions within EuRAD dealing with the subject.

Also, within the entrance hall of the Nuremberg Messe at NCC OST, there will be a special exhibition of technology demonstrators and test cars from Mercedes-Benz, Bosch, Hella and Valeo, which can be viewed during normal exhibition hours. Test cars equipped with radar (Bosch and Hella) will be provided outside the Messe for test drives in the Nuremberg urban environment, while an Intelligent Drive Simulator (Mercedes-Benz) in the entrance hall offers the opportunity for a hands-on operating experience. Last but not least, in front of exhibition hall 7A, automated parking trials (Valeo) can be observed.

Appealing to the practical nature of engineers, the popular exhibitor workshops offered by leaders in their respective fields—Keysight Technologies, Rohde & Schwarz and National Instruments—offer attendees the opportunity to see live demonstrations and gain hands-on experience.

This year, Interactive Sessions will see poster papers displayed on active presentation screens instead of the posters used in previous years. The sessions will be located in the conference area on Monday and Friday, and in the exhibition hall for the three days of the exhibition. CST will facilitate vital access to emails and the web through its sponsorship of Wi-Fi, while the exhibition hall will be the home of the Publisher's Corner and the conference Coffee Breaks, sponsored by Copper Mountain. For the first time, water dispensers, sponsored by Keysight Technologies, will be located on all three conference levels to provide refreshment on-the-go to delegates.

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Model: ERDLVA-218-CW-LPD:
http://www.pmi-rf.com/Products/dlva/ERDLVA-218-CW-LPD.htm

Package Size: 2.0" x 1.7" x 0.5" (Hermetically sealed)
DC Voltage: +10.8 V @ 153 mA, -10.8 V @ 53 mA
Connectors: SMA Female

Model: PLVA-500M18G-50:
http://www.pmi-rf.com/Products/dlva/PLVA-500M18G-50.htm

Package Size: 2.2" x 1.5" x 0.4"
DC Voltage: +12 V @ 75 mA, -12 V @ 75 mA
Connectors: SMA Female

Specification	ERDLVA-218-CW-LPD	PLVA-500M18G-50
Frequency Range	2.0 to 18.0 GHz	0.5 to 18.0 GHz
Flatness	±2.0 dB Max. - Measured ±1.42 dB	±1.0 dB Max. - Measured ±0.6 dB
VSWR	2.0:1 Max. - Measured 1.82:1	3.0:1 Max. - Measured 2.8:1
TSS	-64 dBm Min. - Measured -65 dBm	-42 dBm Min. - Measured -43 dBm
Logging Range	-60 to +4 dBm	-40 dBm to +0 dBm
Log Slope	77 mV/dB (±5 mV) Measured 74.19mV/dB @ 10 GHz	50 mV/dB - Measured 50.1 mV/dB
Log Linearity	±1.5 dB (-20 °C to +85 °C) Max. Measured ±0.75 dB	±0.5 dB Max. (+25 °C), ±1.0 dB Average (-54 °C to +85°C) - Measured ± 0.8 @ -54 °C to +85 °
Video Output Range	-0.5 V (-60 dBm) < RF IN < 5.5V (4 dBm)	0 to 2.5 V (50 Ohms minimum load)

Model: PS-360-3237-8-292FF:
http://www.pmi-rf.com/Products/dlva/DLVA-18G40G-42-50-CD-1.htm

Package Size: 1.9" x 1.7" 0.4"
DC Voltage: +15 VDC @ 20 mA, -15 VDC @ 10 mA
Connectors: 2.92mm Female

SDLVA-2020-70 OPT.0518,A03,A07-50OHM:
http://www.pmi-rf.com/Products/SDLVA/SDLVA-2020-70OPT.0518A03A07-50OHM.htm

Package Size: 3.0" x 3.5" x 0.5"
DC Voltage: +15 V @ 450 mA, -15 VDC @ 100 mA
Connectors: SMA Female

Specification	DLVA-18G40G-42-50-CD-1	SDLVA-2020-70 OPT.0518,A03, A07-50OHM
Frequency Range	18.0 to 40.0 GHz (Operational) 30.0 to 31.0 GHz (Full Performance)	0.5 to 18 GHz
Flatness	±0.25 dB @ -23 dBm Measured ±0.1 dB	±2.0 dB Typ (0.5 to 18 GHz) Measured ±1.20 dB
VSWR	1.5:1 Max - Measured 1.18:1	3.0:1 (0.5 to 18.0 GHz @ -20 dBm) Measured 1.60:1
TSS	-34 dBm @ 25 °C - Measured -39.8 dBm	-65 dBm Min (8 to 18 GHz) Measured -68.5 dBm
Logging Range	-32 to +10 dBm	-65 dBm to +5 dBm Measured >-65 to +5 dBm
Log Slope	50 ± 3 mV/dB - Measured 51.83 mV/dB	20 mV/dB (±10% Tolerance) Measured 20.3 mV/dB
Log Linearity	±0.5 dB - Measured +0.4 / -0.35 dB	±1.75 dB Max (-65 dBm to +5 dBm)

Nurnberg Convention Center,
Nuremberg, Germany
October 8th - 13th, 2017
Booth #220
www.eumweek.com

Antenna Measurement Techniques Association
Grand Hyatt Atlanta Hotel, Atlanta, GA
October 15 – 20, 2017
Booth# TBD
http://www.amta2017.org

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- SMT & QFN Products
- Switch Matrices
- Switched Filter Banks
- Switches – Solid State
- Systems - Radar Sense & Avoid
- Systems – Fly Eye Radars
- Threshold Detectors
- USB Products

Exhibition Opening Hours

Tuesday, 10 October:
09:30–18:00, followed by the Welcome Reception

Wednesday, 11 October:
09:30–17:30

Thursday, 12 October:
09:30–16:30

GETTING TO THE NCC, NUREMBERG

Nuremberg (shown in German as Nürnberg on signs, etc.) is located in the south of Germany and it is well connected to the European motorway, rail and flight networks, which allow easy access to the Nürnberg Convention Center. The NCC is connected by subway lines to the main railway station (about eight minutes) and to the airport (about 25 minutes).

By Car

Navigation systems will find the NCC by inserting the address: Karl-Schönleben-Strasse, Nuremberg, Germany or entering Messezentrum, Nuremberg as a special destination.

By Rail

Nuremberg is served by four different kinds of trains: ICE (Intercity Express), IC (Intercity), RE or RB (local trains) and the S (commuter train). ICE trains are the fastest and enable access to Nuremberg from Frankfurt am Main and Munich in two hours and one hour, respectively. For more information for connections within the German railway system (Deutsche Bahn), visit www.bahn.com. To obtain more information for local connections and subway lines in and around Nuremberg, visit www.vgn.de/home_engl/.

By Plane

Nuremberg Airport (NUE) offers numerous direct flights from nearly all major European cities—more than 50 European direct connections are available. From overseas, NUE is easily reached by international flights via Frankfurt am Main or Munich. Within Germany, there are also excellent national flight connections. To get more information for connections to NUE, visit www.airport-nuernberg.de/english.

Free Public Transportation

Public transportation will be free for all conference delegates during EuMW for the local traffic network (bus, tram and underground). Detailed information on the tickets will be provided prior to the conference online and by email.

The Nürnberg Card

For €25.00, the Nürnberg Card provides two days of free admission to all museums and attractions, as well as two days of free travel on all public transport services within Nuremberg and the entire region of Nuremberg, Fürth and Stein. The one requirement for anyone buying a Nürnberg Card is that they must stay overnight in Nuremberg or Fürth. For those with families at EuMW, the card is free for children age five and under; children up to age 11 pay only €5.00 (when at least one adult

card is purchased). Cards can be purchased from any Nuremberg Tourist Office and are also available from reception at most hotels.

HOTEL RESERVATIONS

Horizon House has teamed with Connex Hotels and Events to offer a wide range of accommodation at competitive rates. To make a booking, simply visit Connex Hotels and Events' booking page at www.connexhotelsandevents.com/eumw-2017-nuremberg.html or email sally@connexhotelsandevents.com.

SHOPPING & SIGHTSEEING

The Old Town of Nuremberg offers the experience of almost one thousand years of history. The city presents numerous shopping possibilities, whether it is on the Main Market Square, with its fruit and vegetable stalls under their red and white umbrellas, or the glass facades of elegant shopping malls. The inner city offers a unique shopping atmosphere with 500 shops in an historical backdrop that are open until 20:00 during the week.

The city has an active art and culture scene and for those with culinary aspirations, picturesque roast sausage "kitchens" entice guests to sample Franconian specialities, while star-rated restaurants offer gastronomic delights, even for the most discerning palate.

Locals suggest that one should not leave Nuremberg without having watched the Männleinlaufen clockwork on the facade of the Frauenkirche on the Main Market Square just five minutes before noon, looking down on the roofs of the city from the Imperial Castle or eating some of the famous Nuremberg roast sausages or a *Schäuferle*.

There are various tours and excursions organised as part of the Social Events & Partner Programme and www.nuernberg.de/internet/portal_e/kultur offers information on shopping and sightseeing.■

Photos courtesy @nurnbergmesse.

The 2017 Defence, Security and Space Forum

Richard Mumford
Microwave Journal *International Editor*

**The Forum on Wednesday, 11 October addresses the application of RF and microwave technology to The Internet of Space.
Room St. Petersburg, Nürnberg Convention Center**

This year's guiding topic is **The Internet of Space—Technologies and Applications**. Vast areas of the globe, from oceans and deserts to inhabited areas with lagging infrastructure development, are without sufficient Internet connectivity. Yet, commercial and societal progress, as well as safety and security, are increasingly linked to access to the information superhighway. Equally, military missions require reliable and secure data communication pathways. A new class of satellite communication services promises to cover those needs, using various platforms from low earth orbit (LEO) to geostationary (GEO) satellites, jointly referred to as the Internet of Space (IoS).

The IoS is a nascent field where opportunities abound, yet many crucial technological decisions still have to be made. For many in the field, it offers a once-in-a-lifetime opportunity to make important contributions to a field closely related to state-of-the-art microwave and mmWave technologies.

The Forum will feature executives from industry, academia, the military and space agencies. It will be held in combination with the opening of EuRAD, and will conclude with a round-table discussion and cocktail reception.

THE FORUM FORMAT

Below is a brief outline of each session. For the sixth year, the EuMW Defence, Security and Space Forum will incorporate the **EuRAD Opening Session**, which begins the day's proceedings from 08:30 to 10:10.

After a coffee break, the theme of this year's Forum will be dealt with comprehensively. During **The Internet of Space—Technologies and Applications Session** (10:50 to 12:30), two keynote speakers from the industry will present their view on key applications and the related technologies needed for the realisation of the IoS. The presentations will cover commercial as well as military applications. Wolfgang Duerr of Airbus DS Inc. will consider "The World's Largest Satellite Constellation: OneWeb—Redefining Satellite Communications," while Joe Mariani of Deloitte will explain why "The Connections are Key: The Implications of the Internet of Things on Military Technology."

Providing sustenance for the mind as well as the body, the **Strategy Analytics Lunch & Learn Session** (12:40 to 13:40) will add further dimension by offering a market analysis perspective, illustrating the status, development and potential of the market.

The afternoon ***Microwave Journal* Industry Panel Session** (13:50 to 15:30) offers an industrial perspective on **The Internet of Space —Technologies and Applications**, with particular emphasis on how industry can address the technological challenges and bring concepts to reality. The presentations are:

- The Internet of Space—Technologies and Applications by Mark Lombardi, Keysight Technologies
- Internet of Space, Past, Present, & Future by Timothy Boles, MACOM
- Leveraging Technology to Develop Solutions for IoT to the IoS by Roger Hall, Qorvo
- New Approaches in End-To-End Payload Testing by Yassen Mikhailov, Rohde & Schwarz

Completing the technical sessions, the **EuMW DSS Executive Forum** (16:10 to 17:50) provides the opportunity for high level speakers from leading defence and space companies to present their views and experiences on the upcoming technologies and applications in the civil and military domains. They will be complemented by speakers from a government agency, consulting company and a start-up, who will proffer thoughts on research needs, trends and new space opportunities and challenges. The forum includes: Siegbert Martin from Tesat-Spacecom, Wolfgang Duerr of Airbus DS Inc., Matthias Spott of eightyLEO, Joe Mariani from Deloitte and Siegfried Voigt of DL.

REGISTRATION AND UPDATES

Registration fees are €20 for those who have registered for a conference and €60 for those not registered for a conference. Register online at www.eumweek.com. As information is formalized, the "Conference Special Events" section of the EuMW website will be updated on a regular basis and provide further details. ■

The 2017 Defence, Security and Space Forum
At European Microwave Week

Wednesday, 11 October

A focused Forum addressing the application of RF and microwave technology to The Internet of Space.

Vast areas of the globe are without sufficient Internet connectivity. Commercial and societal progress as well as safety and security are linked to access to the information superhighway, while military missions require reliable and secure datacommunication pathways. This one-day Forum highlights The Internet of Space – Technologies and Applications, a new class of satellite communication services being developed to address these needs.

Programme:

08:30 – 10:10 EuRAD Opening Session

10:50 – 12:30 The Internet of Space – Technologies and Applications

Two keynote speakers from the industry will present their view on key applications and the related technologies needed for the realisation of the **Internet of Space**. The presentations will cover commercial as well as military applications.

- The World's Largest Satellite Constellation 'OneWeb' – Redefining Satellite Communications
  Wolfgang Duerr, Airbus DS Inc.
- The Connections are Key: The Implications of the Internet of Things on Military Technology –
  Joe Mariani, Deloitte

12:40 – 13:40 Strategy Analytics Lunch & Learn Session

This session adds a further dimension to the topics by offering a market analytics perspective, illustrating the status, development and potential of the market for the **Internet of Space**.

14:20 – 16:00 *Microwave Journal* Industry Panel Session

This session offers an industrial perspective on the key issues to be addressed in the defence, security and space sector. In accordance with this year's Defence, Security and Space theme the panel will investigate the opportunities for applications of the **Internet of Space** as well as address the technological challenges.
The presentations are:

- *The Internet of Space – Technologies and Applications – Mark Lombardi, Keysight Technologies*
- *Internet of Space, Past, Present, & Future – Timothy Boles, MACOM*
- *Leveraging Technology to Develop Solutions for IoT to the IoS – Roger Hall, Qorvo*
- *New Approaches in End-To-End Payload Testing – Yassen Mikhailov, Rohde & Schwarz*

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16:10 - 17:50 Defence, Security & Space Executive Forum
High level speakers from leading Defence and Space companies present their views and experiences on the upcoming technologies and applications in the civil and military domains. They will be complemented by speakers from a government agency, consulting company and a start-up, who will offer their views on research needs, trends and New Space opportunities and challenges. Speakers at the Forum will include:

- *Siegbert Martin, TeSat SpaceCom*
- *Wolfgang Duerr, Airbus DS Inc.*
- *Matthias Spott, eightyLEO*
- *Joe Mariani, Deloitte*
- *Siegfried Voigt, DLR*

17:50 - 18:30 Cocktail Reception
The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates
Registration fees are €20 for those who registered for a conference and €60 for those not registered for a conference

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

Organized by:

Microwave Journal EuMA

Microwaves in Europe—Predicting a Brighter Future

Richard Mumford
Microwave Journal *International Editor*

After an uncertain few years, the stars on the European flag may be aligning to prophesy recovery and growth. While not claiming any clairvoyant insight, this report examines the specific actions that the RF and microwave industry is taking to affect a more certain and prosperous future.

One of the greatest threats to economies, markets, industrial development and employment is uncertainty. You cannot taste it, see it or hear it, but its effects can be felt by nations, industries, institutions and individuals. It can impact development and growth and shape society. For nearly a decade now, triggered by the financial crisis in 2008 and aided and abetted by political uncertainty—epitomised by Brexit and the economic fragility of the Eurozone—uncertainty has shackled Europe in recent years.

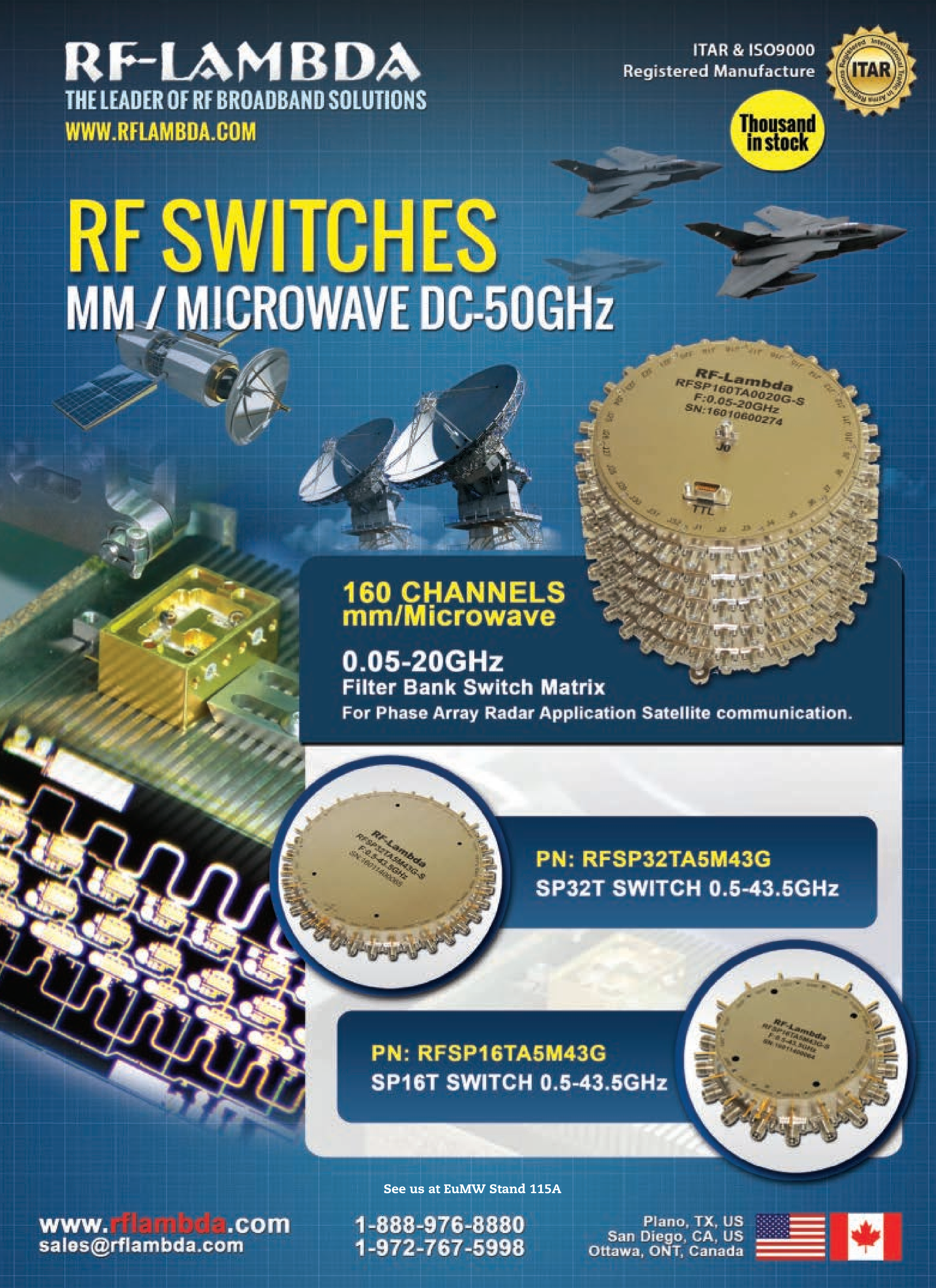
However, there is optimism that, Houdini-like, Europe is systematically removing the shackles and regaining the strength and flexibility to invest, innovate and compete on the world stage. And, unlike the great escapologist's feats, this premise does not appear to be an illusion, as there is evidence that, thanks to determined action, the European Union (EU) economy is now back on a more stable footing, with unemployment falling and growth expected.

"uncertainty has shackled Europe..."

Indeed, the rhetoric from the European hierarchy is unflinching and bold in its positivity, as it set out its ambitions and objectives in black and white, or at least the latter, with the publication in March of the "White Paper on the Future of Europe—Reflections and Scenarios for the EU27 by 2025," in which the President of the European Commission (EC), Jean-Claude Juncker, wrote, "This white paper is the European Commission's contribution to this new chapter of the European project. We want to launch a process in which Europe determines its own path. We want to map out the challenges and opportunities ahead of us and present how we can collectively choose to respond."

As the white paper points out, Europe is home to the world's largest single market and second most-used currency. Also, thanks in part to Horizon 2020, the world's biggest multinational research programme, Europe is at the cutting edge of innovation.

Indeed, the latest available statistics on the European Union's investment in research and innovation that appeared in "The 2016 EU Industrial R&D Investment Scoreboard," published in December 2016 by the EC, show that EU companies invested €188.3 billion in research and development in the fiscal year 2015/2016. This constitutes an annual increase of 7.5 percent, which puts EU companies ahead of the global (6.6 percent) and U.S. (5.9 percent) trends.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Thirty EU companies are among the world's top 100 R&D investors. Significant for the RF and microwave sector, these investors are especially active in the fields of automotive, information and communications technology (ICT) and aerospace and defence. The top investors are based in Germany (€69.8 billion), France (€28.5 billion), the U.K. (€28.2 billion) and the Netherlands (€14.1 billion).

According to the WSTS Semiconductor Market Forecast Spring 2017, the worldwide semiconductor market is forecast to be $378 billion in 2017, an increase of 11.5 percent from 2016. WSTS expects the world semiconductor market to grow in 2017 and 2018 to $378 billion and $388 billion, respectively. For 2017, this represents growth of 11.5 percent, which is the largest growth year since 2010. In 2017, all geographical regions are expected to grow.

For 2018, all major product categories and regions are forecast to grow with the overall market up 2.7 percent and sensors contributing the highest growth. Europe is expected to show the greatest growth with a 3.2 percent increase in 2018. This is supported by the latest figures from the European Semiconductor Industry Association, which reported that May was the third consecutive month of growth in Europe, with sales reaching $3.1 billion. With a growth rate of 3.9 percent during April, Europe outperformed all the other regions worldwide in that month, too.

Although certain sectors are growing, especially in high technology fields, there is a general acceptance overall that Europe's place in the world is shrinking, as other parts of the globe grow. In 1900, Europe accounted for around 25 percent of global population; by 2060, that figure will be less than 5 percent, and no single European Member State will have more than 1 percent of the world population. Europe's relative economic power is also forecast to wane, accounting for much less than 20 percent of the world's GDP in 2030, down from around 22 percent today.

"...shape the world we live in..."

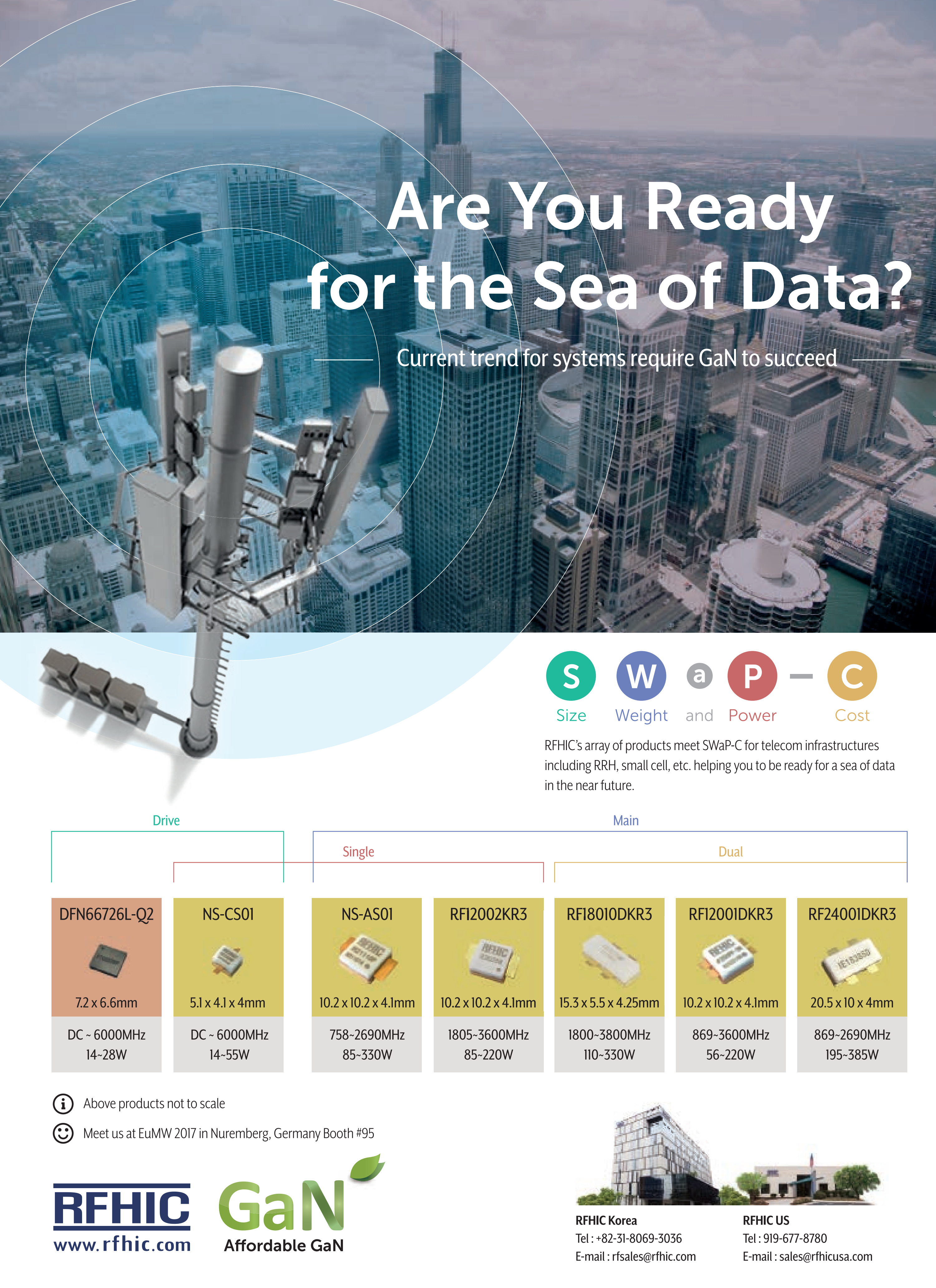
That said, rather than bemoaning the situation and clasping its head in its hands or, even worse, burying it in the sand, the EC has recognised the need to address and combat the rapidly rising influence of emerging economies and the importance of Europe speaking with one voice and acting with the collective weight of its individual parts.

HORIZON 2020 WORK PROGRAMMES

As has been highlighted in this annual report in previous years, a key driver for research and innovation in Europe is Horizon 2020, which has built on the Framework Programmes (the last being FP7) and which it superseded. Funding opportunities under Horizon 2020 are set out in multiannual work programmes that cover the large majority of support available. These are prepared by the EC within the framework provided by the Horizon 2020 legislation.

The Commission Work Programme for 2017 focused specifically on the delivery of the 10 priorities outlined in the Political Guidelines to address the biggest challenges which Europe faces. For the RF and microwave industry, key initiatives are the implementation of the Digital Single Market Strategy, the European Defence Action Plan and the EU Global Strategy. Another key, broader objective is to provide a new boost for jobs, growth and investment, particularly a youth initiative and the formulation of a financial framework beyond 2020.

Looking forward, in August 2017, the European Research Council (ERC) announced its 2018 grant competitions, with a total budget of around €1.86 billion, most of which is earmarked for early- to mid-career researchers. The work programme



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includes all the well-known and established ERC funding schemes: starting, consolidator and advanced grants, as well as proof-of-concept grants for ERC grantees wishing to explore the innovation potential of their research results.

Whether it is via such work programmes, collaborative work through academic institutions or the commercial development of technology, the RF and microwave industry is in a prime position to contribute to and benefit from cutting-edge technology that will shape the world we live in. In this report it would be impossible to cover all fields of application where our industry is currently or has the potential to deliver. So, I will highlight three sectors where European initiatives and activity is of particular significance and importance.

5G

The most obvious sector to highlight is 5G, which is a specific area where Europe is pushing the pace and endeavouring to take the lead, both technologically and commercially. 5G will be a critical factor in formulating a "digital society," and Europe has demonstrated its determination to lead the global development of this vital technology. Unsurprisingly, the intentions are not entirely altruistic, as 5G has the potential to reward its developers, with all regions/countries recognising the benefits of the successful development and adoption of this technology.

The EU has made 5G development a priority. Forward thinking saw the formation of the EU 5G Public-Private Partnership (5G-PPP) in 2013, which has put Europe to the forefront of the current research phase. The research results are now feeding the global standardisation process and being used to prepare the first large-scale trials and demonstrators in Europe, in cooperation with several key sectors.

The follow-on stage from the 5G-PPP saw the launch of the 5G Action Plan in September 2016, which aims to boost EU efforts for the deployment of 5G infrastructure and services across the Digital Single Market by 2020. It is a strategic initiative that concerns all stakeholders—private and public, small and large, in all member states—to meet the challenge of making 5G a reality for all citizens and businesses by the end of this decade.

To achieve those goals, the EC proposes key measures, including

- aligning roadmaps and priorities for a coordinated 5G deployment across all EU member states,
- targeting early network introduction by 2018 and moving toward commercial large-scale introduction by the end of 2020 at the latest,
- making provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible and working toward a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz,
- promoting early deployment in major urban areas and along major transport paths,
- promoting pan-European, multi-stakeholder trials as catalysts to turn technological innovation into full business solutions,
- facilitating the implementation of an industry-led venture fund in support of 5G-based innovation and
- uniting leading players in working toward the promotion of global standards.

In the regulatory framework, the 5G Action Plan is closely related to the new European Electronic Communications Code: they both aim to foster competitiveness in the digital single market. They support the deployment and take-up of 5G networks, notably the assignment and availability of radio spectrum, more favourable conditions for small cell deployment or sectorial issues preventing the deployment of particular services, investment incentives and favourable framework conditions.

In the U.K., the government, with an alliance of universities and commercial partners, is pushing forward. In its Autumn Statement 2016, the government announced its intention to invest in a nationally coordinated programme of 5G Testbeds & Trials as part of a £1 billion package

of announcements made to boost the U.K.'s digital infrastructure. Under this initiative, a world-class 5G technology test network 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 country's economy by 2030.

For the first part of this four-year programme of investment and collaboration, experts from leading 5G research institutions at the Universities of Surrey and Bristol and King's College London have been awarded £16 million to develop the cutting-edge 5G test network, which will see academic expertise and commercial leadership brought together to trial the technology and make sure people and businesses can enjoy the benefits sooner. The universities will work together to create three small-scale mobile networks, which together will form the test network. Each network will have a number of the elements expected in a commercial 5G network, including mobile signal receivers and transmitters and the technology to handle 5G signals, to support trials of its many potential uses.

This investment also aims to deliver a 5G end-to-end trial in early 2018, with the aim of testing the capability of 5G to make an application or service work in a real-world environment. The project will combine the strengths of Surrey, Bristol and King's, which are internationally renowned for their work on 5G and specialise in different aspects of the technology.

The University of Surrey's 5G Innovation Centre (5GIC) will lead the project and develop 5G radio technologies and a fully virtualised mobile core network at 3.5 GHz and 700 MHz for enhanced mobile broadband (eMBB) and ultra-reliable low latency communications (URLLC).

Bristol University will deploy 5G capability in the extensive smart city and smart campus test beds in the city, targeting full 5G and fibre infrastructure convergence. Bristol will also contribute to the key software-defined network technologies for end-to-end 5G service delivery. Public demonstrators will be the focus of delivery, targeting media, gaming and transport applications. As an illustration of Bristol University's research, the cover story for this issue of *Microwave Journal*, outlines the university's current work to investigate and develop massive MIMO to increase the capacity possible within the sub-6 GHz bands.

King's College London is driving the vision for ultra-low latency 5G tactile internet developments, with "Internet of Skills" applications. Through its 5G Tactile Internet Lab, King's is also pioneering several important 5G co-design approaches with various industries, including smart cities, smart transport, performing arts and health.

"…5G will be a critical factor…"

Similarly, in Finland, the 5G Test Network Finland (5GTNF) test environment, which is a joint venture between industry, academia and the Finnish government, is promoting research and technology development by interconnecting 5G test networks belonging to the 5thGear Programme funded by Tekes. The 5GTN is a scalable test environment enabling future business model piloting and service development in real-life use cases that provide a platform for testing and developing the 5G system's technology components.

Significant, too, is the first field trial of 5G fixed wireless access (FWA) technology in the U.K. and Europe, which went live in central London on July 2017 via collaboration between Samsung and the infrastructure company Arqiva. The primary aim of the four month trial is to demonstrate the stability of the FWA service and its potential as a fast-to-market and cost-effective alternative to fibre for connectivity to homes and businesses. Powered by Samsung's 5G network solution and customer premises equipment (CPE) and using Arqiva's 28 GHz millimetre wave spectrum, the 5G FWA system consists of a radio access unit that wirelessly links to an easily

installable CPE, which implements intelligent beamforming technology and accesses millimetre wave spectrum to provide high bandwidth connectivity.

In a wider context, the European Space Agency (ESA) and the European space industry have joined forces to develop and demonstrate the added value that satellites bring in the context of 5G. As part of the ESA Satellite for 5G, set for 2018–2020 and beyond, ESA and the European space industry will work together on

- 5G service trials, including satellite capabilities, with a focus on selected sectors targeted by 5G,
- verticals such as transport, media, entertainment and public safety,
- transversal activities in the areas of applications development, standardisation, resource management, interoperability demonstration campaigns and supporting technologies and
- outreach activities.

The next step will be to consolidate the defining elements of the trial projects and transversal actions by the end of 2017.

AUTOMOTIVE

The European automotive industry is strong, with a history of innovation and development that continues with major initiatives being undertaken. For instance, at the end of 2016, the EC adopted a European Strategy on Cooperative Intelligent Transport Systems (C-ITS). Through cooperative, connected and automated mobility, the objective of the strategy is to facilitate the deployment of vehicles that can talk to one another and to the infrastructure on EU roads as of 2019.

The strategy foresees the adoption of the appropriate legal framework at the EU level by 2018, to ensure legal certainty for public and private investors. It also addresses the availability of EU funding for research and development projects and international cooperation on all aspects related to cooperative, connected and automated vehicles.

It also involves continuous coordination, in a learning-by-doing approach, with the C-Roads Platform, which gathers real-life deployment projects in member states. With the help of the Connecting Europe Facility (CEF), projects in Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, the Netherlands, Norway, Slovenia, Spain, Sweden and the U.K. have received funding.

Under Horizon 2020, research into ITS has focused on the integration of transport modes and the links with automation. A dedicated call for project proposals on automated road transport was launched in 2016. In the context of the Strategic Transport Research and Innovation Agenda, the commission is developing a roadmap on connected and automated transport to steer and coordinate future research and investigation activities in Europe. This work is complemented by large-scale deployment projects to develop cooperative systems on the Trans-European Transport network in 13 countries, making use of EU funding programmes such as the CEF.

Earlier this year, the CAR 2 CAR Communication Consortium and the C-Roads Platform signed a memorandum of understanding for enabling close cooperation between the automotive industry, road authorities and road operators for preparing the deployment of initial C-ITS services across Europe by 2019. Both partners support the recommendation developed by the EC's C-ITS Deployment Platform to utilise short-range communication in the 5.9 GHz frequency band. In accordance with the European C-ITS, the hybrid communication approach builds on combining short-range ITS-G5 and wide area cellular and broadcast communication under a complementary principle.

"...Highly Automated Driving..."

For the commercial market, automotive radars are growing in importance and volume of manufacture, and Europe is at the forefront of development and implementation of 24 and 77 GHz radar

chips for cars. Of course, Germany is a leading nation with RF and microwave technology playing a vital role in the industry's advancement. As would be expected, automotive technology development will be demonstrated to a greater extent than ever at EuMW 2017 in Nuremberg in October, where the focus is on advanced driver assistance systems (ADAS) on its way to highly automated driving (HAD) in the future, with four workshops and three sessions within the European Radar (EuRAD) conference dealing with the subject. There will also be a special exhibition of technology demonstrators and test cars from Mercedes-Benz, Bosch, Hella and Valeo.

INDUSTRIALISATION, IoT AND M2M

As mentioned at the beginning of this report, the EC President Jean-Claude Juncker is clear on his vision for Europe. At the beginning of his mandate, he identified the re-industrialisation of Europe as one of his top priorities and confirmed the objective of increasing the share of industry in the European GDP to 20 percent by 2020.

The reality of this objective was brought into focus in February, when 125 associations representing the European manufacturing industry—including the European Automobile Manufactures' Association (ACEA), the Aerospace and Defence Industries Association of Europe (ASD), the European Carbon and Graphite Association (ECGA), the European Motor Industry Organisation (EMO), the European Semiconductor Industry Association (ESIA) and the Nanotech Industries Association (NIA)—published a joint declaration for an EU Industrial Strategy.

The declaration stated, "The time has come to raise the alarm about the considerable challenges that we are all facing. Between 2000 and 2014, the share of manufacturing in total EU output fell from 18.8 percent to 15.3 percent, while 3.5 million manufacturing jobs were lost between 2008 and 2014. Meanwhile, countries around the world are putting industry at the very top of their political agendas. The Make in India strategy aims to ensure India is the next manufacturing destination and Made in China 2025 seeks to turn China into the leading manufacturing power. The recent U.S. shift toward America First will inevitably have a strong impact on their industrial policy."

The declaration continued, "As we approach the preparation of the next Multiannual Financial Framework, it is vital for the EC to act and help the EU remain a competitive global industrial power playing in a fairer world market."

To achieve the EC's goals, in its declaration, European manufacturing industry called on the EC to

- reaffirm its commitment to reaching the target of 20 percent of GDP from industry, with an ambitious and realistic timeline,
- adopt an action plan to tackle the challenges that the industrial sectors are facing, in the framework of a communication that would include concrete steps and milestones and
- commit to implement the action plan in a timely manner and regularly report on progress.

Technologically, how can these objectives be achieved? One answer could be offered by microwave and millimetre wave systems in the form of M2M and IoT. To enable the necessary step-change in the number of internet connected devices would mean industry moving from the currently saturated IPv4 to IPv6. Such developments are required to achieve Industry 4.0, whereby RFID identified parts, subassemblies, manufacturing systems, robots and human operators work together.

Strictly speaking, as it was originally a German concept, it should be referred to as "Industrie 4.0" or the digital transformation of industry and the fourth industrial revolution. In whatever language, it is defined as the digital transformation of manufacturing, leveraging third platform technologies such as big data, analytics and innovation accelerators, including the Industrial IoT (IIoT). It requires the convergence of information technology (IT) and operational technology (OT), robotics, data and manufacturing processes to realize connected factories, smart decentralized manufacturing, self-optimizing systems and the digital supply chain in the information-driven,

cyber-physical environment of the fourth industrial revolution. It is related to the industrial internet and, since 2016, the Industrial Internet Consortium and Industry 4.0 Platform have begun to work in collaboration.

In May 2017, Productive 4.0, the largest European research initiative in the field of Industry 4.0, was launched with the aim of digitizing and networking industry. Coordinated by Infineon Technologies, more than 100 partners from 19 European countries are involved in the project, including partners such as BMW, Bosch, Philips, Thales, NXP, STM, SAP, ABB, Volvo and Ericsson, along with leading institutes such as the Karlsruhe Institute of Technology, the Fraunhofer Gesellschaft and the TU Dresden. It is scheduled to run until 30 April 2020.

The aim is to create a user platform across value chains and industries that promotes the digital networking of manufacturing companies, production machines and products. The participating partners will examine methods, concepts and technologies for service-oriented architecture, as well as for components and infrastructure in the IoT. Other aspects are standardization and process virtualization, namely simulating manufacturing processes to optimize real workflows. The platform can be used in the three interlocked process pillars for managing the supply chains, the product life cycle and digital production.

On paper, such initiatives could be viewed as theoretical aspirations with futuristic goals but, as Infineon demonstrates, that is not the case. The company began implementing Industry 4.0 live when it opened a new building complex in Villach, Austria for production, research and development in October 2015. The expansion, which is being driven forward through 2017 by investments and research expenditure totalling €290 million, focuses on designing the development and production environment according to the principles of Industry 4.0.

Thus, the company is helping to shape the global trend toward connected and knowledge-intensive production on two levels: on one hand, by developing and producing microchips and sensors that are used in smart factories; on the other, as a company that consistently uses Industry 4.0 technologies itself on a large scale.

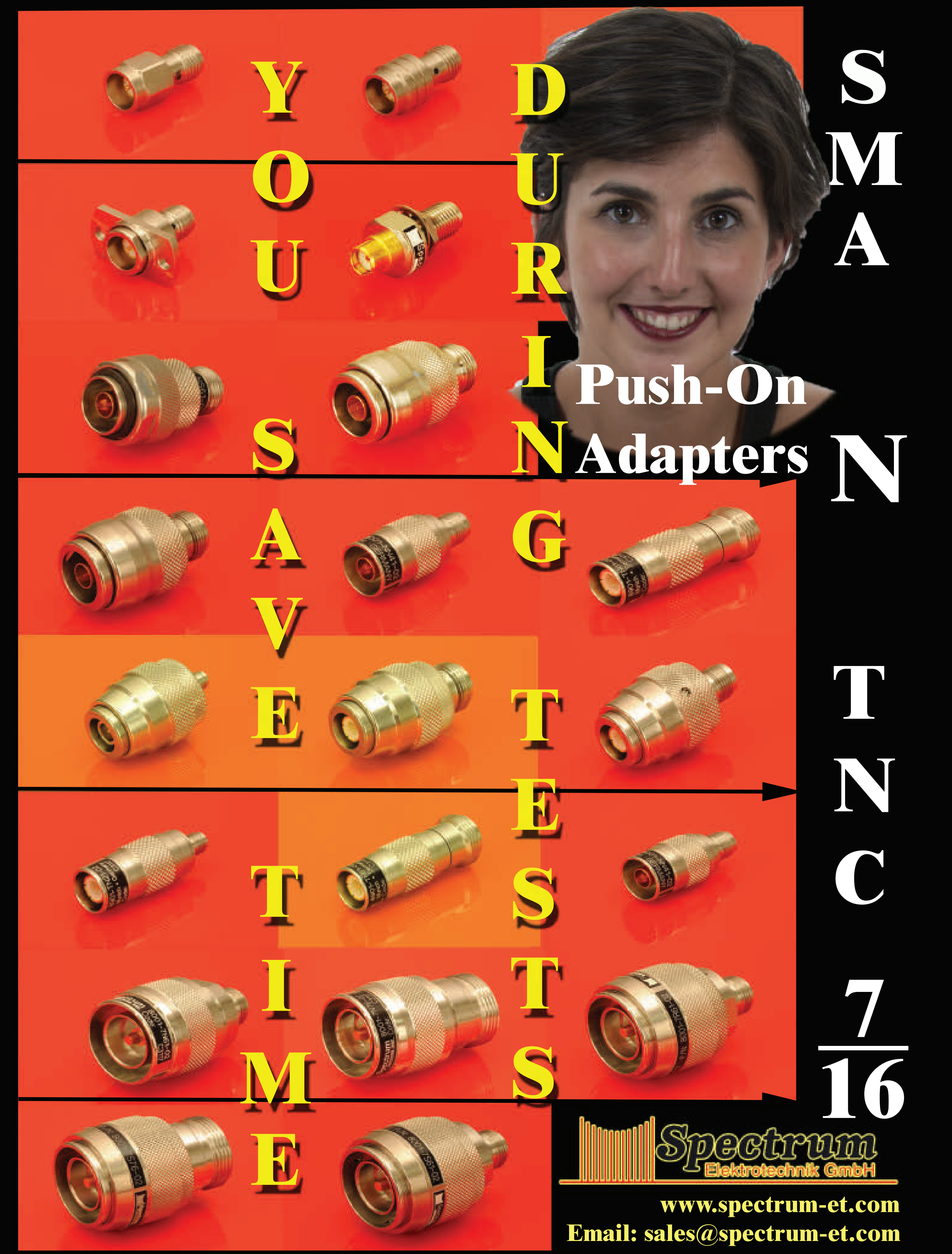
“...a fairer world market...”

CONCLUSION

There is no doubt that over the past decade, Europe has had to face up to the realities of an economic downturn, internal distractions and the challenge posed by emerging nations. However, Europe has always been able to adapt and transform challenges into opportunities, and it appears to be showing its mettle by taking positive action now. With 28 member states, the EU always has to overcome the perception of being a cumbersome machine fighting inertia to be able to drive forward. Athough we are talking about streamlining an SUV rather than a Ferrari, efforts have been made to deliver and mechanisms put in place to improve cooperation, eliminate red tape, provide incentives and fund projects.

For research and innovation, Horizon 2020, like the Framework Programmes before it, along with a myriad of guidelines, codes, action plans and strategies, is offering a platform for technological development and growth. Consequently, there is potential for commercial development, and this report has highlighted areas where the RF and microwave industry is at the forefront of development on the road to implementation. Such activity in areas such as 5G, automotive, IoT and M2M will not only benefit our industry, but society as a whole.

Of course, forecasting anything —be it gambling, markets or even the weather—is fraught with danger, but at a time when Europe’s role as a positive global force appears to be more important than ever, there does seem to be less uncertainty and tangible positivity regarding the future, with the RF and microwave industry having a significant and vital role to play.■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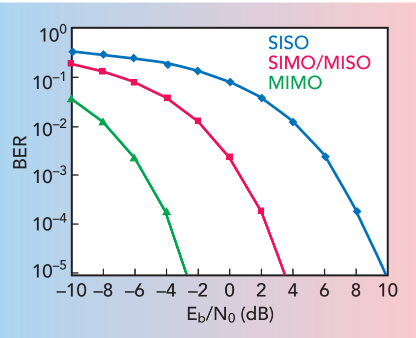
INVITED PAPER

Antenna Arrays for 5G Improve SNR and Capacity

Honglei Chen and Rick Gentile
MathWorks, Natick, Mass.

One objective of today's wireless communication systems is to serve as many users with the highest possible data rates within the constraints of radiated power limits and operating budgets. Improving the signal-to-noise ratio (SNR) is key to improving data rates. Serving more users is possible if channel resources are reused. Many algorithms have been adopted to improve the SNR with the goal of reuse across the time, frequency and coding spaces.

Antenna arrays have become part of the standard configuration in 5G wireless communication systems. Because there are multiple elements in antenna arrays for these types of applications, they are commonly referred to as multiple-input-multiple-output (MIMO) communications systems. Antenna arrays can help improve the SNR by exploiting the redundancy across the multiple transmit and receive channels. Arrays also make it possible to reuse the spatial information in the system to improve coverage.[1] The following sections explain the benefits and tradeoffs that can be made in a MIMO communications system design. For the examples described, an operating frequency of 60 GHz is assumed.



▲ **Fig. 1 BER for LOS systems using BPSK modulation.**

ARRAY GAIN FOR LOS PROPAGATION

The simplest wireless channel is based on line-of-sight (LOS) propagation. This type of channel can often be found in rural areas. Antenna arrays in this scenario can improve the SNR at the receiver and, in turn, improve the communication link's bit error rate (BER). ***Figure 1*** shows the BER using binary phase shift keying (BPSK) modulation for the following communication system configurations:

- Single-input-single-output (SISO)
- Multiple-input-single-output (MISO) and single-input-multiple-output (SIMO)
- MIMO

To simplify the analysis, we use a four-element uniform linear array (ULA) with half wavelength element spacing. The number of elements can be extended and different array geometries considered.

In the MISO and SIMO systems, we assume the array on one end of the channel can be steered toward the single antenna on the other end of the channel to improve the SNR. With pre-steering, the performance of a MISO system matches the performance of a SIMO system, both resulting in a 6 dB gain in SNR. A MIMO system with LOS propagation can benefit from both transmit and receive array gains. As expected, the BER in Figure 1 shows that the transmit array and the receive array each contribute 6 dB of array gain, resulting in a total gain of 12 dB over the SISO case.

DIVERSITY GAIN FOR MULTIPATH CHANNELS

Because LOS channels do not apply in all applications, we next look at multipath fading environments, starting with an example that uses 10 randomly placed scatterers in

the channel. This results in 10 paths from the transmitter to the receiver, as shown in ***Figure 2***. For simplicity, assume that the signals traveling along all paths arrive within the same symbol period; this is a frequency-flat channel. The resulting BER is shown in ***Figure 3*** for a fading channel. When compared with a SISO LOS channel, the BER falls off much more slowly, with the increase of energy-per-bit to noise power spectral density ratio (E_b/N_0) due to fading caused by multipath propagation.

SIMO/MISO Multipath Channel

We now look at multipath cases where the single antenna at the transmit or at the receive end is replaced with a four-element array. Beginning with the SIMO case, optimal combining weights can be derived by matching the channel response. This type of combining scheme is often referred to as maximum ratio combining (MRC). The received signal is no longer weighted by a steering vector toward a specific direction. Instead, the receiving array weights in this case are given by the complex conjugate of the channel response. This assumes that the channel response is known to the receiver. If the channel response is unknown, pilot signals can first be used to estimate the channel response.

Figure 4 shows two important results. First, the SIMO system provides added SNR gains compared to the SISO system. Second, the slope of the BER curve of the SIMO system is also steeper compared to the BER curve of the SISO system. The gain represented by the slope

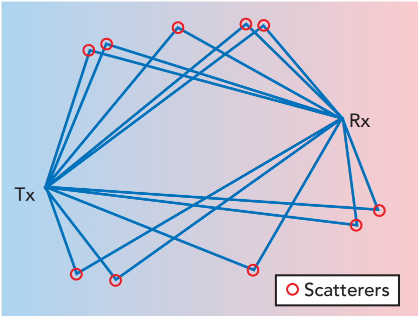


Fig. 2 10-scatterer channel.

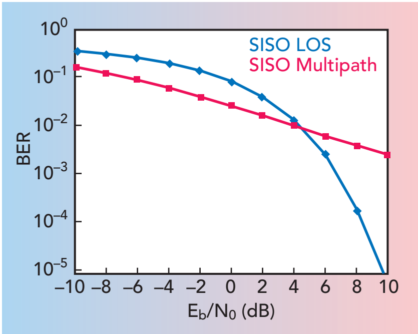


Fig. 3 BER for a fading channel (1,000 frames, 10,000 bits/frame).

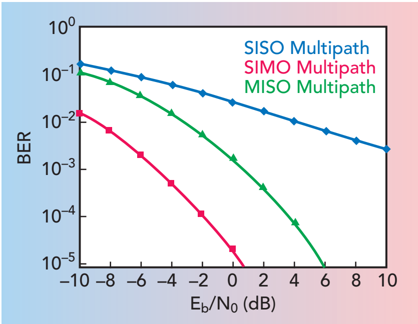


Fig. 4 BER for a multipath channel.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change is often referred to as diversity gain.

Things get more interesting when there is multipath propagation in a MISO system. In this case, if the channel is known to the transmitter, the strategy to improve the SNR is similar to MRC. The signal radiated from each element of the transmit array should be weighted so that the propagated signal can be added coherently at the receiver. The transmit diversity gain can be seen in Figure 4: When comparing the MISO results to the SIMO multipath channel case, the performance of a MISO multipath system is not as good. This is because there is only one copy of the received signal, while the transmit power is spread among multiple paths. It is certainly possible to amplify the signal at the transmit side to achieve an equivalent gain, but that introduces additional system cost.

If the channel is not known to the transmitter, there are still ways to exploit diversity via space time coding. For example, the Alamouti code is a well known coding scheme that can be used to achieve diversity gain when the channel is not known.[2]

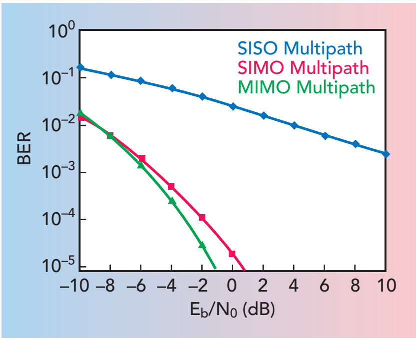
MIMO Multipath Channel

We next focus on a multipath MIMO channel where the number of scatterers in the environment is larger than the number of elements in the transmit and receive arrays. This type of environment is often referred to as a rich scattering environment. As was the case shown in Figure 2, there are multiple paths available between the transmit array and the receive array because of the existence of the scatterers. Each path consists of a single bounce off the corresponding scatterer.

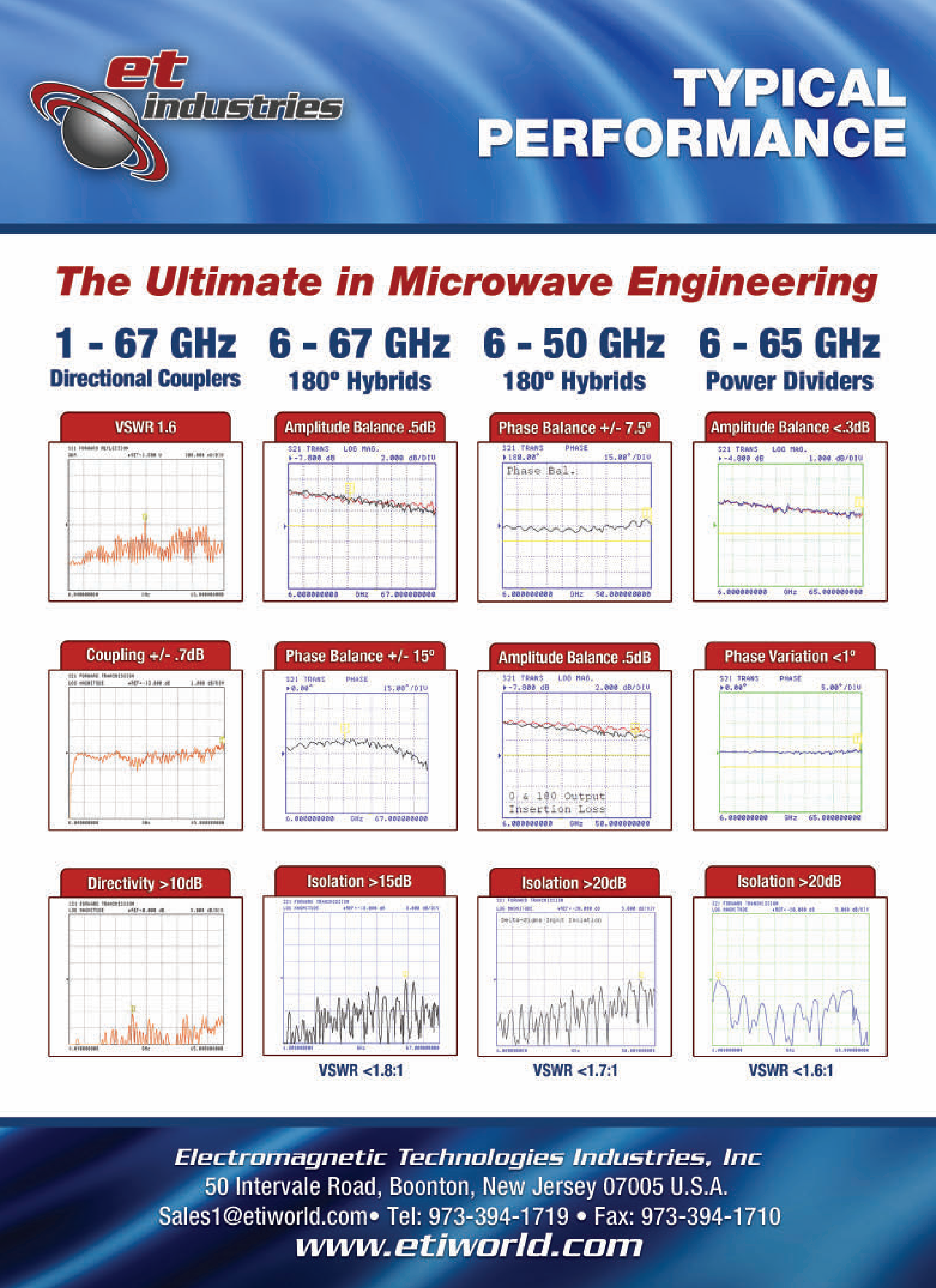
There are two ways to take advantage of a MIMO channel. The first is to explore the diversity gain. Assuming the channel is known, ***Figure 5*** shows diversity gain with the BER curves showing how MIMO compares with SIMO. In the multipath case, the diversity gain from a MIMO channel is not much greater than the diversity gain provided by a SIMO channel. This is because obtaining the best diversity gain in a single stream system, only uses the dominant mode in the MIMO channel. This means that there are other modes in the channel that are not used.

IMPROVING MIMO CAPACITY

Are there alternative ways to utilize the channel? The answer lies in a scheme referred to as spatial multiplexing. The idea behind spa-



▲ **Fig. 5 Diversity gain for multipath propagation.**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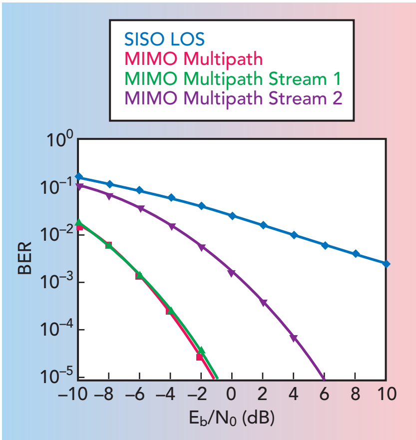
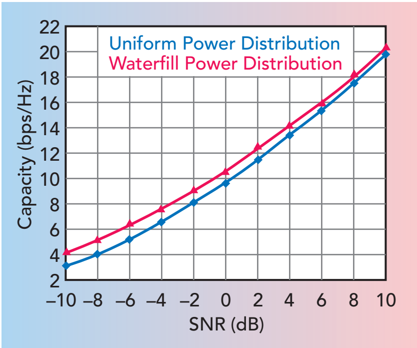
tial multiplexing is that a MIMO multipath channel with a rich scatterer environment can send multiple data streams simultaneously across the channel. For example, the channel matrix of a 4 × 4 MIMO channel becomes full rank because of the scatterers. This means that it is possible to send as many as four data streams at once. The goal of spatial multiplexing is less about increasing the SNR and more about increasing the information throughput.

The idea of spatial multiplexing is to separate the channel matrix into multiple modes so that the data stream sent from different elements in the transmit array can be independently recovered from the received signal. To achieve this, the data stream is pre-coded before transmission and then combined after reception. Information received by each receive array element is simply a scaled version of the transmit array element, which means it behaves like multiple orthogonal subchannels within the original channel. The first subchannel corresponds to the dominant transmit and receive directions so there is no loss in the diversity gain. It is now possible to use other subchannels to also carry information, as shown in ***Figure 6***, for the first two subchannels. Although the second stream does not provide gain as high as the first stream, because it uses a less dominant subchannel, overall information throughput is improved.

The most intuitive way to transmit data in a MIMO system is to uniformly split the power among transmit elements. However, the capacity of the channel can be further improved if the channel is known at the transmitter. In this case, the transmitter could use the waterfill algorithm[3] to make the choice of transmitting only in the subchannels where a desired SNR can be achieved. ***Figure 7*** shows the comparison of system capacity between



▲ **Fig. 6 BER based on spatial multiplexing.**



▲ **Fig. 7 Comparison of power distribution schemes.**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the two power distribution schemes. The result confirms that the waterfill algorithm provides better system capacity compared with the uniform power distribution. The difference gets smaller when the system level SNR improves.[2]

FROM BEAMFORMING TO PRECODING

How do these different techniques relate to each other? Starting from the LOS channel, the benefit provided by the array is an improvement in the SNR. Array gain is achieved with beamforming. On the other hand, ***Figure 8*** shows a MIMO channel. Note that the figure depicts only the pattern for the first data stream; nevertheless, it is clear that the pattern no longer has a dominant main beam. ***Figure 9*** represents the scene if the number of scatterers is reduced to one. Therefore, the LOS channel case or, more precisely, the single scatterer case

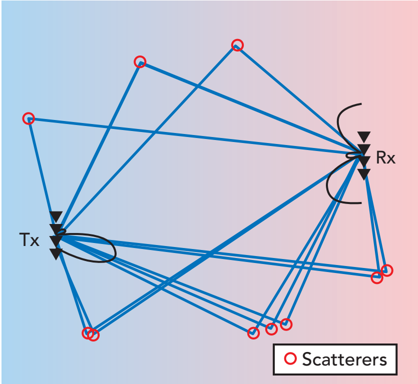

Fig. 8 MIMO with multiple scatterers.

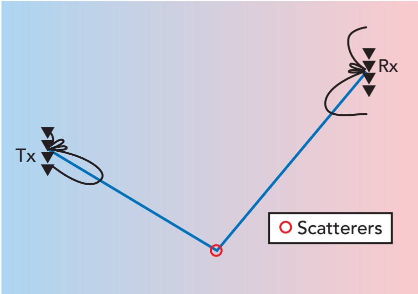

Fig. 9 Single-scatterer system.

can be considered a special case of precoding. When there is only one path available between the transmit and receive arrays, precoding simplifies to a beamforming scheme.

SUMMARY

Array processing can be used to improve the quality of a MIMO wireless communications system. Depending on the nature of the channel, the arrays can be used to either improve the SNR, via array gain or diversity gain, or improve the capacity via spatial multiplexing. The plots shown in the article were generated with MATLAB® and the Phased Array System Toolbox.[4] ■

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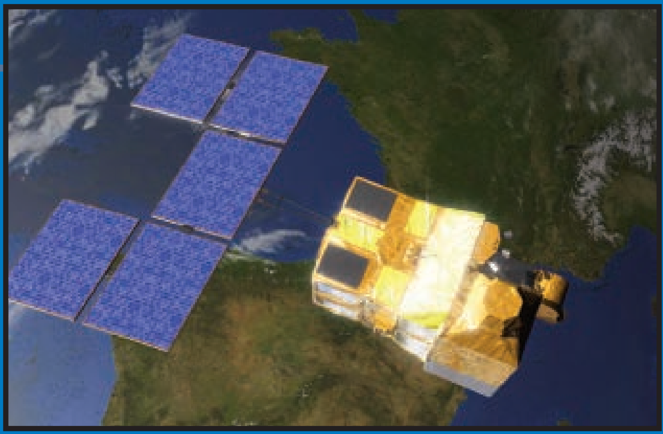

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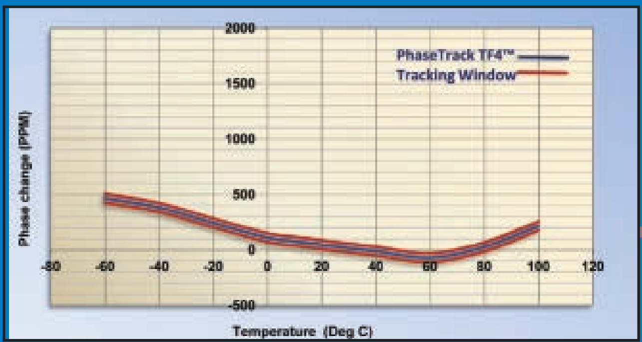

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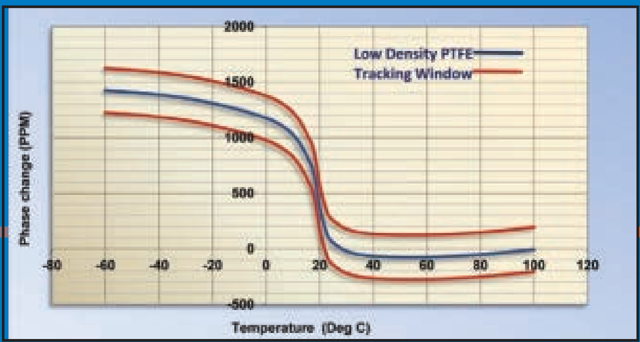

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A Wideband High Efficiency Doherty Power Amplifier Based on Coupled Line Architecture

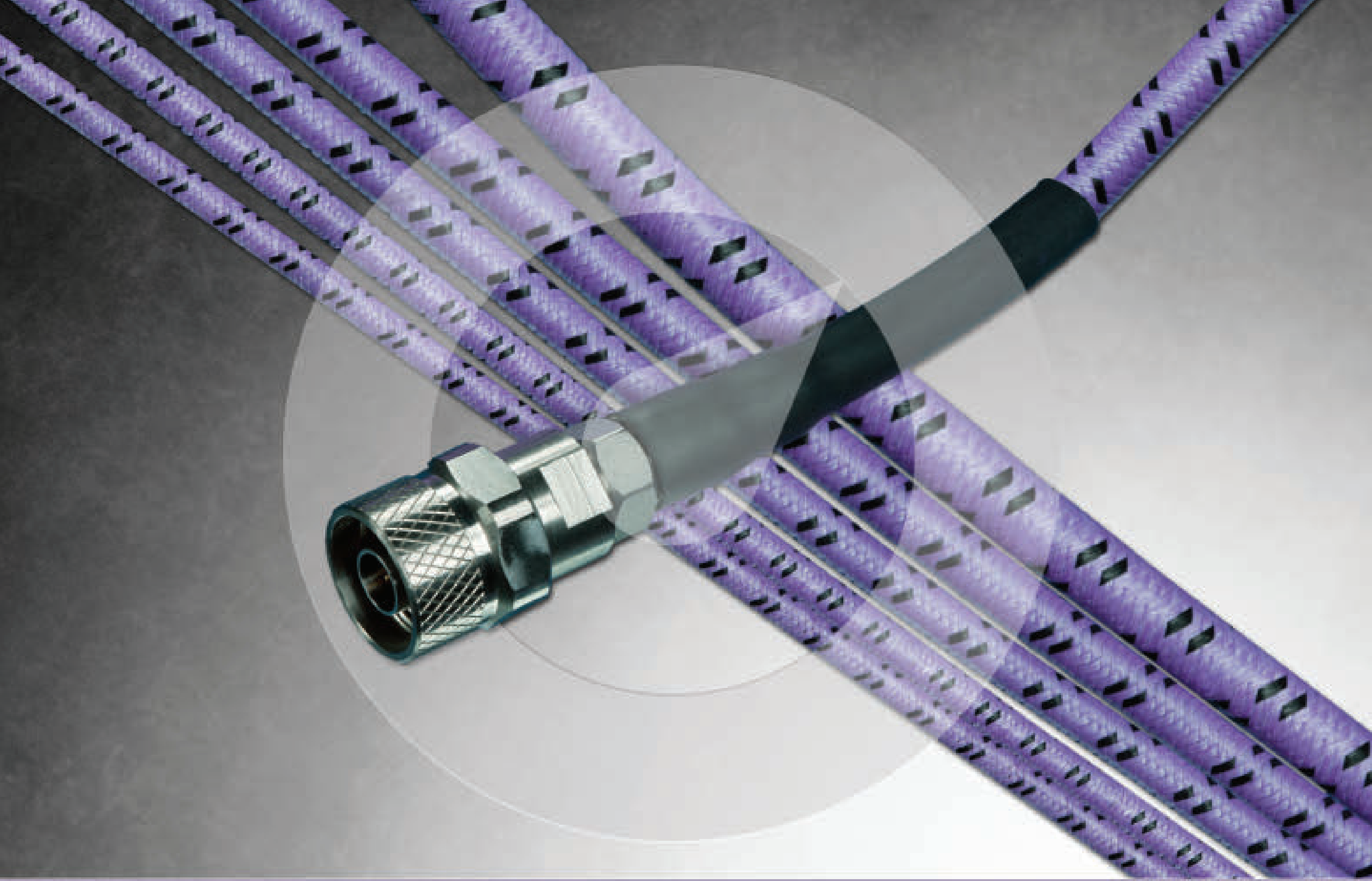
Guangping Xie , Zongxi Tang, Biao Zhang and Xin Cao
University of Electronic Science and Technology of China

A wideband high efficiency Doherty power amplifier (DPA) that works in the 1.85 to 2.4 GHz band (26 percent fractional bandwidth) employs two pairs of anti-coupled lines with stepped impedance resonators to replace the $\lambda/4$ transmission lines in a conventional DPA for harmonic suppression and phase compensation. Maximum output power is between 43.0 and 44.1 dBm. At 6 dB output power back-off (OPBO), the maximum drain efficiency (DE) is 61.3 percent, with gain higher than 12 dB. In the saturated output power region, the efficiency is between 67 and 76.6 percent with gain higher than 8 dB. Compared with a conventional DPA, the third-order intermodulation distortion (IMD3) is reduced by 22 dB while efficiency and gain performance are greatly improved.

In wireless communication basestations, Doherty power amplifiers[1] are widely used to provide high efficiency in the presence of modulated signals with high peak to average power ratios. The $\lambda/4$ transmission line in a conventional DPA is used mainly to perform impedance matching and provide phase delay compensation. The fractional bandwidth is typically narrow (usually less than 10 percent), because the $\lambda/4$ transmission line can achieve an optimum impedance transformation and phase compensation only at one frequency. This limits its application in multiband, multistandard base stations. Moreover, the peaking amplifier in the DPA operates class C, and as a result, has relatively poor linearity.

The $\lambda/4$ transmission line in a conventional DPA also exhibits weak harmonic suppression. Some strategies to address this, like composite right/left-handed transmission lines (CRLH-TL), defected ground structures (DGS), analytical model simplification and harmonic tuning, have been successfully reported.[2–5] Fang and Quaglia[2] report a DPA with 18 percent fractional bandwidth; however, the DE and gain at 6 dB OPBO are only 36 percent and 6 dB, respectively. For comparable linearity, CRLH-TL and DGS were adopted with the standard DPA topology for a power-added efficiency (PAE) at 6 dB OPBO of about 20 percent.[3,4] Zhao et al.,[5] report on a similar case with measured results showing less obvious improvement in linearity by utilizing a simple analytical model. A 35 percent fractional bandwidth is reported by Bathich et al.,[6] by exploiting wideband filters; in this case, a standard topology is also adopted, but the Doherty behavior is not clearly demonstrated. Sarkeshi et al.,[7] employ frequency reconfigurable matching networks enabling a fractional bandwidth of about 20 percent; however, this requires an external control circuit.

In this work, a compact phase compensation architecture based on two pairs of anti-coupled lines loaded with stepped impedance resonators replaces the $\lambda/4$ trans-



mission line in a conventional DPA. This structure performs impedance conversion, phase compensation, phase correction and harmonic suppression. At the same time, it provides an easy way to tune performance by adjusting the width and length of the stepped impedance resonators.

PHASE COMPENSATION NETWORK

Even/odd mode analysis was used to analyze the axially symmetric novel and compact DPA structure shown in ***Figure 1***. First analyzed is the two-port network in area 1. Z_{oe} and Z_{oo} represent the even mode and odd mode characteristic impedances of the parallel coupled line. $[Z_U]$, $[Z_D]$ and $[Z_T]$ represent the impedance matrices of the parallel coupled line, the low impedance line and the two-port network in area 1, respectively. The impedance matrix of the two-port network is given by[8,9]

$$[Z_T]=[Z_D]+[Z_U]=\begin{bmatrix} Z_{T11} & Z_{T12} \\ Z_{T21} & Z_{T22} \end{bmatrix} \qquad (1)$$

where

$$Z_{T11}=j(Z_{oe}\tan\theta_e+Z_{oo}\tan\theta_o)/2-jZ_0\cot(\beta l_{om})$$

$$Z_{T12}=j(Z_{oe}\tan\theta_e-Z_{oo}\tan\theta_o)/2-jZ_0\cot(\beta l_{om})$$

$$Z_{T21}=j(Z_{oe}\tan\theta_e-Z_{oo}\tan\theta_o)/2-jZ_0\cot(\beta l_{om})$$

$$Z_{T22}=j(Z_{oe}\tan\theta_e+Z_{oo}\tan\theta_o)/2-jZ_0\cot(\beta l_{om})$$

θ_e and θ_o represent the even and odd mode electrical lengths, respectively. From the relation between the ABCD matrix and the impedance matrix,[9] we derive the ABCD matrix of the two-port network. The physical length of the microstrip curved line in area 2 is designated l and the ABCD matrix of the two-port network is designated $[M_H]$. These are given as follows,

$$[M_H]=\begin{bmatrix} A_H & B_H \\ C_H & D_H \end{bmatrix} \qquad (2)$$

$$l=\left[w_{in}+\pi(R_{inner}+R_{out})\right]/2 \qquad (3)$$

where,

$$A_H=\frac{\cos(\beta l)[\cos(\beta l)Z_{T11}+jZ_\Delta Y_0\sin(\beta l)]+jZ_0\sin(\beta l)[\cos(\beta l)+jY_0\sin(\beta l)Z_{T22}]}{Z_{T21}}$$

$$B_H=\frac{\cos(\beta l)[jZ_0\sin(\beta l)Z_{T11}+Z_\Delta\cos(\beta l)]+jZ_0\sin(\beta l)[jZ_0\sin(\beta l)+\cos(\beta l)Z_{T22}]}{Z_{T21}}$$

$$C_H=\frac{jY_0\sin(\beta l)[\cos(\beta l)Z_{T11}+jZ_\Delta Y_0\sin(\beta l)]+\cos(\beta l)[\cos(\beta l)+jY_0\sin(\beta l)Z_{T22}]}{Z_{T21}}$$

$$D_H=\frac{jY_0\sin(\beta l)[jZ_0\sin(\beta l)Z_{T11}+Z_\Delta\cos(\beta l)]+\cos(\beta l)[jZ_0\sin(\beta l)+\cos(\beta l)Z_{T22}]}{Z_{T21}}$$

and then $Z_\Delta=Z_{T11}Z_{T22}-Z_{T12}Z_{T21}$

The networks in areas 2 and 3 are symmetric and have a parallel relationship. $[M_F]$ represents the ABCD matrix of the two-port network that consists of the structures in areas 2 and 3. By analyzing the relation between voltage and current of the two-port networks of areas 2 and 3, $[M_F]$ is given as follows,

$$[M_F]\begin{bmatrix} A_H & B_H/2 \\ 2C_H & D_H \end{bmatrix} \qquad (4)$$

A_H, B_H, C_H and D_H are defined in Equation 2.

The input microstrip line in area 5, the output microstrip line in area 4 and the parallel network of areas 2 and 3 have a cascade relationship. With $[M_G]$ representing the ABCD matrix of the entire structure and $[M_K]$ representing the input microstrip line in area 5, $[M_G]$ is given as

$$[M_G]=[M_K][M_F][M_K]=\begin{bmatrix} A_G & B_G \\ C_G & D_G \end{bmatrix} \qquad (5)$$

From the relationship between the ABCD matrix and the scattering

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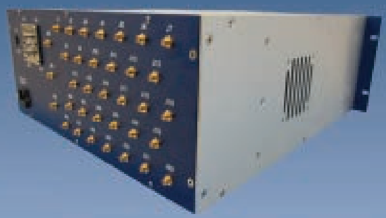

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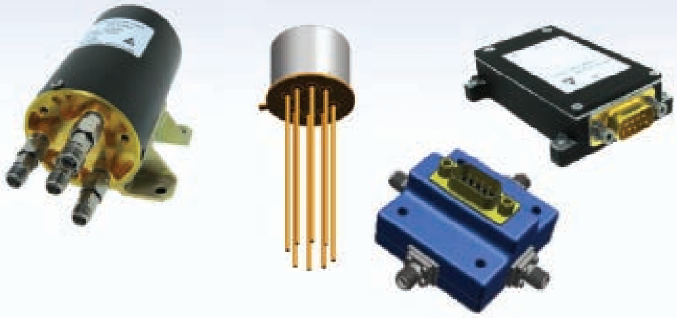

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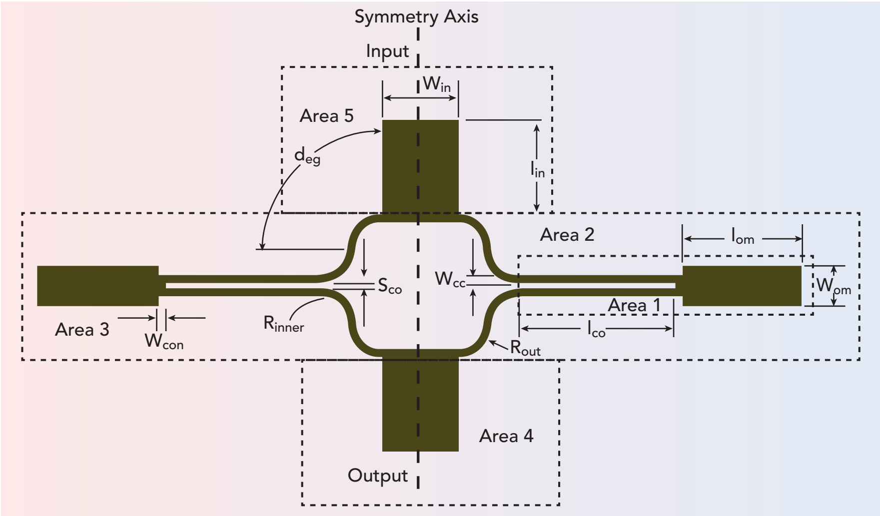
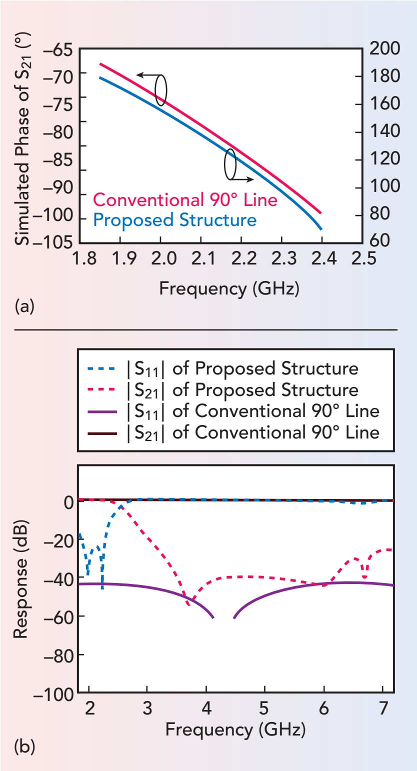


▲ **Fig. 1** Phase compensation structure for the Doherty power amplifier.



▲ **Fig. 2** Simulated performance of the phase compensation structure vs. a conventional 90° line: $\angle S_{21}$ (a), $|S_{11}|$ and $|S_{22}|$ (b).

matrix,[9] the scattering parameters of the structure are

$$S_{21} = 2/A_G + B_G/Z_0 + C_G Z_0 + D_G = |S_{21}| e^{j\varphi_{21}} \quad (6)$$

$$S_{11} = \left(A_G + B_G/Z_0 - C_G Z_0 - D_G\right) / \left(A_G + B_G/Z_0 + C_G Z_0 + D_G\right) = |S_{11}| e^{j\varphi_{11}} \quad (7)$$

$$Z_{21} = 1/C_G = |Z_{21}| e^{j\psi_{21}} \quad (8)$$

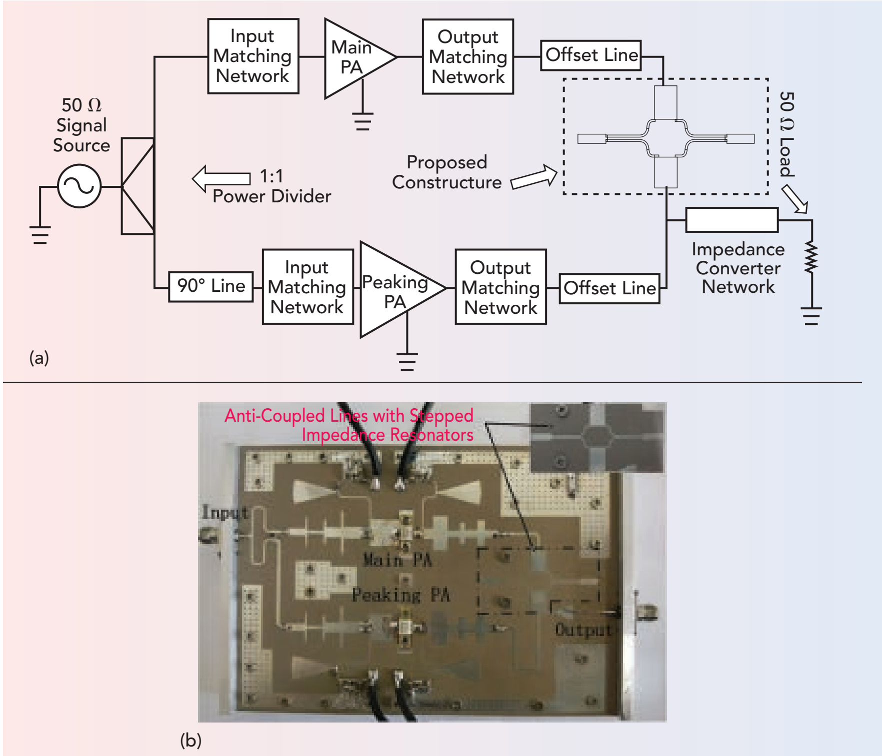
TABLE 1

Z_{21} OF THE PROPOSED STRUCTURE

f (GHz)	$\|Z_{21}\|$	Phase (°)
2.10	62.42	91.89
2.15	55.07	91.38
2.20	54.76	90.84
2.25	53.57	90.29
2.30	55.65	89.62
2.35	61.66	88.67

φ_{21}, φ_{11} and ψ_{21} are the phase of S_{21}, S_{11} and Z_{21}, respectively. A_G, B_G, C_G and D_G are given in Equation 5. Using design specifications for $|S_{21}|$, $|S_{11}|$, $|Z_{21}|$ and φ_{21} and Equations 6–8, a compact phase compensation architecture based on two pairs of anti-coupled lines with stepped impedance resonators is implemented.

Figure 2 shows its simulated performance. The simulated transmission phase of the structure is shown in Figure 2a, while the magnitude of the S-parameters is shown in Figure 2b. Figure 2b shows that the conventional λ/4 transmission line provides almost 0 dB harmonic suppression, while second harmonic suppression is better than 40 dB and third harmonic suppression is about 30 dB in the new structure. ***Table 1*** shows the characteristic impedance of the structure, which is around 50 Ω. A compact structure implemented by capacitor-loaded coupled lines is reported by Li et al.,[8] but its second and third harmonic suppression is only about 20 dB. Zhang et



▲ **Fig. 3 Block diagram (a) and fabricated (b) DPA.**

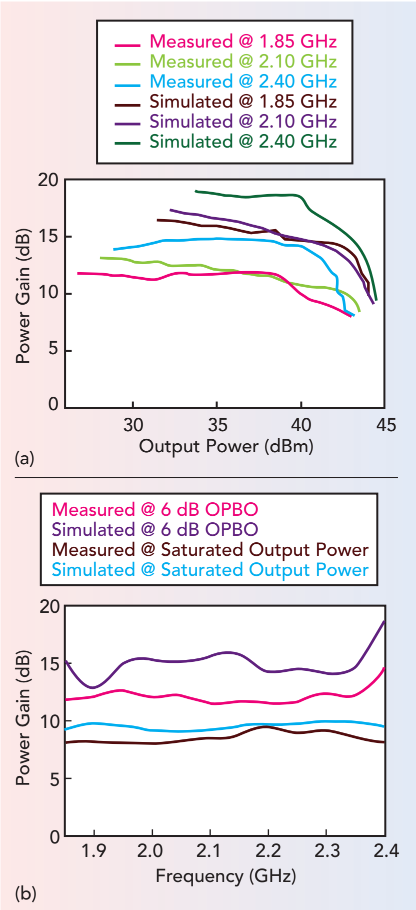
al.,[10] report on a structure consisting of a pair of anti-coupled lines short circuited by a low impedance line; however, second and third harmonic suppression are also limited to around 20 dB.

REALIZATION AND CHARACTERIZATION

To verify this design, a DPA operating over a 1.85 to 2.4 GHz band was realized. It is fabricated on a Taconic substrate with copper metallization (RF35 with a relative dielectric constant ε_r = 3.5, substrate height h = 0.508 mm, metal thickness t = 0.035 mm and loss tangent tan δ = 0.0018). The main and peaking power amplifiers are implemented with Cree CGH40010F GaN HEMTs.

Figure 3 shows the block diagram and photo of the implemented DPA, respectively. A Wilkinson power divider splits the input power equally. The location of the phase compensation structure is indicated in Figure 3a. The dimensions of the DPA are approximately 1.5 λg × 1 λg, where λg is the guide wavelength at center frequency f_0 = 2.125 GHz.

Measurements were taken in 50 MHz steps with single-tone CW excitation. The main PA operates class



▲ **Fig. 4 Measured and simulated power gain vs. output power (a) and frequency, at 6 dB OPBO and saturation (b).**

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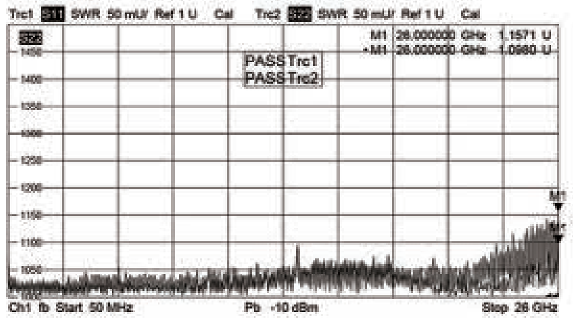
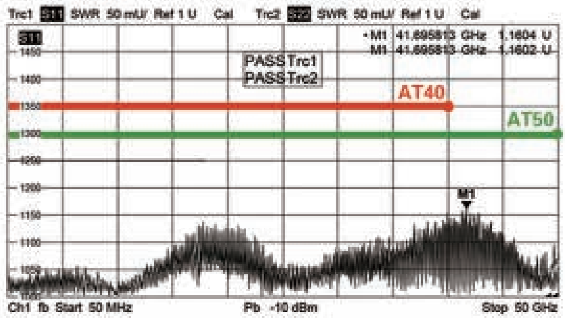
Min.Bend Radius (mm)		50	
VSWR (Typ.)	1.20	1.20	1.25
Insertion Loss (dB/m, Max.)	2.52@26.5GHz	2.92@40GHz	3.29@50GHz
Shielding Effectiveness (dB)		<-90	
Phase Stability vs Flexure	±2°@26.5GHz	±3°@40GHz	±4°@40GHz
Amplitude Stability vs Flexure	<±0.04dB@26.5GHz	<±0.06dB@40GHz	<±0.08dB@40GHz
Operating Temperature		Room Temp.(23±5℃)	
Available Connector	3.5MM (Male & Female) SMA (Male & Female) N (Male , 18GHz)	2.4MM (Male & Female) 2.92MM (Male & Female)	2.4MM (Male & Female)
Standard Length		2FT / 3FT / 1M	
Price (2FT Qty.1-24)	$ 258.00	$ 307.00	$ 355.00

AT26 VSWR



AT40 / AT50 VSWR



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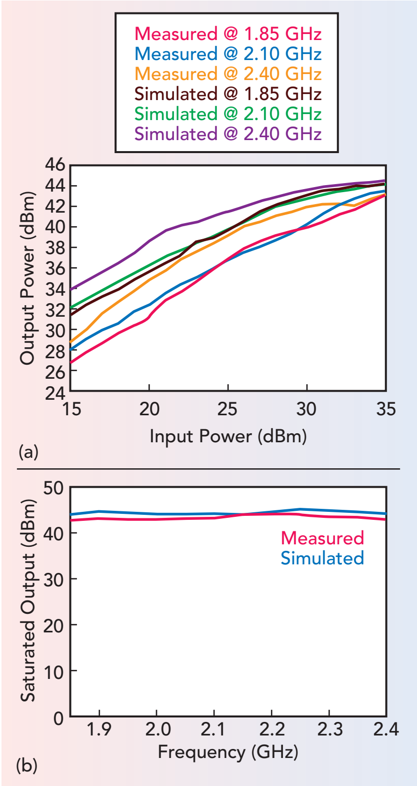
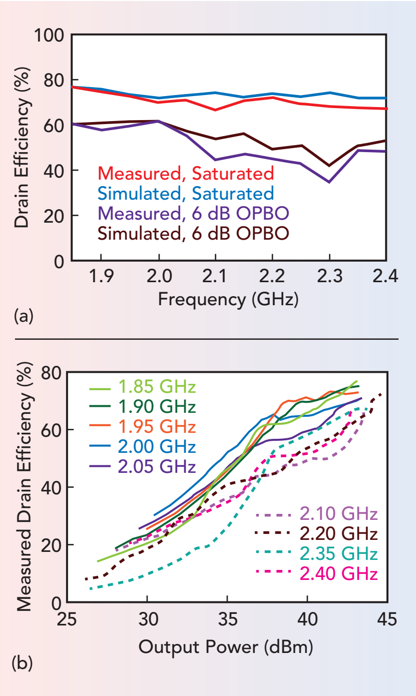
A/B with V_{DS} = 28 V and V_{GS} = -2.5 V (I_d = 210 mA). The peaking PA operates class C with V_{DS} = 28 V and V_{GS} = -3.7 V. Measured and simulated power gain as a function of output power are shown in ***Figure 4***. Differences between measurement and simulation at low and moderate output power are attributed to simplifying assumptions used in the model for the PA output load impedance. Saturated gain is higher than 8 dB, as shown in both measurement and simulation. Figure 4b shows measured and simulated gain as a function of frequency at 6 dB OPBO and in saturation. Gain at 6 dB OPBO is higher than 12 dB in the 1.85 to 2.4 GHz band. Gain flatness is similar at 6 dB OPBO or when saturated. ***Figure 5a*** shows the measured and simulated output power as a function of input power at 1.85, 2.1 and 2.4 GHz. Saturated output power over frequency is shown in ***Figure 5b***; the saturated power is between 43 and 44.1 dBm.

The DE at saturated output power and 6 dB OPBO as a function of frequency and output power are shown in ***Figures 6a*** and ***6b***,



▲ **Fig. 5** Measured and simulated output power vs. input power (a) and saturated output power vs. frequency (b).



▲ **Fig. 6** Measured and simulated drain efficiency vs. frequency at 6 dB OPBO and saturation (a); measured drain efficiency vs. output power vs. frequency (b).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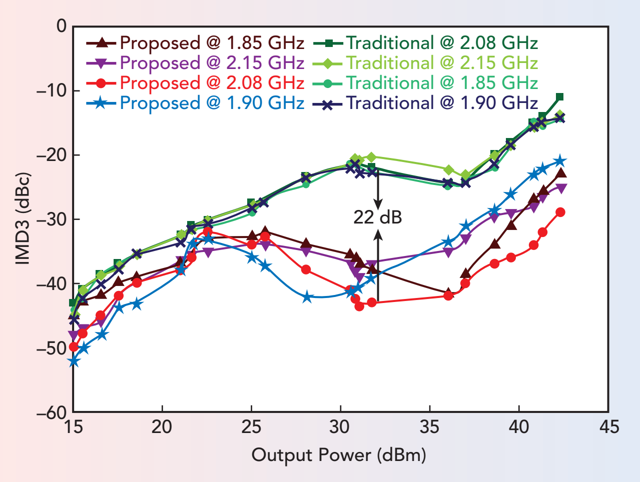
respectively. The DE at saturation is between 67 and 76.6 percent, and the drain efficiency at 6 dB OPBO is between 35 and 61.3 percent. Measured and simulated DE at saturation are comparable; however, the drain efficiency at 6 dB OPBO shows some differences from the simulated results. This is due mainly to the influence of fabrication tolerances.

Figure 7 shows the measured IMD3 of the DPA based on this work versus a conventional DPA, using two tones spaced 6 MHz apart, at 1.85, 1.90, 2.08 and 2.15 GHz. The IMD3 is improved by about 22 dB at high-power compared to the conventional DPA. In the region where output power is higher than 30 dBm, the best IMD3 is -44 dBc at 2.08 GHz. IMD3 performance is improved across the board. Note the rise in IMD3 as the output power is increased above 38 dBm. This is because the peaking amplifier is completely turned on, generating more third-order intermodulation.

DPA performance from this work is compared with other reported results in ***Table 2***.[4,11-13] Several DPAs with fractional bandwidths higher than 30 percent are shown, but their saturated efficiencies and efficiencies at 6 dB OPBO are lower. The DPA described by Sun and Jansen[12] achieves a bandwidth higher than 30 percent, but its best IMD3 is only -35 dBc at high-power.

CONCLUSION

A compact phase compensation architecture based on two pairs of anti-coupled lines loaded with stepped impedance resonators replaces the λ/4 transmission line in a conventional DPA. Compared to a conventional DPA, this design demonstrates an improvement in efficiency, gain and IMD3.■



▲ **Fig. 7 Measured IMD3 performance vs. output power, comparing the coupled line design with a conventional Doherty.**

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TABLE 2
COMPARISON OF REPORTED WIDEBAND DPAS

References	4	11	12 (Version 1)	13	This Work
Frequency (GHz)	3 to 3.6	1.7 to 2.4	2.2 to 3.0	1.63 to 1.98	1.85 to 2.40
P_{sat} (dBm)	44 to 43	41.5 to 34.5	41.8 to 40.2	34 to 31	44.1 to 43.0
Saturated DE (%)	65 to 56	53 to 72	68 to 52	60 to 44 (PAE)	76.65 to 67
DE @ 6 dB OPBO (%)	54 to 38	59 to 43	53 to 30	49 to 20 (PAE)	61.3 to 35
Gain (dB)	11.2 to 6	10.1 to 8.6	8.7 to 5.5	17 to 6	14.8 to 8.0
Max IMD3 (dBc)	–	–	−35 (IMD3 Upper)	–	−44.0
Type	GaN HEMT	GaN HEMT	GaN HEMT	GaN HEMT	GaN HEMT

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• ZHL-20W-13SW+	20-1000	50	13	20	1595
• LZY-22+	0.1-200	43	16	30	1595
ZHL-30W-262+	2300-2550	50	20	32	1995
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ZHL-30W-252+	700-2500	50	25	40	2995
LZY-2+	500-1000	47	32	38	2195
LZY-1+	20-512	42	50	50	1995
• ZHL-50W-52+	50-500	50	63	63	1395
• ZHL-100W-52+	50-500	50	63	79	1995
• ZHL-100W-GAN+	20-500	42	79	100	2845
ZHL-100W-272+	700-2700	48	79	100	7995
ZHL-100W-13+	800-1000	50	79	100	2395
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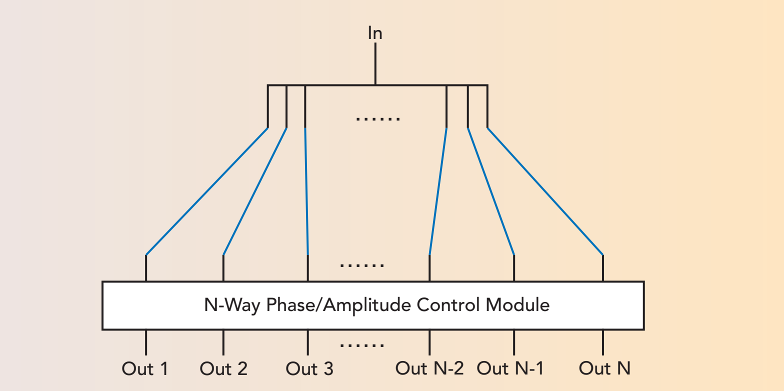
High Resolution Phase/Amplitude Control Matrix for Massive MIMO

Mitron
Fuzhou, China

Massive MIMO is one of the technologies being developed to enable 5G to reach the advertised data rates of 10 Gbps, particularly at frequencies below mmWave. Developing massive MIMO systems requires simulation and test of the electromagnetic signal environment, over-the-air (OTA) beamforming algorithms, antenna arrays and the entire 5G system. Once 5G is ready to be deployed, the massive MIMO arrays will have to be tested as they are manufactured. To support development and testing of these systems, Mitron has developed a highly accurate, multichannel, phase/amplitude control matrix.

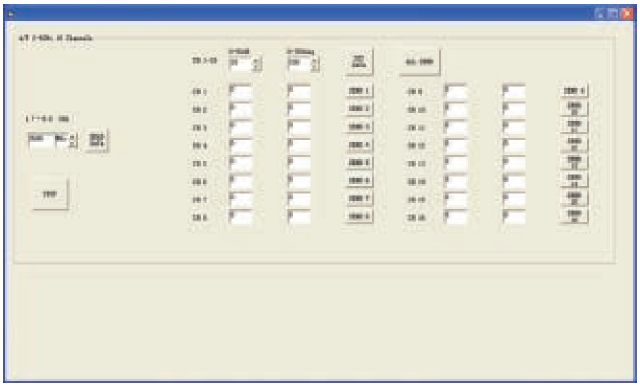


▲ **Fig. 1 Block diagram of a 1xN phase/amplitude control matrix.**

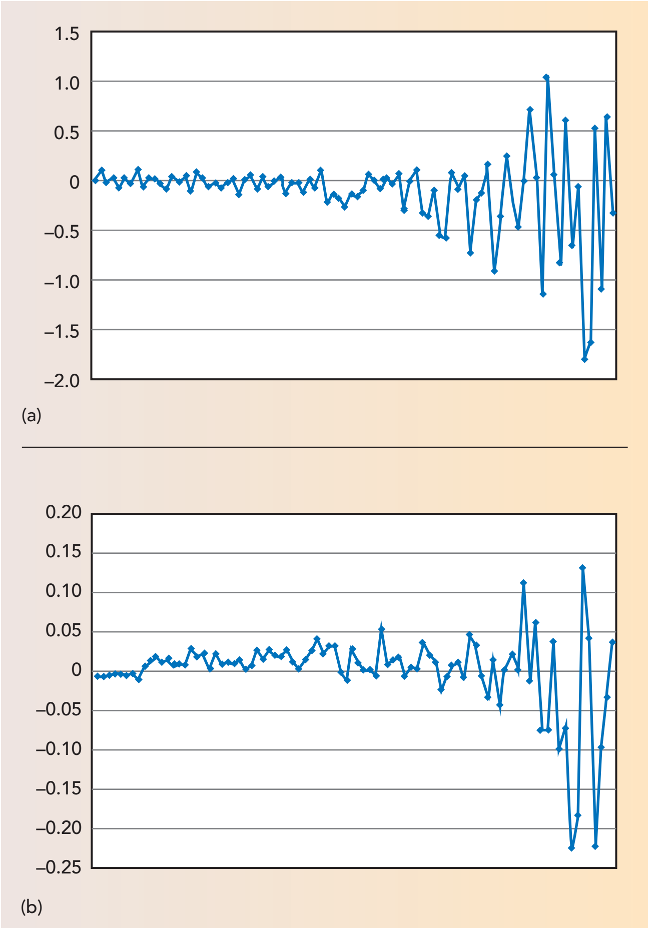
All the phase/amplitude control matrices and modules now on the market use digitally-controlled MMIC phase shifters and attenuators. The smallest steps available for such phase shifters and attenuators are 1.4 degrees and 0.25 dB, respectively, up to 6 GHz. Theoretically, these step sizes provide ±2.8 degree phase and ±0.5 dB attenuation resolution; in the real world, actual products have worse performance because of inaccuracies. At the mmWave frequency bands presently proposed for 5G, primarily in the range from 25 to 40 GHz, few digitally-controlled MMIC phase shifters and attenuators are found. Reported products have only 5.6 degree and 0.5 dB step resolution, and their accuracies will be worse than the ±11.2 degree and ±1 dB theoretical values. These existing products cannot meet the accuracy requirements of future 5G systems. Further, most of these products are narrowband,

typically with only 200 MHz bandwidth. So testing a massive MIMO system across the various 5G bands will require many narrowband phase and amplitude control channels, adding significant cost to the test system.

Mitron adopted a completely different approach to achieving phase and amplitude control: designing analog control circuits that are controlled digitally—which improves the resolution—and calibrating the frequency response of the phase and amplitude circuits using software algorithms on a fast automatic test system. Compared to the MMIC-based products discussed, Mitron achieves better phase and amplitude resolution and accuracy, as well as wider bandwidth. Mitron's analog phase and amplitude control circuits cover 1.7 to 6, 6 to 18 and 25 to 40 GHz, such that a single unit handles multiple 5G frequency bands, reducing the investment in test equipment for 5G R&D and production testing.



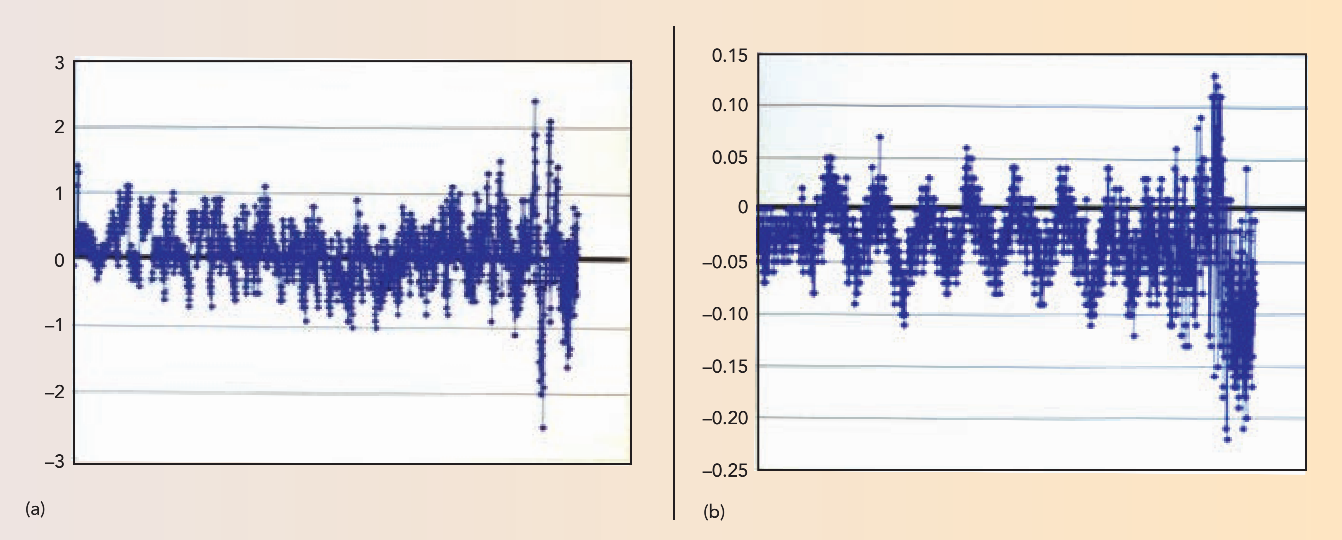
▲ **Fig. 2** Phase and amplitude are set with a GUI.



▲ **Fig. 3** Phase (a) and amplitude (b) accuracy over the 0 to 50 dB amplitude control range at 1.7 GHz.

Using these analog control circuits, Mitron has developed 1x16 phase/amplitude control matrix systems covering 1.7 to 6 GHz and 24 to 40 GHz (see ***Figure 1***). Each system fits in a 2U 19 in rack and is controlled via a graphical user-interface (GUI) on a PC (see ***Figure 2***). The products handle very wide instantaneous bandwidth, and just two systems support the primary microwave and mmWave bands proposed for 5G.

Each 1×16 matrix has maximum control ranges of 360 degrees and 50 dB, with steps of 1 degree and 0.1 dB, respectively. At any phase and amplitude value over the whole frequency band, the phase and amplitude accuracies are 2 degrees



▲ **Fig. 4** Phase (a) and amplitude (b) accuracy over the 0 to 50 dB amplitude control range at 40 GHz.

and 0.2 dB maximum from 0 to 30 dB attenuation and 2.5 degrees and 0.4 dB maximum from 30 to 50 dB attenuation. ***Figure 3*** shows the phase and amplitude accuracy at 1.7 GHz for attenuation values from 0 to 50 dB. ***Figure 4*** shows similar performance data for the mmWave unit measured at 40 GHz.

Using the analog control circuits as "LEGO® building blocks," additional matrix configurations with the same accuracy can easily be developed: 1×32, 1×64, 2×32, 4×8, 4×32 and M×N.

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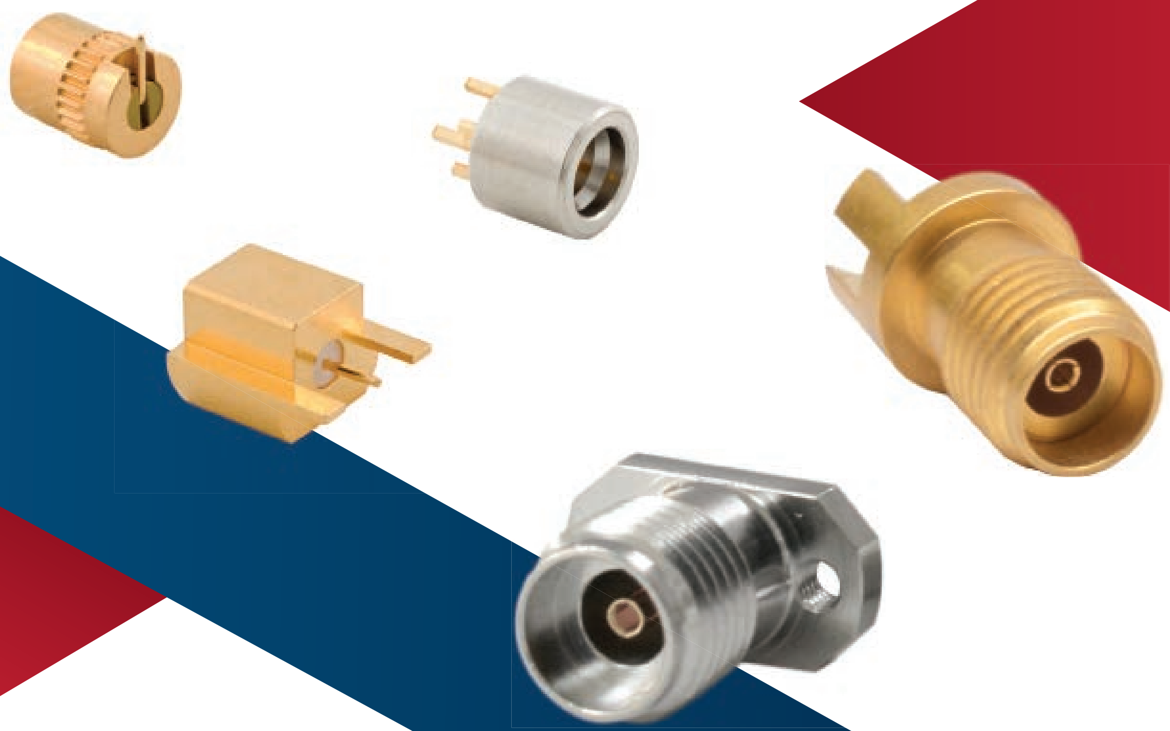
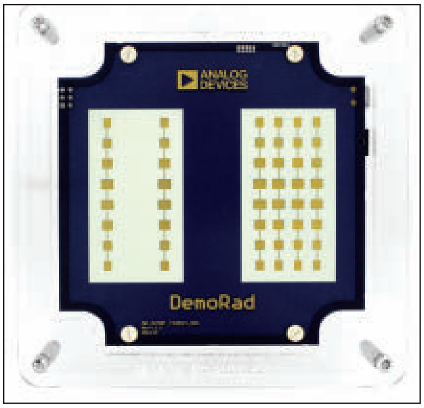


24 GHz Radar For Non-Contact Industrial Sensors

Analog Devices Inc.
Norwood, Mass.

Silicon-based 24 GHz radar technology is enabling a new generation of real world, non-contact smart sensors that are increasingly being used in industrial and consumer mass market applications, such as automotive and drones. These radar sensors provide real-time information about an object's presence, movement, angular position, velocity and range, from a few centimeters to several hundred meters away from the sensor. Until recently, radar sensors at mmWave frequencies required discrete components and were large, complex and expensive, which limited broad industrial market adoption. Now, 24 GHz radar products from Analog Devices (ADI) provide the performance and integration to achieve small size, low cost and ease-of-use for applications such as object detection, tracking, security control and collision avoidance warning systems.



▲ **Fig. 1** Demorad 24 GHz radar platform showing transmit (left) and receive (right) antennas.

SPEEDING DEVELOPMENT

Acknowledging the time-to-market challenges for companies motivated to evaluate, design and manufacture radar sensing technology, ADI recently introduced a 24 GHz radar system-level prototype solution called Demorad (see ***Figure 1***). The Demorad system is a novel radar evaluation platform, with out-of-the-box software, that allows setup of a radar sensor within minutes. Demorad enables rapid product prototyping of radar products that measure target/object presence, movement, angular position, velocity and range in real-time.

As shown in ***Figure 2***, the platform includes the antennas and a full RF-to-baseband signal chain, including ADI's 24 GHz chipset and Blackfin digital signal processor (DSP). The front-end contains two transmit (Tx) and four receive (Rx) channels, with the antennas located on one side of a printed circuit board (PCB) and the 24 GHz RF chipset, analog-to-digital converters and DSPs on the reverse side.

The multiple channels enable multiple-input-multiple-output (MIMO) capability,

which increases the angular resolution of the sensor. Using the two Tx outputs and appropriate antenna placement yields seven Rx channels—four real channels and four virtual channels, with one channel overlapping.

Signal processing options include raw data sampling and digital post processing, with real-time fast Fourier transform (FFT) and control firmware available in the Blackfin libraries. The system handles data rates up to 1.2 MSPS per IF channel. Via a USB 2.0 interface, Demorad connects to a PC that hosts software with an easy-to-use graphical user interface (GUI). The GUI enables control of the 24 GHz front-end and accesses a library of radar algorithms. Alternatively, Demorad can write the raw sensor data for post processing using custom routines developed in MATLAB, such as 2D/3D radar FFTs, constant false alarm rate (CFAR) and classification algorithms.

FMCW RADAR

The Demorad platform uses FMCW for the Tx waveform. ***Figure 3*** explains the basic FMCW theory, showing the ramp or chirp waveform and the radar equations that define performance. Range resolution is dependent on the Tx carrier sweep bandwidth; the higher the Tx sweep bandwidth, the higher the range resolution of the radar sensor. Velocity resolution depends on dwell time and carrier frequency; the higher the carrier frequency or dwell time, the higher the velocity resolution. Angular resolution depends on the carrier frequency; the higher the carrier frequency, the better the angular resolution.

Demorad detects range and velocity of objects up to 200 m away with a resolution of approximately

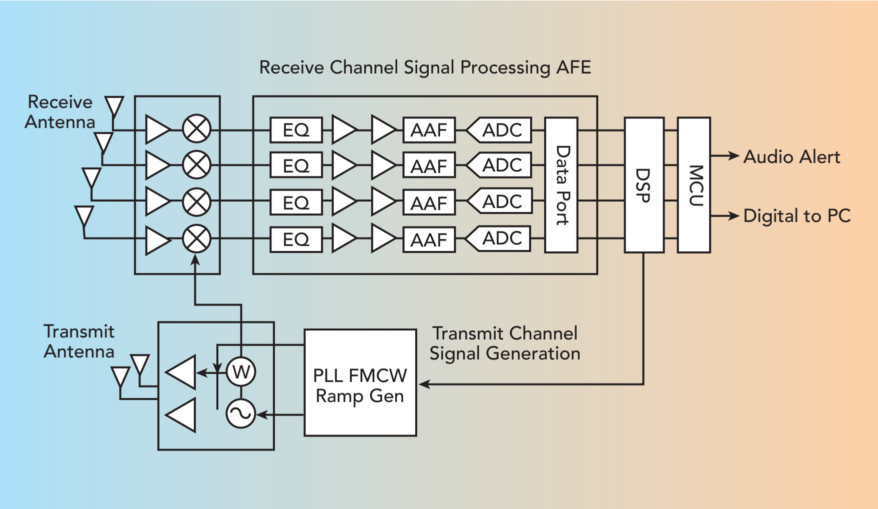


Fig. 2 RF-to-baseband signal chain.

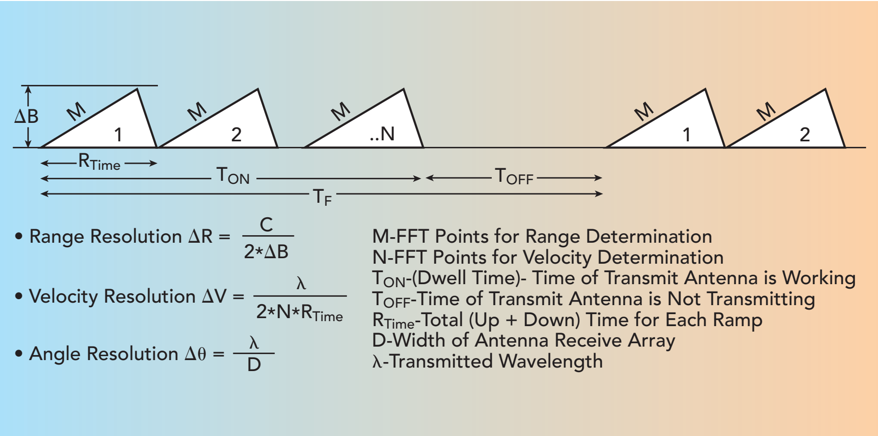
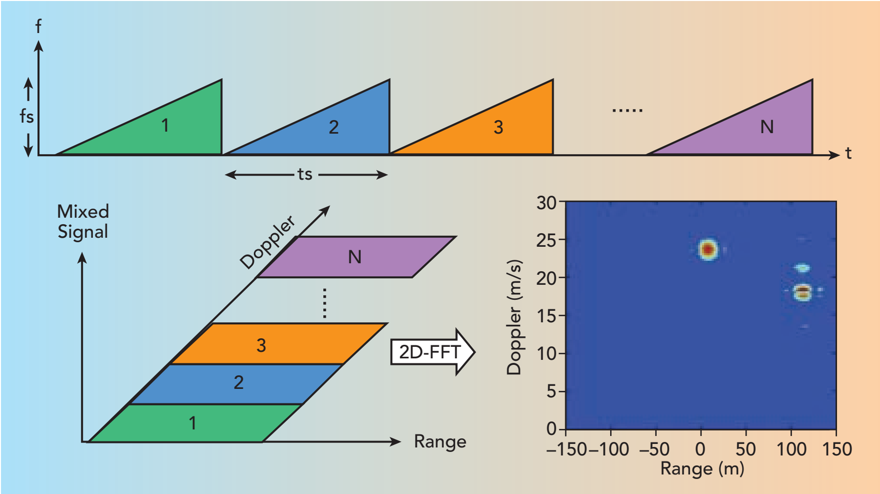


Fig. 3 FMCW radar concept.



▲ Fig. 4 Range and Doppler frequency obtained using a 2D FFT.

75 cm. The field of view (FOV) is approximately 120 degrees in azimuth and 15 degrees in elevation, based on the antenna array design.

The radar system signal chain includes some basic algorithms in the DSP: FFT, beamforming and CFAR. The FFT provides range and velocity data, beamforming estimates the angular position and CFAR detects the target in the presence of clutter or other noise. Basic target detection and target classifications are run on the host PC. Demorad is primarily designed for collecting radar signals in the time and frequency domains and does not include advanced target detection or object classification algorithms. This application development is generally performed by the end-system developer, having knowledge of the environment that the radar sensor will be working in and the type of object detection required.

Demorad offers users several operating modes:

FMCW Radar: In FMCW mode, the distance to stationary targets is measured, with the frequency of the down-converted Rx signal for a target proportional to the distance to the target. The built-in FFT determines the frequency. Using the Range-Time display option, moving targets can be viewed and the display stores several FMCW sweeps.

Range-Doppler: In Range-Doppler mode, the range to the targets and speed are determined. Range-Doppler mode is one of the most powerful modes because it can process multiple Tx ramps or chirps simultaneously by evaluating a two-dimensional Fourier transform, with the processed data displayed in the Range-Doppler map (see ***Figure 4***). Range-Doppler is so powerful because it separates targets with different velocities, even if they are located at the same range. This is useful for identifying multiple fast-moving targets going in different directions. An example is resolving complicated traffic scenarios, where cars are moving in opposite directions or during overtaking maneuvers.

Digital Beam Forming (DBF): In DBF mode, the distance and the angle to the target are displayed. The signals from the four Rx channels are used to estimate the angle of the target, and the display shows the spatial distribution of targets in the xy-plane. In this mode, the system is configured the same as in FMCW but processes the IF down-converted signals differently. After calculating range, the angle of the target is determined by evaluating the phase differences between the four Rx channels. In DBF mode, a front-end system calibration is required to eliminate unwanted deterministic phase variations between Rx channels. Each Demorad system comes with factory calibration data that is loaded when the GUI runs, and the sampled IF signals are corrected before evaluating the sensors' measured data.

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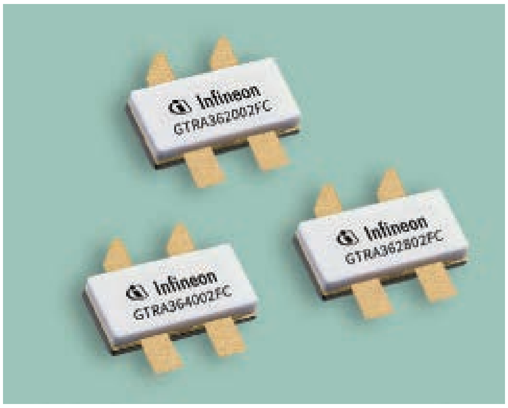


GaN on SiC Power Transistors for 3.5 GHz Cellular

Infineon Technologies
El Segundo, Calif.

The promise of 5G new radio technologies to provide significant improvements in throughput, super low latency and reliable, ubiquitous coverage is critically based on the availability of new spectrum. The 3GPPP group has identified new spectrum both below and above 6 GHz in a drive toward global harmonization. The future 5G ecosystem will most likely feature macro base stations transmitting in spectrum below 6 GHz for physical coverage, while mmWave frequencies will be used for capacity enhancements.

The frequency band from 3400 to 3800 MHz has generated wide interest due to its potential to be available on a global basis, having already been identified for mobile communications use in many European countries, in China (which includes frequencies down to 3300 MHz) and in the U.S. RF characteristics at 3.5 GHz make this band suitable for use in both massive MIMO systems with beamforming antennas and in more traditional cellular base station architectures. ITU identifies these 3.5 GHz frequencies as band 42 (3400 to 3600 MHz) and band 43 (3600 to 3800 MHz).

THREE NEW DOHERTY TRANSISTORS

Many field trials are underway in the 3.5 GHz bands. To address this market, Infineon has developed a line of GaN on SiC RF power transistors for Doherty amplifier applications that are capable of the highest efficiency and broadband operation. GaN on SiC technology has stormed the cellular RF power market in recent years due to its high-power density and high efficiency. These characteristics enable designers to create highly compact amplifier circuits with more than a 10 percentage point improvement in efficiency above 3 GHz, compared to LDMOS solutions, and wideband performance that facilitates the design of Doherty amplifiers.

These transistors are matched for optimal operation between 3400 and 3600 MHz, the band with the most global availability. One of the challenges at this band is the wide signal bandwidth of 200 MHz. To facilitate the design of a wideband Doherty and to compensate for the changing input impedance of the peak amplifier over power (running at class C), special attention was placed on the design of the internal transistor input match, with techniques developed to enhanced wideband operation while leaving the output unmatched. Further, these transistors use an asymmetric design for better efficiency with high peak-to-average ratio (PAR) signals.

The GTRA362002FC is an asymmetric transistor with more than 200 W of combined peak output power, designed for amplifiers in 20 W cellular systems. It has two outputs: the carrier or main side with 85 W output power and the peak side with 115 W of P_{3dB} output, for a split ratio of 1:4. Infineon developed a Doherty reference design that provides 14 dB of gain, 45 percent drain efficiency and -29 dBc adjacent channel power ratio (ACPR), measured with a single carrier WCDMA, 10 dB PAR signal at 3600 MHz and 29 W average output power (see ***Figure 1***).

The GTRA362802FC is also an asymmetric design. Offering more than 300 W

of combined peak output power, it is targeted at 30 W cellular systems. It provides 115 W on the main side and 170 W on the peak side of a Doherty. With a single carrier WCDMA, 10 dB PAR signal at 3600 MHz and 44 W average output power, a Doherty amplifier reference design is capable of 14 dB of gain, 49 percent efficiency and -31 dBc ACPR. Typical Doherty performance of the GTRA362802FC is shown in ***Figure 2*** (P_{out}, efficiency and gain) and ***Figure 3*** (gain and efficiency versus frequency).

The higher power GTRA364002FC has been designed for use in 40 W cellular systems and provides more than 400 W of combined peak output power. Its main side outputs 170 W at P_{3dB} and the peak side 255 W, for a 1:5 power split ratio. Using a single carrier WCDMA, 10 dB PAR signal at 3600 MHz and at 59 W average output power, the Doherty reference design is capable of 13 dB of gain, 43 percent efficiency and -30 dBc ACPR.

All devices are available in an open cavity, ceramic lid package with CPC flange. Thermal resistance for these transistors ranges from 1 to 1.7°C/W (measured at Tcase = 75°C and CW signals using an infrared measurement). Engineering samples are available, as well as a reference Doherty amplifier for each product; volume production is planned for the end of 2017.

Infineon Technologies
El Segundo, Calif.
www.infineon.com/rfpower

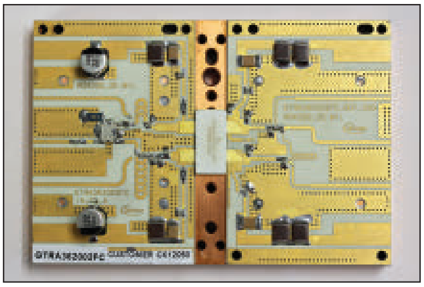


Fig. 1 The GTRA362002FC is an asymmetric transistor delivering more than 200 W of combined peak output power.

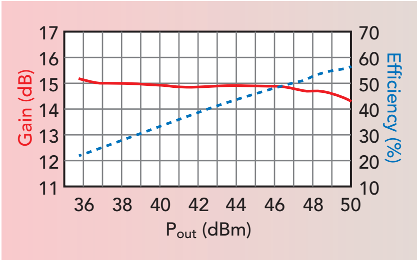


Fig. 2 Typical Doherty output power, efficiency and gain of the GTRA362802FC at 3500 MHz. The transistor is biased at V_D = 48 V, I_{DQ} (main) = 140 mA and V_{GS} (peak) = −5.3 V.

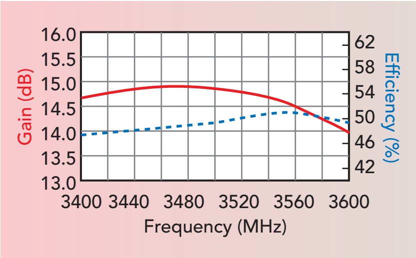
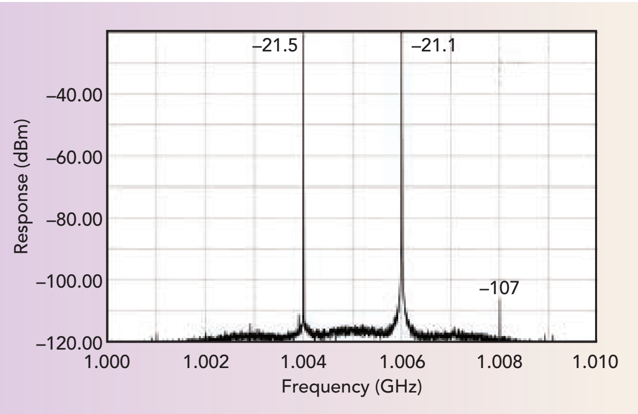


Fig. 3 Typical Doherty gain and efficiency vs. frequency of the GTRA362802FC. The transistor bias is the same as for Fig. 2.

High Performance 20 GHz Spectrum Analyzer and Monitoring Receiver

Signal Hound
La Center, Wash.

The newest addition to Signal Hound's family of headless RF spectrum analyzers, the SM200A, provides high dynamic range, ultra-low phase noise, lightning-fast sweep speeds and 160 MHz of real-time bandwidth—performance previously available only in the most expensive spectrum analyzers from the largest companies in the industry. With a U.S. retail price of $11,900, the SM200A is a compelling alternative to expensive, high performance test equipment without compromising performance. It is a cost effective solution that extends precious capital budgets and creates new markets by slashing the cost of entry for high-end spectrum analysis applications, which have been out of reach for many organizations. Manufacturers no longer have to settle for abbreviated production testing, as the analyzer handles the most demanding production line measurements.

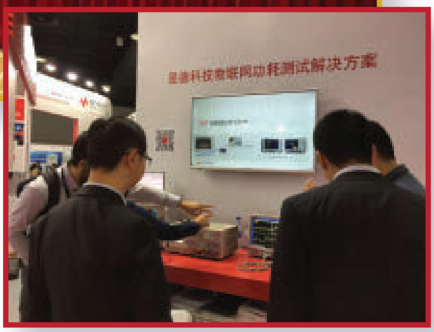


▲ **Fig. 1 The SM200A has better than 110 dB dynamic range, defined as third-order intercept less displayed average noise level (DANL) at 1 Hz resolution bandwidth.**

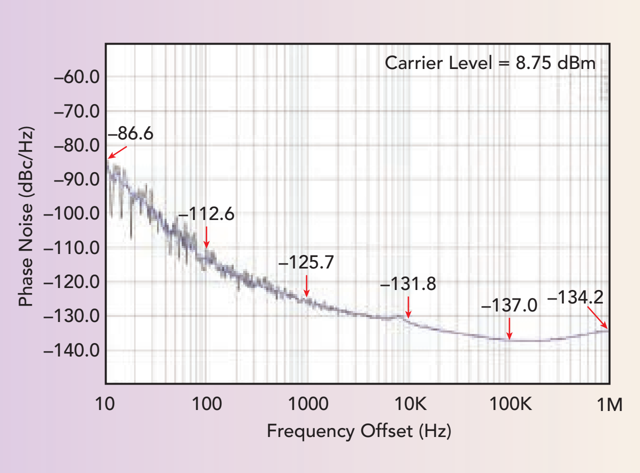
The SM200A tunes from 100 kHz to 20 GHz with 160 MHz of instantaneous bandwidth and a continuously sustained 1 THz/sec sweep speed. It has a high intercept point, with 110 dB of dynamic range (see ***Figure 1***), and phase noise performance low enough to contribute less than 0.1 percent error to error vector magnitude (EVM) measurements.

UNIQUE DESIGN

The signal processing functions of the SM200A are distributed between a state-



of-the-art Altera Arria-10 FPGA and an external PC with an Intel Core i5 or i7 processor. This powerhouse combination produces a full-featured spectrum analyzer and monitoring receiver platform that is readily configurable for even the toughest jobs. Unlike conventional spectrum analyzers that integrate dedicated embedded processing in a single box, the distributed processing of the SM200A achieves comparable performance with unmatched flexibility, at a fraction of the cost. The limitations of traditional, standalone systems make it challenging to add storage, upgrade the processor or change the network interface. These problems are eliminated with the SM200A, because it uses a PC and is not locked into proprietary, expensive or outdated processing hardware.



▲ **Fig. 2 Measured phase noise of a 1 GHz reference signal from Signal Hound's phase noise clock standard.**

The integrated software supports traditional controls such as frequency span/center/start/stop, resolution bandwidth, video bandwidth, reference level, configurable traces and markers. The software provides rich display features such as a 2D waterfall or spectrogram plot and a real-time color persistence display format to enhance and simplify signal identification. There are also digital demodulation tools included for physical layer measurements of many common digital modulation formats, including ASK, FSK, MSK, OOK, PSK and QAM. EMC precompliance tools are also provided.

SM200A connectivity includes a built-in GPS for automatic time and geolocation stamping of the received data. This provides ±50 ns stamping of calibrated streaming I/Q for creating a signals database, as well as improving post-analysis of accumulated data after mobile capture sessions. There is a built-in general purpose expansion port that can be used for a variety of advanced functions, such as switching between multiple antennas with zero latency during a signals monitoring session.

The Signal Hound system may be connected to a network and backend resources through the PC's Ethernet interface, which makes the full range of communications, data transfer, software updates and system management tasks feasible. For specialized applications, the SM200A can be interfaced to automated monitoring systems or automated test equipment (ATE) through its local application program interface (API). The fully documented API, written in C/C++, supports capabilities such as spectrum sweeping, setting record-on-event triggers, real-time analysis and streaming of I/Q data. Programmers can either customize their existing applications or develop targeted applications from scratch, such as inserting custom digital signal processing algorithms into a calibrated stream of I/Q data.

The SM200A weighs less than eight pounds, including the heat sink, and is powered by an external 9 to 15 V_{DC} supply or with the included AC/DC wall adapter.

APPLICATIONS

The high dynamic range and extremely low phase noise of the SM200A are a "dynamic duo," enabling advanced signal measurement techniques.

Many organizations cannot justify spending the money to buy a phase noise test system, even though it would be very beneficial. The affordable SM200A is well suited to take on all but the most difficult phase noise measurements, with internal phase noise very close to the best standalone, big box spectrum analyzers. Signals that typically hide under the phase noise skirt of a larger signal are easily seen. ***Figure 2*** shows the SM200A's phase noise measurement of the phase noise of a 1 GHz reference signal generated from Signal Hound's 1 GHz phase noise clock standard.

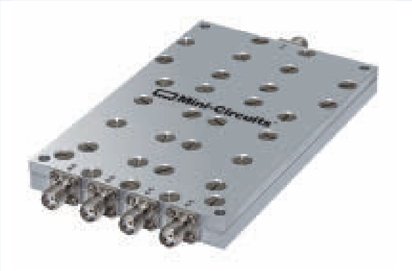
Over-the-Air intermodulation testing of signal quality can be measured at either the output of a cell tower's internal coupler or by receiving a signal from the antenna. Passive intermodulation (PIM) is tested by adding an appropriate high-power duplexer and power amplifier. Those working with difficult third-order intercept requirements will find the SM200A simplifies their measurements.

Signals surveillance technicians and spectrum managers will benefit from a built-in bank of sub-octave preselector filters covering 20 MHz to 20 GHz. Weak or elusive signals, even in the presence of high-power out-of-band signals, are easily identified by the SM200A. It provides 100 percent probability of intercept for on-the-fly targeted signals as short as 10 ms duration anywhere within a 10 GHz span or 20 ms duration over a 20 GHz span. The SM200A also captures radar chirps at a rate of 500 MSPS when dwelling on any given 160 MHz span below 20 GHz.

CONCLUSION

The SM200A, which will be available for purchase in December 2017, offers the highest levels of performance in spectrum analysis and signal monitoring. It supports the most demanding applications across a wide range of lab, production line, portable and field configurations, enabling users to go anywhere. Arguably, the SM200A provides unrivaled value.

Signal Hound
La Center, Wash.
signalhound.com



Four-Way, 2 to 18 GHz Power Splitter/Combiner

A fundamental building block of microwave systems, power splitters and combiners are always in demand, and even small improvements in performance will help system performance, such as reducing noise figure, increasing dynamic range or improving the amplitude and phase matching in multichannel systems.

The Mini-Circuits' ZN4PD-02183+ is a 50 Ω, four-way, in-phase splitter/combiner that covers 2 to 18 GHz. Added insertion loss, above the theoretical 6 dB split, is typically 1.0 dB, 1.6 dB maximum. The typical channel-to-channel amplitude and phase imbalance are 0.3 dB and 3.5 degrees, respectively, and isolation between any two channels is typically 20 dB, 16 dB minimum. Typical VSWR is 1.45:1 at the sum port and 1.35:1 at ports 1 to 4. Used as a splitter, the maximum input power is 30 W, and each of the four ports can carry up to 150 mA DC current (600 mA at the sum port). The splitter/combiner is fabricated in a 2.5 in x 4 in x 0.38 in aluminum alloy housing, with SMA female connectors. It has an extended operating temperature range from −55°C to +100°C and is RoHS compliant.

The broad frequency coverage of the ZN4PD-02183+ supports the requirements of electronic warfare and test and measurement applications and can simplify system architectures. The channel-to-channel amplitude/phase matching and isolation help maintain signal integrity in multichannel systems.

The ZN4PD-02183+ is in stock and available for shipment.

VENDORVIEW

Mini-Circuits
Brooklyn, N.Y.
www.minicircuits.com

Passive Frequency Doubler with Excellent f_0 Isolation

Custom MMIC has expanded its portfolio of high performance MMIC doublers with the CMD226C3. The MMIC design doubles an input frequency between 7 and 11 GHz to an output from 14 to 22 GHz.

The CMD226C3 has low conversion loss and excellent f_0 isolation. With an input drive level of +15 dBm at 9 GHz, the typical conversion loss is 9 dB and f_0 isolation is 44 dB below the input level. Typical $3f_0$ and $4f_0$ isolation are 48 and 50 dB, respectively. Extremely temperature stable, conversion gain versus frequency varies less than 2 dB over the operating temperature range of −40°C to +85°C. Conversion gain is also stable with varying drive.

A passive GaAs design, the doubler has low phase noise and does not require biasing. Housed in a ceramic, QFN-style package, the broadband doubler is designed for 50 Ω systems, with the input return loss better than 6 dB, which occurs at the low end of the input frequency band. The output return loss is better than 5 dB, with the peak also at the low end of the output frequency range.

An evaluation printed circuit board (PCB) is available to speed testing of the CMD226C3. The doubler is also available in die form for integration in chip-and-wire assemblies.

The low phase noise of the passive design makes the doubler particularly useful for local oscillator (LO) chains in radar, switched multimegabit data service (SMDS), satellite communications and point-to-point radio for cellular backhaul and data networks.

VENDORVIEW

Custom MMIC
Chelmsford, Mass.
www.custommmic.com/cmd226c3/

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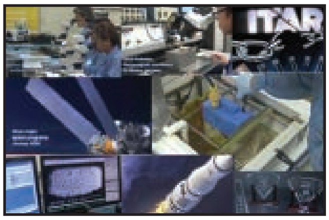
Web and Video Update

Process and Manufacturing Capabilities Video



View AEM Inc.'s new video about their process and manufacturing capabilities for high-reliability components serving the aerospace, missile defense, as well as other mission critical applications. AEM's heritage stretches for decades offering the highest quality components available.

AEM Inc.
www.aem-usa.com

6 to 18 GHz Amplifier Series Product Demo

VENDORVIEW

AR's Design Supervisor, Elias Neno, provides a product demonstration on AR's new Class A solid-state amplifiers designed for applications where instantaneous bandwidth, high gain and linearity are required. The 20S6G18A, when used with a sweep generator, will provide a minimum of 20 W of RF output power instantaneously from 6 to 18 GHz, while the 40S version delivers 40 W. The 20 W model can be expanded to 40 W inside the same cabinet. These instruments are suitable for radiated immunity testing, TWTA replacements and EW applications.

AR RF/Microwave Instrumentation
www.arworld.us/6to18

New Webinar Available

VENDORVIEW

New on the Berkeley Nucleonics website is a webinar that will introduce the Model 7000 series compact integrated phase noise testing (PNT) solution. The webinar will highlight the recent advancements in features and capabilities including: MHz to 40 GHz measurements, offsets from 0.01 Hz to 100 MHz, AM measurements (Absolute Amplitude Noise), high drift mode (ability to measure modulations and high drifting or unstable DUTs, etc.) and offsets from 0.01 Hz to 100 MHz.

Berkeley Nucleonics
www.berkeleynucleonics.com

New Website Look

Ciao Wireless is proud to announce a new website look that is modern, informative and responsive. The latest web update features a new look, mobile device support and improved navigation throughout the website. Users can easily browse through the company's various applications to find a solution for their project. The website also features an option to download catalog sections or the entire catalog.

Ciao Wireless Inc.
www.ciaowireless.com

CST Website Update

VENDORVIEW

CST recently upgraded their website to streamline information and improve the experience of their users. The new site allows users to easily find relevant information about the company's products, including related articles and upcoming related events. The company also debuted MyCST, a personal portal that lets users register for webinars and events, save articles to read later, access any materials from workshops they have attended and more.

Computer Simulation Technology
www.cst.com

New and Improved

K&L Microwave's website provides information and tools, such as the Filter Wizard® web application, to speed the identification of custom design solutions from a full range of company products. The latest web update features a new look, mobile device support, social media links and improved LTE band navigation to test set components for broadband emission monitoring. Research capabilities, access data sheets, submit quote requests and download the company's new Product Catalog.

K&L Microwave
www.klmicrowave.com

Web and Video Update

Updated Product Line Web Pages

KRATOS General Microwave, one of the largest suppliers of microwave products to the defense and non-defense markets, has updated its website to better reflect the company's various capabilities and product lines. Each product line page provides easy access to the various COTS microwave products in each category. To help customers better utilize their microwave products, KRATOS General Microwave has added a link to White Papers that provide greater detail about some of the company's product lines. The KRATOS General Microwave website also now includes archived GMC product catalogs.

KRATOS General Microwave
http://gmcatalog.kratosmed.com/Kratos-General-Microwave-Product-Catalog

Product Guide Available on Site

VENDORVIEW

Rapid growth in the number and variety of wireless applications and connected devices in the market has driven the need for more innovative and highly customized test solutions. Customers are looking for equipment to multiplex application-specific test systems across multiple DUTs, which requires signal routing, distribution and conditioning functions in a variety of configurations. This 2017 Test Solutions Product Guide showcases some of the company's newest, most advanced and most popular test systems developed to date, and is now available on their website.

Mini-Circuits
www.minicircuits.com

Expanded New Products on Website

RLC Electronics Inc. has expanded its "New Products" feature on the website, adding press releases, photos, electrical information and outline drawings where available. Latest releases include High-Power 18 GHz SPDT switches with N connectors, 30 GHz Surface Mount Cavity Filters, 50 GHz Terminated SPDT Switches, Ka-Band Connectorized Cavity Filters, Miniature SP2T Switches with MS Connectors and Phase Trimmers, as well as integrated assemblies such as Switched Filters. New products will be published on a bi-monthly basis. Please also notice RLC's new AS9100 Certification posted on the website.

RLC Electronics Inc.
www.rlcelectronics.com/new-products.html

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CST — Stand 105

CST STUDIO SUITE

VENDORVIEW

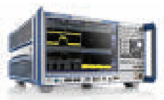
CST STUDIO SUITE is a package of state-of-the-art electromagnetic and multiphysics simulation tools, used by leading companies and research institutes in fields ranging from consumer electronics and healthcare to automotive and aerospace. EM simulation with CST STUDIO SUITE allows engineers to design, characterize and optimize devices with virtual prototypes, reducing the cost and time required to develop new products. The upcoming 2018 version includes new features for designing, managing and simulating complex devices and systems.

www.cst.com

Rohde & Schwarz — Stand 108

High-End Signal and Spectrum Analyzer

VENDORVIEW



Rohde & Schwarz is expanding the internal analysis bandwidth of its R&S FSW high-end signal and spectrum analyzer up to 2 GHz by introducing the new R&S FSW-B2001 option. This test solution enables R&D users to investigate wideband signals in detail without the need for an external digitizer. The R&S FSW-B2001 option provides 14-bit ADC resolution and wide dynamic range, characterized by excellent SFDR figures, for example -65 dBc for 1200 MHz bandwidth. This translates directly into outstanding signal analysis performance.

www.rohde-schwarz.com

Anritsu — Stand 109

Ultraportable mmWave Spectrum Analyzers

VENDORVIEW

The new Spectrum Master™ MS2760A series of mmWave spectrum analyzers, allows up to 110 GHz spectrum analysis with an instrument that fits in the palm of your hand. Anritsu utilizes its patented Nonlinear Transmission Line technology to shatter the cost, size and performance barriers associated with traditional spectrum analyzers. The MS2760A offers a new level of measurement performance in applications such as 5G, E-Band, 802.11ad/WiGig, satellite communications, electronic warfare and automotive radar.

www.anritsu.com

Ducommun RF Product Group — Stand 113

Power Amplifiers

Ducommun RF Product Group is proud to offer models AHP-73062220-01 and AHP-83062120-01, used mostly in E-Band communication infrastructure systems. These power amplifiers provide small signal gain of 28 dB from 70.5 to 76.5 GHz and 80.5 to 86.5 GHz respectively, with +20 dBm output power at1-dB compression. Featuring high output power and IP3, single power, compact and lightweight with wide operational temperature range.

www.ducommun.com

HUBER + SUHNER — Stand 118

Plug, Test, Smile with HUBER+SUHNER

VENDORVIEW

When it comes to test and measurement, SUCOFLEX 500 assemblies guarantee the highest level of satisfaction. The SUCOFLEX 526S is the top performance cable assembly for various applications in test laboratories. Thanks to their unique cable and connector design, they deliver best-in-class phase and amplitude stability with flexure in combination with outstanding return and insertion loss up to 26.5 GHz.

www.smile.hubersuhner.com

IngunPrufMittelbau GmbH — Stand 118

ESD-Equipped RF Exchangeable Kits

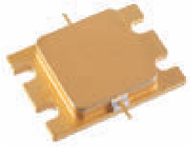
Manually operated radio frequency test fixtures are used to precisely and securely contact highly sensitive RF boards, and to measure the radio frequency signals in a reliable way. The manually operated RF test fixtures are designed as a quick-exchange system and consist of a precision manufactured RF exchangeable kit and of a MA basic unit. To the new RF exchangeable kits, the following optimisations have been made: ESD-equipped version, newly integrated service cover, a new RF interface and more.

www.ingun.com

Sumitomo Electric Device Innovations — Stand 120

Devices for X-Band Applications

VENDORVIEW



Building on their strong position with L- and S-Band GaN devices, Sumitomo Electric Device Innovations announces their new line up of devices for X-Band applications. Delivering up to 220 W in a single device and 38 percent efficiency, these devices are designed for suitability in a range of radar applications. For more information or to discuss your needs in further detail please visit Stand 120 or email eumw@sumielectric.com.
www.sei-device.com

NI AWR — Stand 124

NI AWR Design Environment

VENDORVIEW

AWR

Visit NI AWR at EuMW in Nuremberg, Germany in Stand 124 to see v13 of NI AWR Design Environment, which includes upgrades and enhancements to Microwave Office, Analog Office, Visual System Simulator™ (VSS), AXIEM and Analyst™ software products. This latest release, v13.02, continues to address design challenges associated with highly-integrated RF/microwave components (power amplifiers, filters and more) commonly found in communications and radar systems. In addition, NI AWR will also be showcasing its newest product addition, AntSyn™ antenna synthesis and optimization.
www.awrcorp.com/whats-new

MPI Corp. — Stand 128

Automated Probe System

With ShielDEnvironment™, TS3000-SE addresses the needs for ultra-low noise, extremely accurate and highly reliable DC/CV, 1/f, RTS and RF measurements. The exclusive, actively cooled probe platen design provides maximal stability over the wide temperature range from -60°C to 300°C and is making the TS3000-SE probe system an excellent choice for testing devices under different thermal conditions.
www.mpi-corporation.com/ast

Spectrum Elektrotechnik GmbH — Stand 138

Phase Adjusters DC to 63 GHz

Phase adjusters are needed at applications where the phase adjustment of components or cable assemblies is necessary. Phase adjusters are designed for constant impedance over the whole adjustment range. They are employed to adjust the electrical separation of other components without introducing additional mismatch. All step discontinuities have been carefully compensated. Locking screws are provided to comfort the sliding tension and to lock at the desired adjustment. The best materials have been used for ruggedness, low weight and best performance.
www.spectrum-et.com

Pasternack — Stand 143

Waveguide Phase Shifters

VENDORVIEW

Pasternack's new series of waveguide phase shifters are comprised of seven models that operate in the frequency range of 18 to 110 GHz in seven waveguide bands from K- to W-Band. They provide phase shift range from 0 to 180 degrees and 1 dB maximum insertion loss. These waveguide phase shifters are constructed of gold-plated brass waveguide material and feature UG flange-style per military standard. Additionally, the micrometer allows for precision and repeatable phase settings.
www.pasternack.com

SPINNER GmbH — Stand 148

PCB Probe

VENDORVIEW

At the European Microwave Week, SPINNER is presenting a new PCB probe that takes PCB testing to a new level by enabling abrasion-free and therefore lossless RF transmission. Also featured is a simplified switch matrix with multiple input and output ports for antenna testing. In addition, SPINNER is exhibiting its latest generation of EasyDock push-pull measurement adaptors with nonlocking and lockable versions for manual and automatic use.
www.spinner-group.com

Custom Microwave Components — Stand 149

5G Switch Matrix

Model CMCI1150 is a 20 to 40 GHz Non-Blocking 8 x 8 Solid-State Switch Matrix System that is 5G ready. Insertion loss (including input divider split) is 18 dB typ. Isolation > 70 dB typ. The system features an integral embedded processing unit serving an intuitive browser based user friendly GUI. Bench top model is 12 in × 12 in × 6 in with 2.4 mm RF connectors. Rack mount versions available.

www.customwave.com

Norden Millimeter — Stand 149

Frequency Up- and Down-Converters

Norden Millimeter is a leader in the design and manufacture of frequency converters, transceivers, frequency multipliers and amplifiers operating in frequencies between 500 MHz to 110 GHz. Norden supplies a wide range of frequency up- and down-converters which are used in EW and ELINT systems. Custom assemblies can include frequency multiplication, filtering, LNA's and power amplification. Norden's products include VME, VPX and 3U configurations. Norden's quality system is ISO 9001:2008 and AS9100C certified.

www.nordengroup.com

OML Inc. — Stand 149

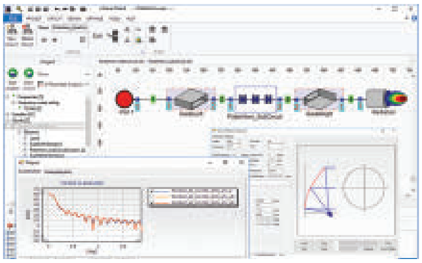
Portable Frequency Converter Module

The MxxH6DC from OML offers a solution to connect to your existing handheld spectrum analyzer to analyze mmWave frequency such as WiGig, 5G, collision avoidance radar systems, E-Band backhaul and military and defense. Models available are E-Band (60 to 90 GHz), extended E-Band (56 to 96 GHz), V-Band (50 to 75 GHz) and W-Band (75 to 110 GHz). Contact OML for more details.

www.omlinc.com

Mician GmbH — Stand 155

µWave Wizard



In Version 8.1, the latest release of Mician's hybrid EM-design software µWave Wizard, a tool for the analysis, synthesis and optimization of passive components, radiating boundary conditions are added to the 3D FEM solver, enabling the simulation of antennas with arbitrary shape and material distribution, like slotted waveguide and dielectric resonator antennas. Outer geometries of waveguide horn antennas can be modeled exactly. Also it allows the simulation of single and dual offset reflector antennas using real feed data including tracking mode support.

www.mician.com

Teledyne Labtech — Stand 160

Microwave Circuit Solutions

Teledyne Labtech provides advanced RF/microwave PCB technology supporting next-generation active electronically scanned array (AESA) radar systems. AESA radar systems are solid state devices known for high-reliability and performance, simpler designs and lower maintenance costs. Teledyne Labtech is one of the world's leading manufacturers of microwave circuit solutions with specialist capabilities in design, manufacturing, assembly and testing.

www.teledynemicrowave.com

Teledyne Relays — Stand 160

Electromechanical Relay

Teledyne Relays introduces the GRF121 electromechanical relay. This magnetic-latching SPDT relay is perfect for broadband, high repeatability, RF and digital applications—where RF performance from DC to 18 GHz or signal integrity up to 40 Gbps is required. This relay is ideal for ATE, semiconductor/IC testing, high-frequency communication and medical imaging devices, RF switch matrices and other applications requiring broadband signal fidelity and high digital throughput. The GRF121 now includes reversed-polarity coil and ungrounded open-contact options for design flexibility.

www.teledynerelays.com

Kuhne Electronic GmbH Stand 164
Bidirectional Amplifier

The KU BDA 240250-25 A amplifier covers the 2.45 GHz ISM Band and is designed to support various analog and digital modulation types and signal waveforms. The transmitter features LDMOS technology and delivers more than 20 W P1dB power. The built-in LNA provides a very low noise figure for further enhancement of the receiver's sensitivity. Ultra-fast switching between transmit and receive path is done automatically using lowest delay circuitry. There is also an optional input for external switch control.
www.kuhne-eletronic.de

Rosenberger Stand 172
Test & Measurement

Rosenberger has available test & measurement equipment and products for microwave and VNA measurements, such as calibration kits (full and industrial versions), with a wide range of coaxial interfaces, as well as compact calibrations kits such as MSO (open, short, load) and MSOT (open, short, load, thru) versions. Rosenberger also supplies microwave and test cable assemblies and test ports for VNAs, multiport connectors such as mini-coax for semiconductor test applications, low profile PCB connector systems such as modular connectors, solderless PCB connectors and spring loaded coax products.
www.rosenberger.com

Dow-Key Microwave Stand 199
Miniature Mechanical, Surface Mounted PC Board Switch

Dow-Key Microwave, an approved supplier for both NASA and ESA, will be showcasing its miniature mechanical, surface mounted PC board switch 509H. The switch is designed for space and high throughput satellite applications where reduced weight and less power consumption are requirements. For the ATE microwave market, Dow-Key's Reliant Switch™ Series, with 10 million life cycles and 0.03 dB insertion loss repeatability will also be on display.
www.dowkey.com

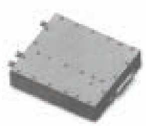
K&L Microwave Stand 199
Pre-Filtered GPS LNA Assemblies

K&L offers a line of pre-filtered GPS LNA assemblies designed with high-reliability applications in mind. The amplifiers cover L1, L2, L5 and combinations of those frequency bands with customer selectable gains of 16 to 40 dB. The noise figure for these products is typically 1.8 dB or less depending on the filtering requirements. Internal limiters can also be included if required by the customer. These LNA assemblies have been used in a number of high performance missile environments.
www.klmicrowave.com

Kratos General Microwave Stand 203
Indirect Synthesizers

Kratos General Microwave enhanced its series of fast switching (1 µSec) indirect synthesizers with the addition of the Model SM6220 with frequency modulation capability covering the full band 2 to 20 GHz. It can provide a frequency deviation of 1 GHz at up to a 10 MHz modulation rate and can be modulated with either analog or digital inputs. Of special significance; the synthesizer output frequency remains fully locked even while in the FM mode. Its small size and high-reliability make it ideal for use in demanding airborne environmental conditions as well as simulators and test systems.
www.kratosmed.com

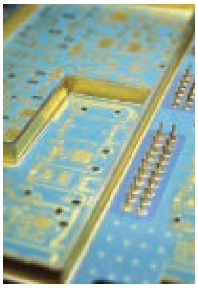
Micro Lambda Wireless Stand 203
MLVS-Series Frequency Synthesizers 50 MHz to 20 GHz



A smaller and lower phase noise frequency synthesizer, this is the first in a series of standard frequency models covering 50 MHz to 20 GHz phase noise at 10 GHz is specified at -124 dBc/Hz at 10 kHz offset with a switching speed of 10 µSec full band. Standard models are specified to operate over the 0 to +60°C. This series of frequency synthesizers have been designed in a miniature package with dimensions are 4.0 in × 3.6 in × 0.9 in tall.
www.microlambdawireless.com

Micro Systems Engineering GmbH — Stand 221

LTCC Substrates Offering Superior RF Performance

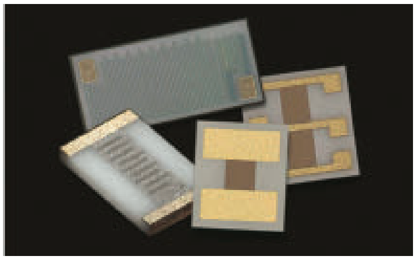


High frequency low loss packages, sensor packages, high reliability substrates: LTCC (Low Temperature Co-fired Ceramic) is a multilayer capable substrate technology offering superb RF and microwave performance characteristics. Excellent mechanical and electrical properties of LTCC, combined with gold and silver metallization systems, fine line patterning and the ability to embed passive components, offer superior RF performance and device miniaturization for high frequency applications. Micro Systems Engineering GmbH, an MST company, specializes in customized solutions for advanced microelectronics.

www.mst.com/msegmbh

Compex — Stand 227

Wire-Bondable and Edge-Terminated Resistors



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

www.compexcorp.com

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MICRO-ADS

Holzworth Instrumentation Stand 229

VENDORVIEW

Real-Time Phase Noise Analyzer

The HA7062C real-time phase noise analyzer is a dual channel, cross correlation system that was designed to address both the needs of R&D engineering as well as high volume manufacturing. The versatile design can collect data to unprecedented noise floor levels with industry leading data acquisition speeds at the touch of a button. The reconfigurable analog front end eliminates issues common to digital phase noise test systems while boasting numerous extended capabilities.

www.holzworth.com

LPKF Laser & Electronics Stand 244

ProtoLaser S4 Laser System

The LPKF ProtoLaser S4 laser system uses a green laser wavelength and can laser etch PCBs in minutes on a wide range of laminated substrates, FR4 and PTFE or woven PCB materials. Prototypes and small production batches can also be produced on short notice if required. The LPKF ProtoLaser S4 is even more precise than the mechanical systems and is therefore ideal for HF and microwave circuits, as well as digital and analog circuits.

www.lpkf.com

Passive Plus Inc. Stand 262

RF/Microwave Passive Components

Passive Plus Inc. (PPI) is a manufacturer of high-performance RF/microwave passive components, specializing in high-Q/low ESR/ESL capacitors, broadband capacitors, non-magnetic resistors and trimmers serving the medical, semiconductor, military, broadcast and telecommunications industries. Capacitor case sizes include 0505, 1111, 2225, 3838; EIA 0201, 0402, 0603, 0805, 1111; high-power 6040, 7676 and the new 1313; broadband capacitors, 01005, 0201, 0402, 0603, 0805. PPI is known for their outstanding quality, fast deliveries, competitive prices and superior customer service.

www.passiveplus.com

SAGE Millimeter Stand 287

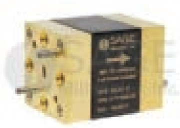
Coaxial Highpass Filter

VENDORVIEW

Model SCF-51346340-121F1F-H1 is a coaxial highpass filter with a passband frequency from 51 to 90 GHz. The filter rejects the frequencies from 1 kHz to 46 GHz and provides a nominal insertion loss of 1.0 dB in its passband with low ripple. Typical rejection for this model is 40 dB. The RF ports offer female 1 mm connectors, however, male connectors are also available under a different model number. For communication systems, radar systems and sub-assemblies applications.

Faraday Isolator

Model STF-12-S1-C is a full band Faraday isolator that operates from 60 to 90 GHz. The Faraday isolator is constructed with a longitudinal, magnetized ferrite rod that causes a Faraday rotation of the incoming RF signal. The compact, robust package is ideal for system integration and testing applications. The Faraday isolator offers 28 dB typical isolation and 1.5 dB nominal insertion loss with good flatness. For test labs, instrumentations and sub-assemblies applications.



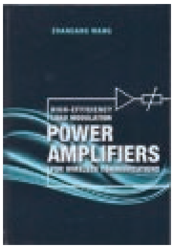
www.sagemillimeter.com

DYCONEX AG Stand 307

Advanced LCP Substrates for HF & Microwave Applications

Liquid Crystal Polymer (LCP) is a superior organic multilayer material for RF applications with stable electrical and mechanical characteristics across a range of frequencies up to 100 GHz. Due to its very low water absorption, LCP properties remain nearly constant regardless of the presence of moisture, allowing its use for near-hermetic packages. DYCONEX, an MST company, delivers leading-edge interconnect solutions in flex, rigid-flex and rigid technology since more than 50 years. DYCONEX is EN 9100 certified.

www.mst.com/dyconex



High-Efficiency Load Modulation Power Amplifiers for Wireless Communications

Zhancang Wang

"High-Efficiency Load Modulation Power Amplifiers for Wireless Communications" is the second book addressing power amplifiers (PA) by Zhancang Wang. His first, "Envelope Tracking Power Amplifiers for Wireless Communications," explores supply modulation techniques for improving PA efficiency. This book addresses the same challenge—improving PA efficiency—using passive and active load modulation approaches. Wang writes that he was motivated by the 80th anniversaries of the Doherty and Chireix PAs, each invention a seminal contribution to improving efficiency and of renewed interest with the high peak-to-average power ratio waveforms used by wireless infrastructure.

Wang thoroughly addresses the topic in seven chapters, beginning with the basic parameters of PAs, communication signals and approaches to improve efficiency. Chapter 2 covers passive load impedance tuning; dynamic and active load modulation are described in chapters 3 and 4, respectively. Chapter 5 explores enhancements to the Doherty architecture to improve efficiency, including uneven and asymmetric configurations, harmonic termination, multistage Doherty amplifiers and bias modulation.

With the proliferation of cellular bands and the development of carrier aggregation to increase data rates, network equipment manufacturers are motivated to increase the bandwidth of wireless infrastructure PAs, i.e., both frequency coverage and video bandwidth. Chapter 6 covers extending the bandwidth of load modulated PAs, discussing dynamic load, Doherty and multiband load modulation amplifiers.

The book concludes with a discussion of evolved active load modulation amplifiers, which reflects the impact of digital signal processing on PA design. Who knew there are so many options? Inverted Doherty, serial-type Doherty, digital Doherty, digital Chireix outphasing transmitters, multilevel linear amplification using nonlinear components (LINC) transmitters and asymmetrical multilevel outphasing are discussed.

Wang is a master PA designer at Ericsson and the owner of the Amplifier Frontier Research group. He has a master's in electrical engineering from Beijing University of Technology.

To order the book:

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www.artechhouse.com
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0.5 to 8 GHz

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*See datasheet for suggested application circuit for PMA3-83LN+
†Flatness specified over 0.5 to 7 GHz

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553 revA

FABS and LABS

Rohde & Schwarz – Producing the Goods

Rohde & Schwarz is a familiar name with a well known, established portfolio. However, in facilities not generally on the radar, a lot goes on behind-the-scenes with its production that customers, competitors and the RF and microwave industry at large are unaware of.

The company's philosophy, since it was founded over 80 years ago, has been to locate development and production in close proximity to one another. That is why most products are manufactured near the company's Munich headquarters, at its plants in Memmingen and Teisnach in Germany and at Vimperk in the Czech Republic. Globally, production facilities in Singapore and Malaysia ensure that production is close to the Rohde & Schwarz R&D activities at its Asian headquarters, while the company has been manufacturing broadcast transmitters for the local market in China since 2010 and in Brazil since late 2012.

The depth, scope and capacity of Rohde & Schwarz' production capability is illustrated by the Teisnach plant, which is the competency center for mechanical and electronic manufacturing within the company's network of production plants. Its broad spectrum of products includes enclosures, shielding components, antennas, printed circuit boards (PCB), precision micromechanical parts and custom electromechanical products of all types. As the competency center for transmitters and systems, the plant produces and supplies all TV and radio broadcast transmitters, as well as customized radiocommunications systems.

The Teisnach plant offers its microproduction customers a comprehensive service from start to finish—from the selection of materials and heat treatment to mechanical processing, electroplating and micro injection molding to final assembly and electrical functional tests.

As the manufacturer of all Rohde & Schwarz PCBs, the plant utilizes the latest technology for production, with the capacity to deliver prototypes, functional samples and series-produced parts. The product range includes double-sided boards, conventional multilayers, RF multilayers and high density interconnect (HDI) multilayers.

Cable production includes ribbon cables, multiconductor connecting cables and cable harnesses, as well as rigid and flexible coaxial cables. Capabilities include the processing of semi-rigid SUCOFORM cables up to 67 GHz, automated 3D bending of metallic sheaths, automated induction soldering, production of control lines—testing up to 4,736 connections—preparation of computer-aided design (CAD) documentation, lead-free soldering in line with Waste Electrical and Electronic Equipment (WEEE) and RoHs and manual production of design models and very small series runs.

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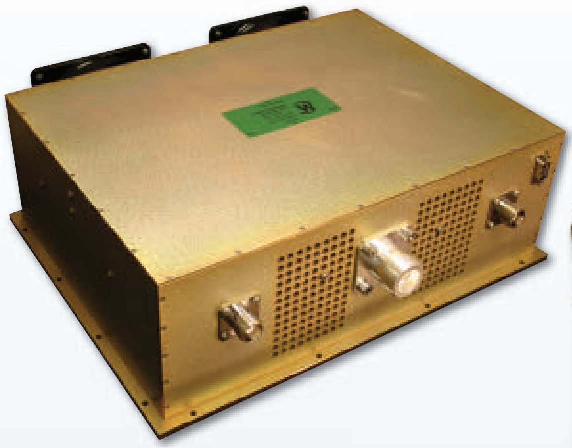

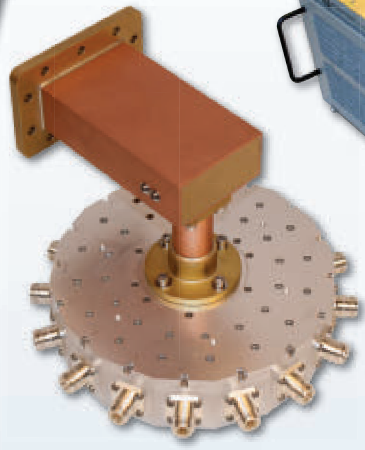

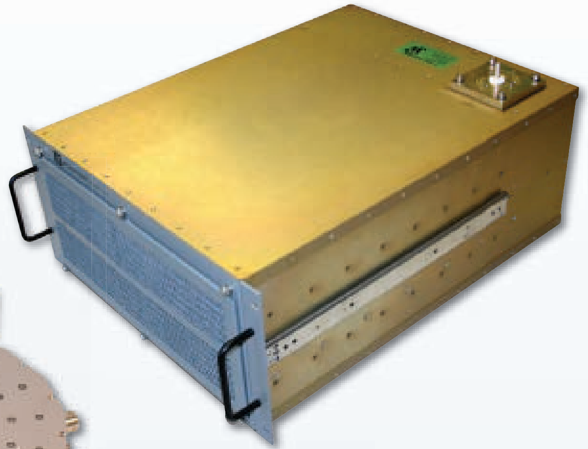

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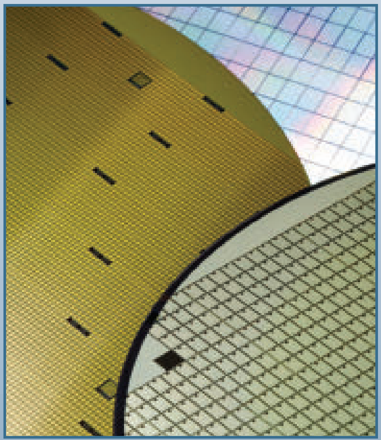

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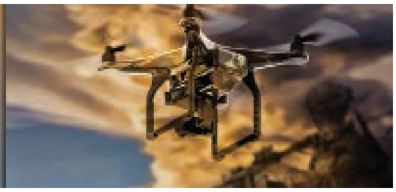

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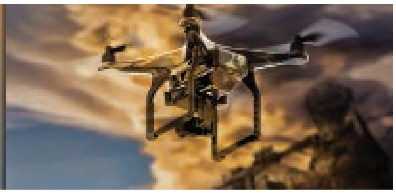

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A 21.4 dBm W-Band GaAs PHEMT MMIC Power Amplifier

Zhao Hua, Yao Hongfei, Jin Zhi and Liu Xinyu
Institute of Microelectronics, Chinese Academy of Sciences

This W-Band MMIC power amplifier (PA) has a small-signal gain (S_{21}) of 11.2 dB, an input/output reflection coefficient (S_{11}) of –9 dB and saturated output power of 21.4 dBm at 88 GHz. A low loss matching network with power combiner and microstrip coupled lines (MCL) is employed to increase the gain and output power of this three-stage design using WIN Semiconductor's 0.1 µm GaAs PHEMT process. Compared with metal-insulator-metal (MIM) capacitors, MCLs have greater stability and are less affected by fabrication tolerances. The chip size of the PA is only 2.86 mm × 1.76 mm^2.

W-Band (75 to 110 GHz) is largely used for imaging, remote sensing, satellite communications and military and automotive radar. In the automotive market, autonomous cruise control and emergency braking systems employing W-Band transceivers have been developed, but the high cost of mmWave components has widely restricted their use. For these applications, the availability of low cost MMICs is key to market expansion. The development of compact and less expensive W-Band transceiver systems,[1] static frequency dividers,[2] PAs,[3] frequency doublers[4] and high gain amplifiers[5] have been reported; however, lower cost higher output power (greater than 20 dBm or 100 mW) PAs for linear W-Band systems are still needed.

Recent advances in SiGe and silicon CMOS technologies have demonstrated output power above 100 mW at W-Band,[6-8] while compound semiconductors including InP, GaAs and GaN primarily occupy this domain. A narrowband PA using GaAs HEMTs achieved an output power of 25 dBm (316 mW) at 94 GHz,[9] while with GaAs MHEMTs, an output power of 213 to 267 mW (23.2 to 24.3 dBm) has been reported.[10,11] Several GaAs PHEMT amplifiers have been designed to achieve output powers of 20 to 22 dBm with bandwidths of 10 percent at W-Band.[12,13] A two-stage structure was used to deliver 25 dBm at around 94 GHz.[14] Over a broad band, a minimum of 14 dBm was obtained, with a peak output power of 16.2 dBm.[15]

Because of their high breakdown voltages and short gate lengths, GaN transistors offer the potential for higher output power at W-Band; however, the results have been limited. Using 0.15 µm gate length GaN transistors, PAs with output powers of 27 dBm at 84 GHz[16] and 29 dBm with 15 percent power-added efficiency (PAE) at 88 GHz[17] have been reported. Using a 0.12 µm GaN HEMT process on SiC, a three-stage PA has been reported that achieves an output power of 30 dBm, a small-signal gain of 10 dB and PAE of 19 percent at 93.5 GHz.[18]

In this article, a W-Band GaAs PHEMT MMIC PA with output power above 20 dBm is described. To achieve enough gain in a small chip area, a three-stage topology is employed. The first and second stages are matched to achieve maximum gain. A low loss matching network incorporated with a power splitter (or power combiner) is used in the third stage. The output stage is matched with an impedance determined from load-pull simulation to deliver maximum RF power. Each device is biased class A for high-power gain with high linearity. An overview of the architecture to achieve 21.4 dBm output power is provided. Measured results show good agreement with simulation, demonstrating the capability to meet goals of high performance and low cost for W-Band applications.

CIRCUIT DESIGN

Having sufficiently high f_t and f_{max}, CMOS and SiGe processes are suitable for the fabrica-


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tion of PAs at W-Band; however, P_{out} and adequate linearity are important requirements that are better achieved using GaAs processes. Due to the advantages of a semi-insulating substrate and low parasitic inductance of substrate vias, it is also easier to achieve higher levels of mmWave integration.

Cell Selection and Topology

As the total gate width increases (more gate fingers and/or wider unit gate width), parasitic effects increase. This reduces available transistor high frequency gain. While the maximum useful device size is different for a given process, generally it is difficult to simultaneously satisfy output power and linearity requirements at W-Band. The GaAs PHEMT process with 0.1 µm gate length is the current industry standard. Maximum practical transistor sizes deliver relatively modest output power. By combining multiple devices, output power can be increased to satisfy a design requirement. Sufficient gain margin is required to compensate additional losses of the combiner networks.

The W-Band amplifier described in this article is based on WIN Semiconductor's PP10 technology. It is a 0.1 µm GaAs PHEMT process manufactured on 150 mm wafers, with f_t > 145 GHz, F_{max} > 195 GHz and the capability to operate at 4 V. Measured data of PP10 PHEMT devices was used in the design to ensure the optimization of power and gain while meeting other amplifier requirements.

Small-signal data for a range of different device sizes (unit gate width and number of fingers) was supplied by the foundry. For 2 × 25 and 2 × 50 µm devices, G_{MAX} was greater than 7 dB at 94 GHz. This is higher than can be achieved in a practical circuit, of course, due to interstage and output network losses, matching for optimum power versus gain and the influence of lossy stabilization networks. Published load-pull data indicates that approximately 0.8 W/mm of saturated power density can be achieved with a 4 V bias. The traditional class A bias point at 50 percent Idss (approximately -0.4 V Vgs for the PP10-10 process) and 4 V Vds.

A single transistor PA is first designed for the purpose of device selection. From S-parameters and load- and source-pull simulations, the characteristics of different transistor sizes are obtained, such as small-signal gain, P_{sat} and optimum impedances (see ***Table 1***). In the simulation, all transistors are biased with Vgs = -0.4 V and Vds = 4 V. Enlarging the transistor size increases P_{sat} at the cost of reduced gain. Gain also depends more on gate width than on finger number. In this design, both two-finger and four-finger transistors with 50 µm gate widths are used in a three-stage structure to compensate for lower transistor gain.

To achieve sufficient gain, all the transistors are biased class A. The basic topology is shown in ***Figure 1***. A 2 × 50 µm device is used in the first and second stages, and two 4 × 50 µm devices are combined in the third stage. Since each third stage transistor has a saturated output power of 21.2 dBm, two transistors can achieve 24 dBm without considering matching network losses and gain compression from previous stages.

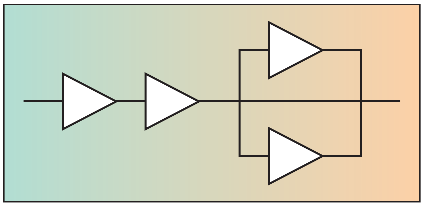

Fig. 1 PA design topology.

MCL and Matching Network Design

For increased stability, the MCL structure is employed for matching and interstage coupling instead of MIM capacitors (see ***Figure 2***). While it is possible to fabricate very small-sized MIM capacitors for this purpose, the losses increase as size is reduced. There are also large variations in capacitance. In the MIM process, a silicon nitride thin film with 150 Å thickness is used as the dielectric material. Silicon nitride has a dielectric constant of 7.5, a resistivity of 10^{14} Ω cm[19] and capacitance per unit area of 0.4 fF/µm^2. Variations in dielectric constant, film thickness and area cause corresponding variations in capacitance; deviations of ±10 percent in the MIM capacitors' properties will

TABLE 1

LOAD- AND SOURCE-PULL SIMULATION AT 94 GHz

Transistor Size	Gain (dB)	P_{sat} (dBm)	Z_S (Ω)	Z_L (Ω)
2 x 25 µm	7.8	16.5	0.8 – j18.9	1.2 + j3.6
4 x 25 µm	7.1	18.7	0.88 – j13.4	1.2 + j2.5
2 x 50 µm	7.2	17.8	3.5 – j15.5	5.4 + j2.3
4 x 50 µm	5.6	21.2	0.7 – j9.4	1.2 + j1.7

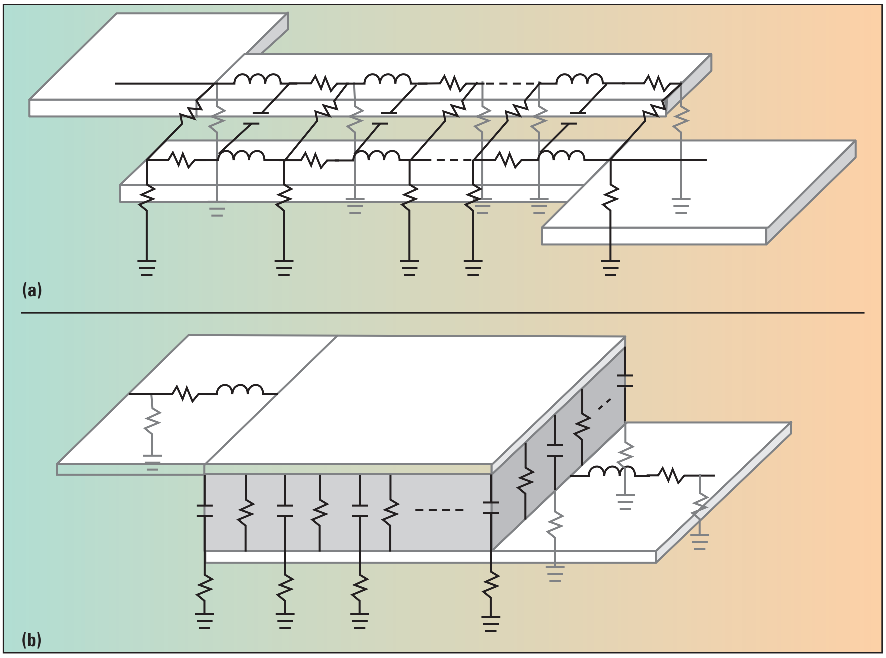

Fig. 2 The matching circuit uses a MCL (a) rather than MIM capacitor (b) structure.


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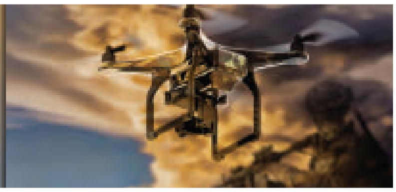

severely degrade amplifier performance.

The MCL exhibits less variation because of its very thin effective metal thickness. In general, the gold plating thickness is about 3 mm, while its skin depth is only 0.2 μm at 90 GHz. Even a ±10 percent change in thickness of the plating has little impact on the effective gold metal thickness at mmWave frequencies. Because they are less influenced by process variation, MCLs offer more stable performance.

For unconditional stability, the necessary and sufficient condition is $\mu > 1$. Larger values of μ imply greater stability.[20,21]

$$\mu = \frac{1-|S_{11}|^2}{\left|S_{22} - S_{11}^*\left(S_{11}S_{22} - S_{12}S_{21}\right)\right| + |S_{12}S_{21}|} > 1 \qquad (1)$$

Through the use of MCLs in the DC block and matching network, interstage networks and the input and output matching networks, performance variation is reduced and overall stability and yield are improved.

Conjugate impedance matching is employed to achieve high output power. The corresponding source and load impedances Z_S and Z_L, respectively, are shown in Table 1. The network between stages 2 and 3 is shown in ***Figure 3***, and S-parameters of the test circuit are plotted in ***Figure 4***. The maximum amplitude imbalance is 0.2 dB with a maximum phase difference of 3 degrees. Return loss is better than 10 dB, while insertion loss is only 3.8 dB at 94 GHz.

Bias Network and Stability

High impedance λ/4 shunt stubs are used as bias chokes at the gate and drain ports. W-Band short circuits are realized using large grounding capacitors that are transformed to open circuits through high impedance λ/4 RF paths. DC bias is then applied to the end of the λ/4 line without affecting amplifier performance. W-Band transistors have gain at lower frequencies, as well. It is convenient to use the gate and drain bias networks for low frequency stabilization by introducing resistors and capacitors at the ends of the bias stubs.

The schematic layout of the complete PA including stabilization components is shown in ***Figure 5***. Two cells are directly combined together in a corporate matching network configuration. A cell of the same size is also employed as a driver amplifier. This ensures that the driver stage does not impact power saturation and linearity. To ensure the absence of odd mode and loop oscillation,[22,23] further stability analysis is performed.

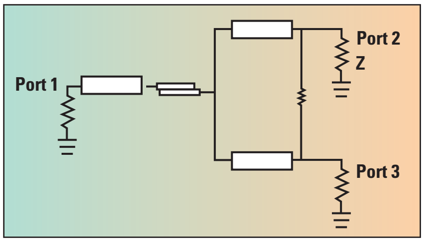

Fig. 3 Interstage matching network between stages 2 and 3.

SIMULATION AND MEASUREMENT

The entire layout was analyzed and


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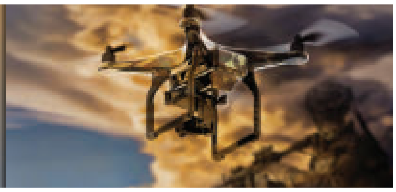

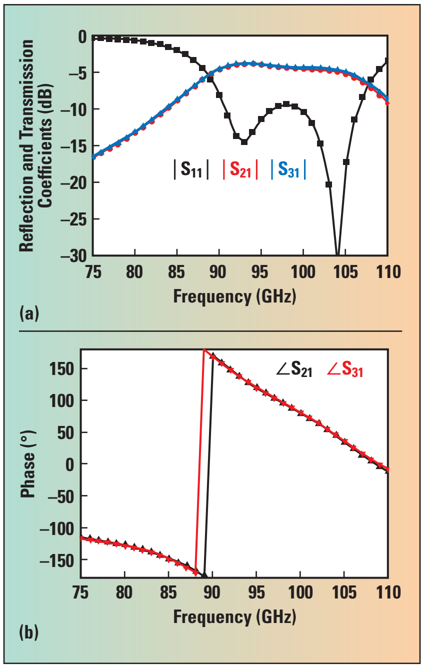

▲ Fig. 4 S-parameters of the interstage matching network between stages 2 and 3; magnitude (a) and phase (b).

optimized using Keysight's Momentum. Co-simulations were also employed in the schematic environment. The harmonic balance method was used for predicting MMIC PA output power. ***Figure 6*** shows the three-stage amplifier.

The small-signal characteristics were measured with a frequency-expanded HP8510C vector network analyzer. All stages of the PA were biased at Vgs = -0.4 V and Vds = 4 V, with the drain currents of the three stages measuring 31.3, 62.5 and 123.4 mA, respectively. The total current was 217.2 mA, and the power consumption was 869 mW.

Figure 7 compares the measured and simulated small-signal S-parameters. The maximum measured power gain of the amplifier was 11.2 dB at 88.25 GHz, while the simulated power gain was 11.6 dB at 91.75 GHz. The shapes of the gain and reflection coefficient curves are similar, but the measured passband is shifted lower in frequency by about 3.5 GHz. $\Delta S_{21}/S_{21}$, defined as the relative deviation, is only 3.8 percent. This is attributed to process tolerances and an inadequate simulation of electromagnetic (EM) coupling effects. The MIM capacitor, as previously mentioned, is especially sensitive to process variation. Meanwhile, load/source impedance optimization is sensitive in areas situated around the edges of the Smith chart causing slight process deviations to degrade matching. The measured results show $|S_{11}|$ better than -10 dB from 88 to 97 GHz, while S_{22} is better than -10 dB from 89 to 99 GHz.

A Keysight E4417A power meter and W8486 power sensor were used to measure output power. A two-port thru-reflect-line (TRL) calibration was performed to shift reference planes to the probe tips. Input power was varied to cover the linear and gain compressed regions. ***Figure 8*** shows output power versus input power at 88 GHz. The amplifier has a linear gain of 11.2 dB and a saturated output power of 21.4 dBm (137.7 mW) at a gain of 7.4 dB. ***Figure 9*** shows output power versus input power at 94 GHz. The amplifier delivers a linear gain of 8.6 dB, saturated output power of 18.2 dBm (66.7 mW) with a gain of 4.7 dB. This amplifier is compared with previously published results using different process technologies in ***Table 2***.

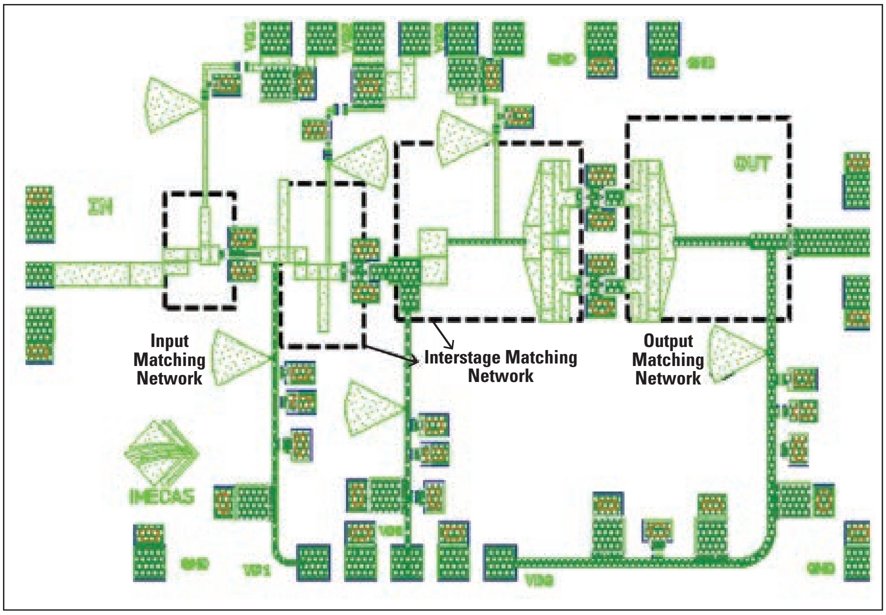

Fig. 5 PA layout.

CONCLUSION

A W-Band PA is designed and fabricated using WIN Semiconductor's 0.10 μm GaAs PHEMT process. MCLs are used for matching to flatten the gain response and decrease matching network sensitivity to the fabrication process. The three-stage MMIC PA achieves a gain of 11.2 dB and a saturated output power greater than 21.4 dBm at 88 GHz. The die size is 2.86 mm x 1.76 mm^2. Simulated performance is in good agreement measurements.■

ACKNOWLEDGMENTS

This work is supported by the Major Program of the National Natural Science Foundation of China (Grant No. 61434006) and the National Natural Science Foundation of China (Grant No. 61401457). The authors would also like to acknowledge WIN Semiconductors for development of the PHEMT MMIC process used for the PA.

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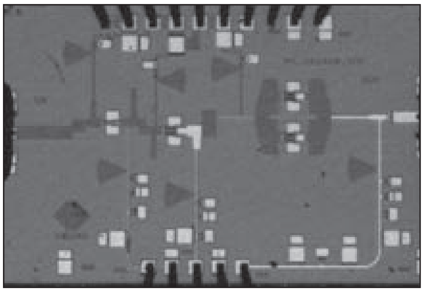

Fig. 6 The three-stage amplifier die (2.86 mm × 1.76 mm).

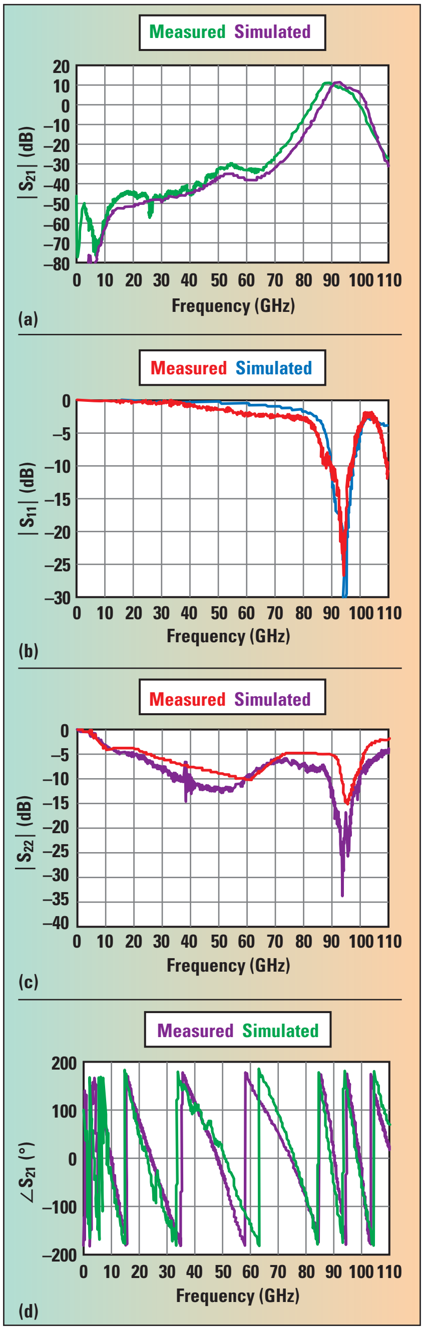

Fig. 7 Simulated vs. measured $|S_{21}|$ (a), $|S_{11}|$ (b), $|S_{22}|$ (c) and (c) $\angle S_{21}$ (d).

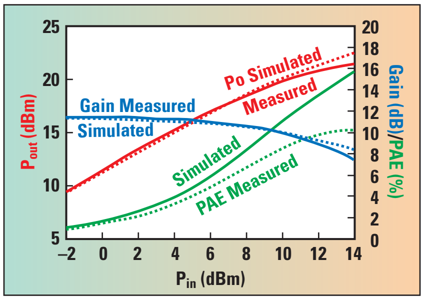

Fig. 8 Output power, PAE and gain vs. input power at 88 GHz.

TABLE 2
COMPARISON WITH OTHER PUBLISHED RESULTS

Process	Center Frequency (GHz)	Gain (dB)	P_{sat} (dBm)	Peak PAE (%)	Supply Voltage (V)	Number of Transistors in Output Stage
CMOS 65 nm[6]	109	14.1	14.8	9.4	1.2	4
CMOS 65 nm[7]	93	12	14.8	8.7	1.2	2
SiGe HBT 0.13 μm[8]	90	10.6	19.6	15.4	2.3	1
GaAs HEMT 0.1 μm[9]	94	10	25	10	4	8
GaN HEMT 0.15 μm[17]	88	16	26.2	11	14	8
GaN HEMT 0.12 μm[18]	92	10	30	19.4	12	4
This Work	88	11.2	21.4	16.4	4	2


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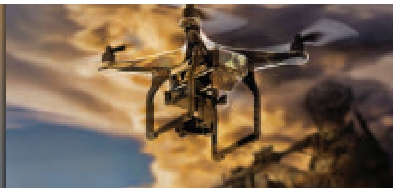

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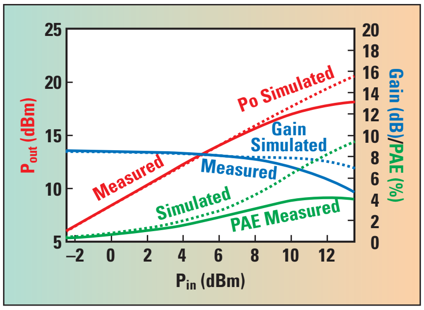

▲ Fig. 9 Output power, PAE and gain vs. input power at 94 GHz.

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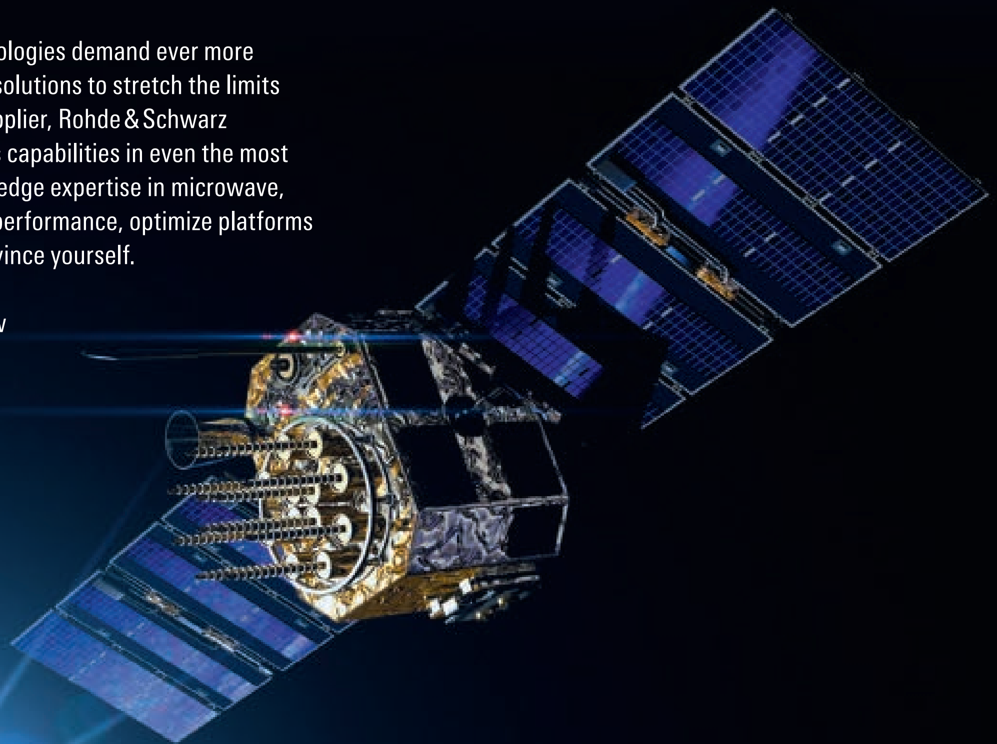

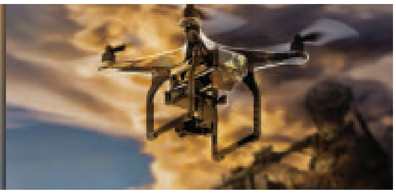

REVIEW BOARD MWJ APPROVED

Ultra-Wideband Bandpass Filter

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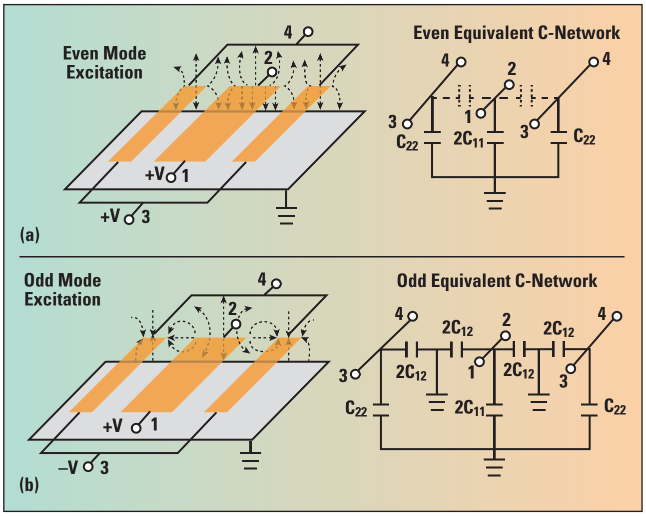
Xin Feng, William T. Joines and Qing Huo Liu
Duke University, Durham, N.C.

A bandpass filter (BPF) design using double-sided edge-coupled microstrip lines and stepped impedance stubs features intrinsic transmission poles, beneficial for achieving an ultra-wide bandwidth. When shunted with stubs of different length ratios, multiple transmission zeros are introduced, yielding sharp band edges, deep out-of-band attenuation and high in-band return loss. Experimental results show in-band return loss greater than 16 dB from 3.1 to 10.6 GHz and out-of-band attenuation of 34 dB and 18 dB for the lower and upper stopbands, respectively, while the band edges are very sharp.

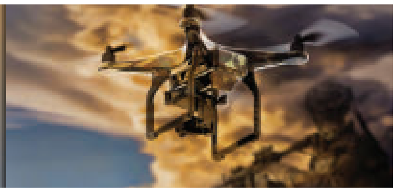
Owing to its unique advantages—very high data rates, less power frequency density, interference immunity and suitability for covert communication—ultra-wideband (UWB) (3.1 to 10.6 GHz) technology has been employed in many applications since the frequency band was licensed by the U.S. Federal Communication Commission in 2002.[1] The stringent frequency mask requirement, however, is a challenge for the design of an UWB BPF. It must have good return loss, low insertion loss, sharply sloped band edges and deep stopband attenuation.



▲ Fig. 1 Electric field distributions and equivalent capacitance networks for the even (a) and odd (b) modes.

Several design techniques have been used. The stepped impedance resonator, a type of multi-mode resonator (MMR), is good for achieving a wide passband.[2] It is made up of a half wavelength transmission line of characteristic impedance Z_1 placed between two quarter wavelength lines of characteristic impedance Z_2. In an UWB BPF design, Zhu et al.,[3] demonstrated an ultra-wide passband from 2.96 to 10.67 GHz; however, the band edges were not sharp.

Several subsequent modified MMR techniques that added open and/or short-circuited stubs increased the roll-off rate to some extent,[4-7] yet the stopband rejection was not satisfactory and the passband return loss was poor. The size of the MMR is large because it is at least one wavelength long. Other techniques such as the use of a multi-layer broadside coupling structure[8] and a ring resonator shunted



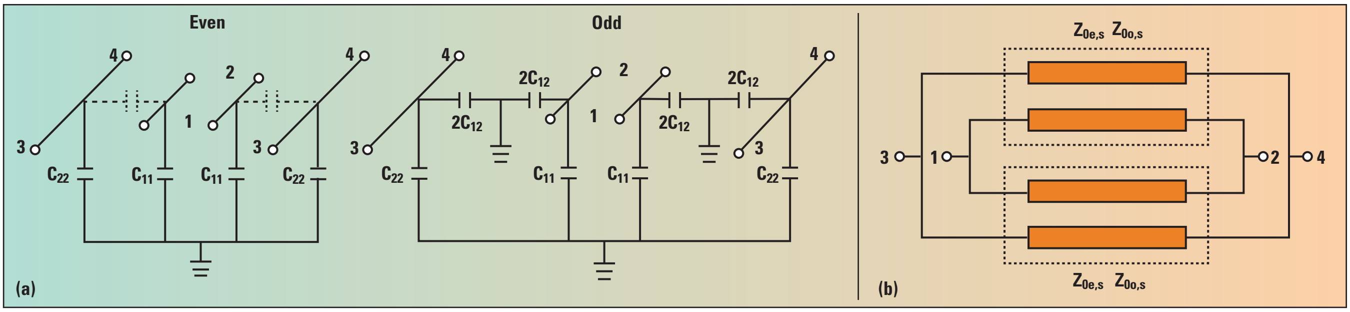


Fig. 2 The split form equivalent C-network (a) and the resulting transmission line model (b).

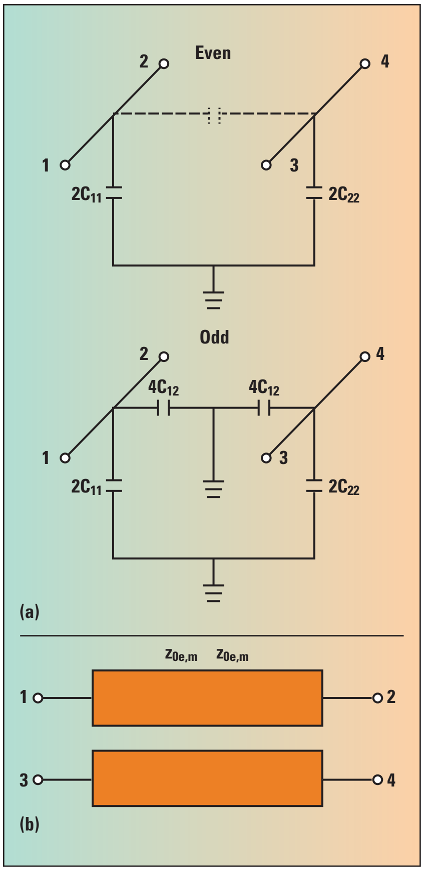


Fig. 3 The merged form equivalent C-network (a) and the resulting transmission line model (b).

with a grounded stub[9] have also been studied but exhibit gradual roll-off characteristics as well.

In this article, the double-sided edge-coupling structure loaded by stepped impedance stubs is utilized. This is similar to the approach taken by Singh et al.,[10] but with one more stub and the incorporation of bent stubs with different length ratios. With loading of the fourth stub and different length ratios, more transmission zeros, deeper rejection in the stopband, sharper band edges and better in-band return loss is observed.

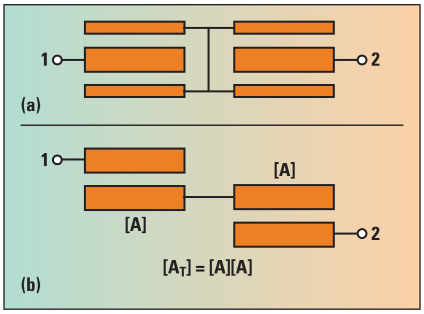


Fig. 4 Double-sided (a) and single-sided (b) edge-coupled line equivalence.

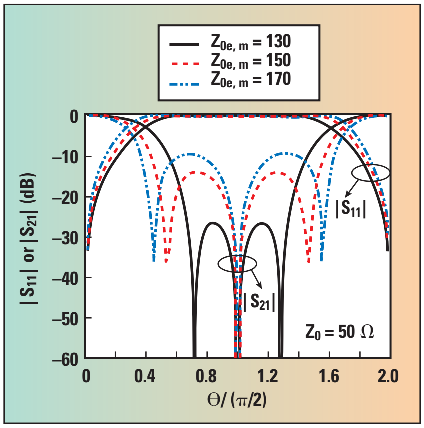


Fig. 5 S-parameters of an ideal two stage circuit. $Z_0 = 50\ \Omega$ (not necessary but used for simplicity).

DOUBLE-SIDED EDGE-COUPLED LINE MODEL

The double-sided edge-coupled line is also referred to as a three-line transmission line with six ports.[11] If the ends of the two side lines are connected, a four-port network is obtained and even/odd mode analysis can be applied. ***Figure 1*** shows the electric field distributions for even and odd mode excitations. The deduction of the equivalent capacitance networks (C-network) is similar to the single-sided case described by Pozar.[12]

An even mode is excited when the sources added on ports 1 and 3 are in phase; a magnetic wall occurs in the gap between the center and either side conductor. As no E-field goes across the gap, the equivalent C-network is composed solely of self-capacitances (C_{11} and C_{22}). However, when sources on ports 1 and 3 are out of phase, an electrical wall occurs and a voltage null appears in the gap. So, in addition to self-capacitances, symmetric mutual capacitances (C_{12}) shunted to ground are included to account for the effects.

The C-networks in Figure 1 can be transformed into the split form in ***Figure 2a***, or the merged form in ***Figure 3a***. These two new C-networks give rise to models in which the more commonly used single-sided coupled line model is configured in two different topologies:

1. Two coupled lines with characteristic parameters $Z_{0e,s}$ and $Z_{0o,s}$, as shown in ***Figure 2b***, are stacked to compose a four-port network for the resulting model of the split form.
2. As shown in ***Figure 3b***, one coupled line model with characteristic parameters of $Z_{0e,m}$ and $Z_{0o,m}$ is the result for the merged form.

The even and odd capacitances of each C-network are:

$$C_{e,s} = C_{11} = C_{22} \tag{1}$$

$$C_{o,s} = C_{11} + 2C_{12} \tag{2}$$

for the split form, and

$$C_{e,m} = 2C_{11} = 2C_{22} \tag{3}$$

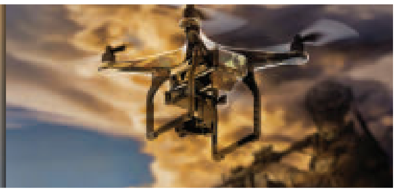
$$C_{o,m} = 2C_{11} + 4C_{12} \tag{4}$$

for the merged form.

The even and odd mode characteristic impedances of each single-side coupled line in the resulting transmission line model are:

$$Z_{0e,s} = \frac{1}{v_p C_{e,s}} = \frac{1}{v_p C_{11}} \tag{5}$$

$$Z_{0o,s} = \frac{1}{v_p C_{o,s}} = \frac{1}{v_p\left(C_{11} + 2C_{12}\right)} \tag{6}$$



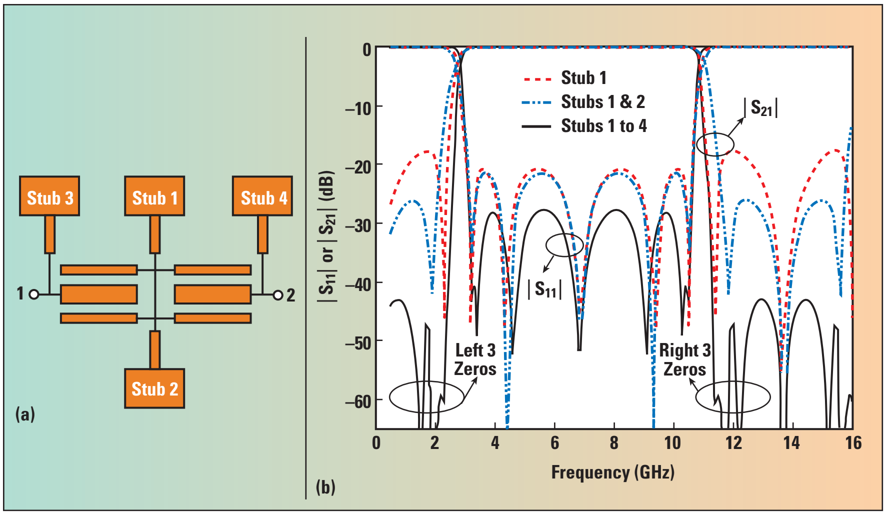


Fig. 6 Two stage circuit (a) and modeled S-parameters vs. number of shunted stubs (b).

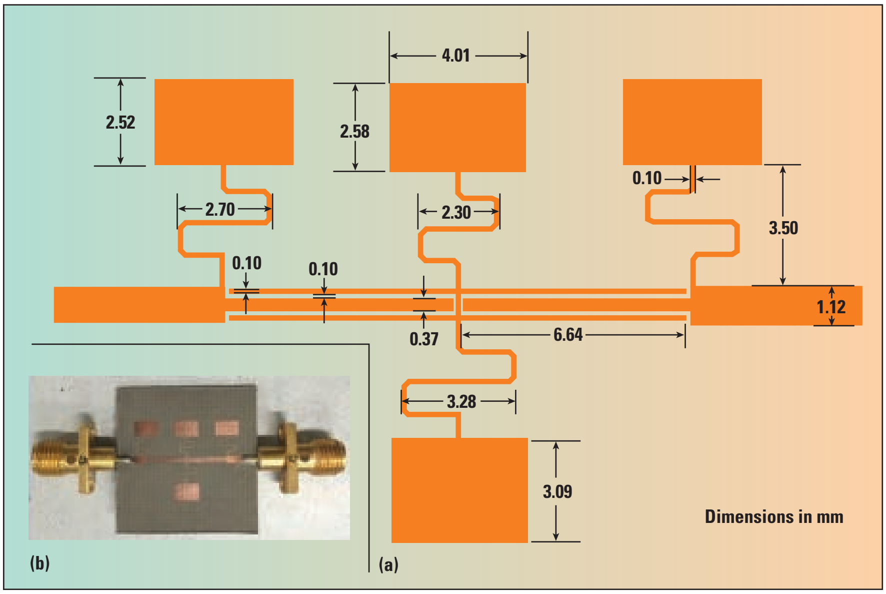


Fig. 7 The circuit configuration (a) and fabricated filter (b). Dimensions in mm.

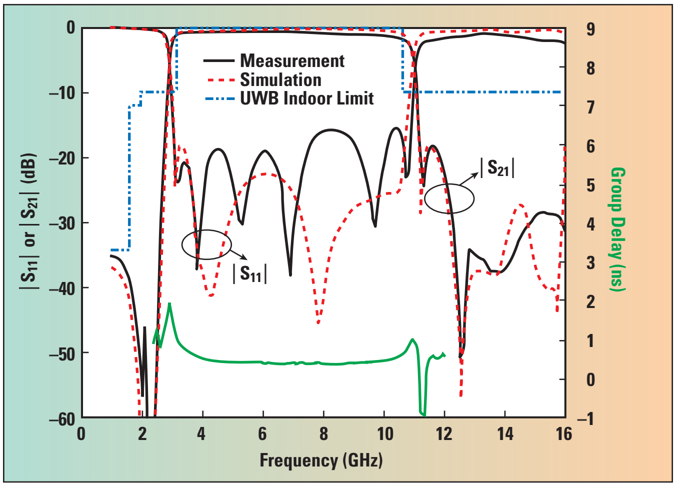


Fig. 8 Measured results compared with simulation and the UWB indoor frequency mask.

for the split form, and

$$Z_{0e,m} = \frac{1}{v_p C_{e,m}} = \frac{1}{2 v_p C_{11}} \quad (7)$$

$$Z_{0o,m} = \frac{1}{v_p C_{o,m}} = \frac{1}{v_p \left(2C_{11} + 4C_{12}\right)} \quad (8)$$

for the merged form. The phase velocity v_p is assumed equal for even and odd modes.

Notice that the models transforming Figure 1 to Figure 2 and Figure 1 to Figure 3 are equivalent. There are two assumptions behind this: The self-capacitance of the center conductor is twice that of the side conductor in Figure 1, so the center is wider. The mutual coupling between the center line and either side in Figure 1 is assumed equal to that of the single-sided coupled line in Figure 2b and half that of the one in Figure 3b.

From Equations 5 to 8, the relationships between the characteristic impedances of the two forms are

$$Z_{0e,m} = 0.5 Z_{0e,s} \quad (9)$$

$$Z_{0o,m} = 0.5 Z_{0o,s} \quad (10)$$

FILTER DESIGN

The equivalent models derived above can be used to facilitate the filter design. For example, a cascaded two stage, double-sided, edge-coupled transmission line model can be simplified to a single-sided model as shown in ***Figure 4***.

The Z matrix of one single-sided coupled line is given by Pozar.[12]

$$[Z] = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \quad (11)$$

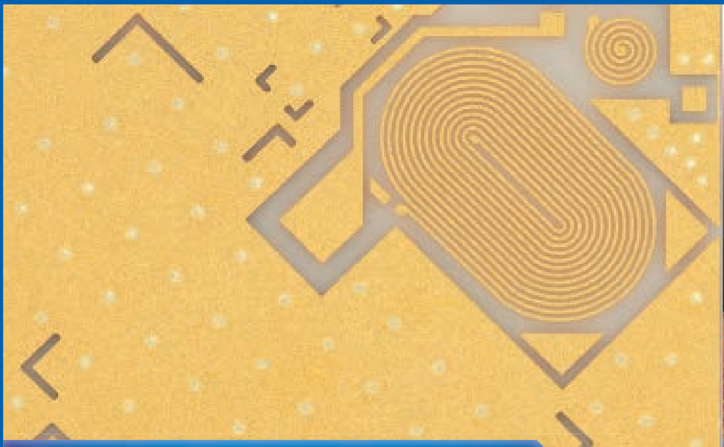
$$\begin{bmatrix} \frac{-j}{2}\left(Z_{0e,m} + Z_{0o,m}\right)\cot(\theta) & \frac{-j}{2}\left(Z_{0e,m} + Z_{0o,m}\right)\csc(\theta) \\ \frac{-j}{2}\left(Z_{0e,m} - Z_{0o,m}\right)\csc(\theta) & \frac{-j}{2}\left(Z_{0e,m} + Z_{0o,m}\right)\cot(\theta) \end{bmatrix}$$

in which θ is the electric length.

Deriving the ABCD matrix using Z elements gives

$$[A] = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} = \begin{bmatrix} Z_{11}/Z_{21} & |Z|/Z_{21} \\ 1/Z_{21} & Z_{22}/Z_{21} \end{bmatrix} \quad (12)$$

in which $|Z| = Z_{11}Z_{22} - Z_{12}Z_{22}$.



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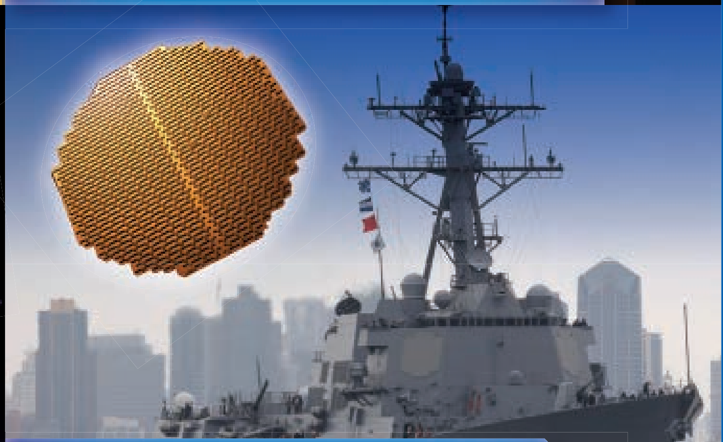

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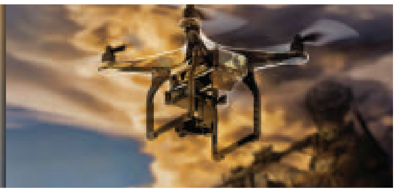


Then the total ABCD matrix and the S-parameters of the two stage circuit can be found by

$$\left[A_T\right]=\left[A\right]\left[A\right]=\begin{bmatrix} a & b \\ c & d \end{bmatrix} \qquad (13)$$

$$S_{11}=\frac{a+b/Z_0-cZ_0-d}{a+b/Z_0+cZ_0+d} \qquad (14)$$

$$S_{21}=\frac{2(ad-bc)}{a+b/Z_0+cZ_0+d} \qquad (15)$$

If we let $Z_0^2 = Z_{0e,m}{}^*Z_{0o,m}$ and solve for θ when $S_{11} = 0$, we find three transmission poles in the passband:

$$\theta=\begin{cases} \pi/2 \\ \pm\arcsin\left(\dfrac{2Z_0}{Z_{0e,m}-Z_{0o,m}}\right) \end{cases} \qquad (16)$$

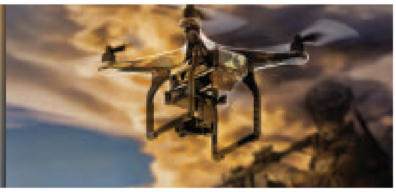
A real solution of θ is obtained when $Z_{0e,m} - Z_{0o,m} \geq 2Z_0$. The number of poles in the circuit in Figure 4 is the same as what a stepped impedance MMR can provide by itself,[3] which increases if more stages are cascaded. Example S-parameters of the two stage circuit are shown in ***Figure 5***.

The next step is to shunt the stepped impedance stub to increase the roll-off rate. It is convenient to control the transmission zeros by tuning the impedance ratio of the stub.[10] If we locate the first zero to the left edge of the passband and the second to the right, sharp edges can be obtained. Using the coupled line model above, we can quickly obtain the theoretical performance with stubs as shown in ***Figure 6***. There are three cases, according to the number of stubs used. Case 1 is a single stub (1). Case 2 contains two stubs with the same length and impedance ratio, so that there is only one transmission zero beside each edge, which is the same as for case 1. For case 3, stubs 1 and 2 are different, and stubs 3 and 4 are the same but different than either stub 1 or 2, so that there are three transmission zeros beside each edge. It can be seen from Figure 6 that with more stubs shunted and with the impedance ratio varied, not only the roll-off rate but also the out-of-band attenuation increases. The in-band return loss increases as well.

MEASURED RESULTS

To verify the analysis, an UWB BPF was simulated and then fabricated. The chosen substrate was the popular low-cost RF-35 with a dielectric constant of 3.5 and a thickness of 0.508 mm. The filter (see ***Figure 7a***) consists of two cascaded double-sided coupled lines and four shunted stubs with three different length ratios (stubs at two sides are mirrored to each other). The coupled line is a quarter guided-wavelength long at the center frequency of 6.85 GHz, so that the length of this filter is about half that of an MMR based UWB filter.

To locate the transmission zeros beside the edges, we adjusted the length ratio of the stubs rather than impedance ratio, because it is more convenient to vary the length of the line without enlarging its size. HFSS was used



to optimize the overall performance. Compared to the design by Singh et al.,[10] this design has one more shunted stub located in the center (below the through line) to increase out-of-band attenuation and band edge selectivity. All the stubs are bent to reduce size. ***Figure 7b*** shows the assembled filter.

As seen from the measured results in ***Figure 8***, a passband with return loss greater than 16 dB is achieved from 3.1 to 10.6 GHz. Insertion loss, including the connector, is less than 1 dB from 3.1 to 10 GHz. The roll-off rate is very high at both lower and upper band edges. Out-of-band attenuation is greater than 35 dB in the lower stopband and greater than 18 dB in upper stopband, which satisfies the UWB indoor requirement. Meanwhile, the group delay is flat and less than 0.5 ns. Measured results agree well with simulation and are consistent with the design prediction.

CONCLUSION

An UWB BPF using a double-sided edge-coupling structure and shunted stepped impedance stubs is shown to be well suited for achieving ultra-wideband performance. With shunted stubs, transmission zeros at both the lower and upper band edges are introduced to increase selectivity and out-of-band attenuation. Measured results show good agreement with simulation and validate the design analysis.■

ACKNOWLEDGMENT

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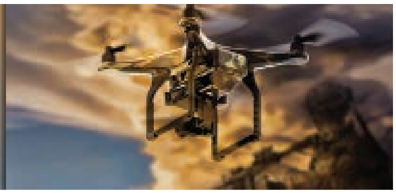


INVITED PAPER

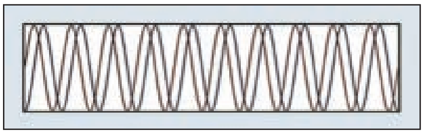
Addressing the Challenges of Testing Multichannel Phase-Coherent Systems

Shivansh Chaudhary and Eddie Rodriguez
National Instruments, Austin, Texas

With rapid advancements in the areas of RF components and subsystems, and high-density digital signal processing electronics, multiple input multiple output (MIMO) technologies are receiving high attention for their capabilities to increase the data rates through multiplexing, or to improve the system performance by an order of magnitude or more through spatial diversity. Engineers are employing MIMO systems in a wide range of electronic warfare and radar applications ranging from phased array radars to beamforming and direction finding systems.

However, such MIMO systems must overcome key technical challenges related to channel-to-channel phase and amplitude synchronization to coherently receive and process the data acquired or generated from each input/output. The precise phase and amplitude synchronization of each channel poses serious challenges to testing and verification of multichannel phase-coherent systems. To efficiently test these systems, it is mandatory for test and measurement equipment to provide equal or better precision in signal coherence, and complete control over phase, time, frequency and amplitude.

This article will provide an overview of the challenges and requirements for testing a multichannel phase-coherent measurement and generation system and review how these requirements map to test instrument design specifications. Additionally, the article will look at the actual steps needed to develop a multichannel phase-coherent test system from commercially available software-defined modular instruments, and discuss the details of a real-time calibration process for fine-alignment in phase and amplitude. Finally, an example of a next-generation multichannel phase-coherent test system including tests performed to validate that the system meets the requirements will be studied.



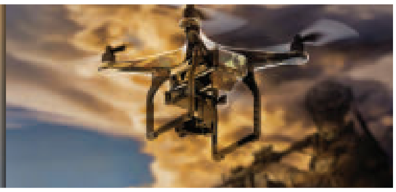
▲ Fig. 1 Phase coherency at the same frequency.

▲ Fig. 2 Phase coherency at different frequencies.

Phase coherency is an attribute of two or more waves where the relative phase is constant during the resolving time of the observer.[1] ***Figure 1*** shows conceptual diagrams of phase coherency of two channels with same frequency. ***Figure 2*** shows the coherency for two channels with different frequencies, where the signals are at a specified phase relationship at every N cycles. After achieving phase coherence, the constant phase difference between the coherent signals can be compensated for by using phase alignment methods[1].

In practical MIMO test systems, the radio hardware should be capable of acquiring and generating phase-coherent and phase aligned signals across the multiple channels. Many modern electronic warfare systems utilize a multichannel phase-coherent system for tasks such as direction finding in passive radar systems, or providing multipath redundancy in jamming-resistant communications. For example, phased array radars use hundreds of phase-coherent transmit/receive (Tx/Rx) modules to provide rapid electronic beam steering, where the relative phases of the respective signals feeding the elements are varied in such a way that the effective radiation pattern of the array is reinforced in desired directions and suppressed in undesired directions.[2]

Geolocation systems such as interferometric synthetic aperture radar (InSAR) employ several phase-coherent receivers to detect the location of events such as earthquakes and floods by precisely determining the position of a transmitted or reflected signal. In addition to the increased complexity of the design, the requirements of tight synchronization and fine-alignment in a mul-



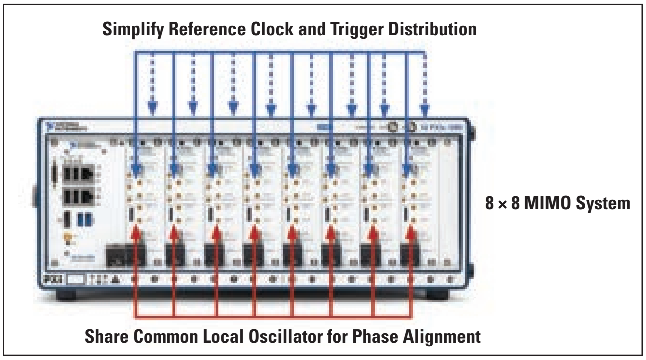
tichannel phase-coherent system are some of the most stringent test requirements in the aerospace and defense industry.

The primary challenge to building a test system for multichannel phase-coherent systems is the phase alignment of the coherent signals. Further, the systems need to be able to sustain the phase coherence and alignment over considerable time. However, drifts will occur, owing to effects like temperature, thermal expansion, mismatched cable lengths, uncorrelated phase noise, ADC sample clock, phase noise and quantization noise. At microwave frequencies, even small differences between cable lengths, amplifier devices and filters can create delays or phase shifts that destroy the desired relationships.

Phase stability of components, non-linear AM/PM effects and group delay variations can make phase matching a concern for the multichannel designer. Many applications in the direction finding and beamforming sectors demand that the phase relationships between channels be constant over time with minimal deviations, which may be as little as one degree or less phase drift.

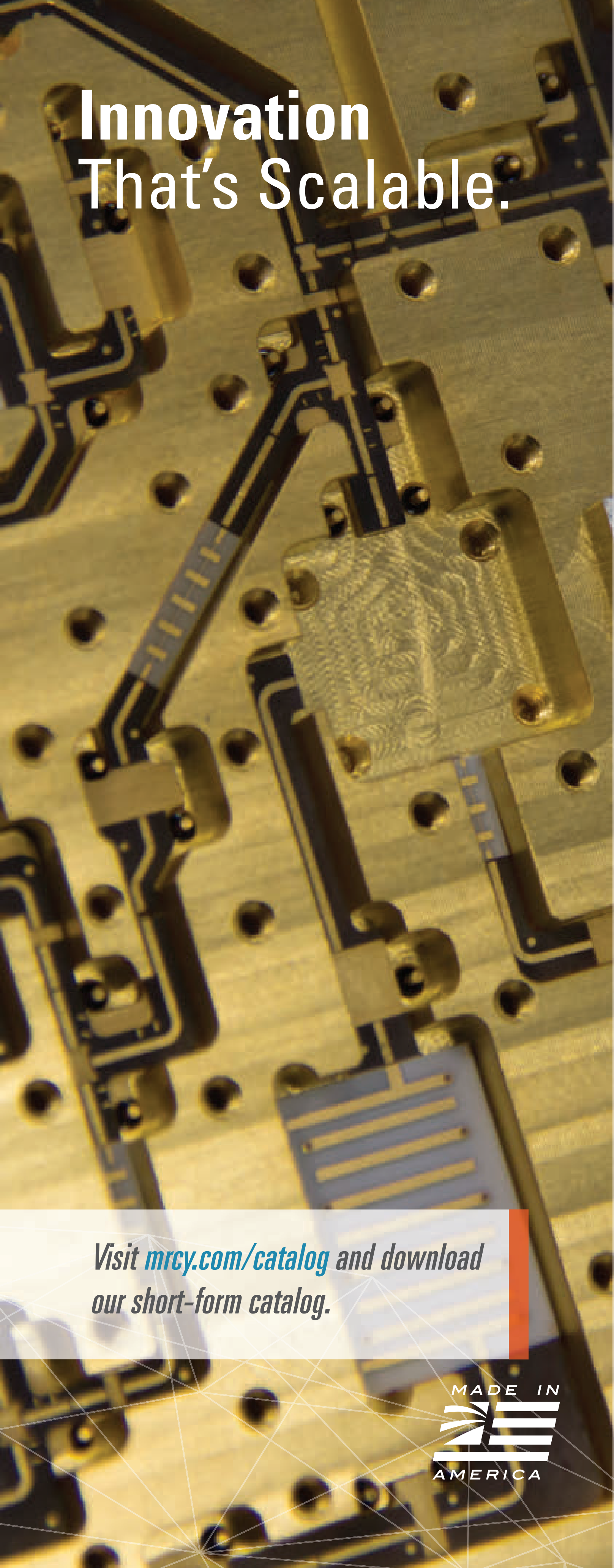
TESTING MULTICHANNEL PHASE-COHERENT SYSTEMS

The following section will discuss the techniques to address the challenges of developing a test system for multichannel phase-coherent systems, using a modular software-designed instrumentation approach. The first challenge to overcome in a multichannel system is ensuring that all channels start acquiring or generating at the same time by creating a consistent and reliable triggering mechanism. Often, alignment between channels is required to have less than a nanosecond of difference, and cabling frequently proves an obstacle to achieving this. Long cables within test systems add a significant amount of propagation time to triggers, around 5 ns per meter of coaxial cable, so there is a need for simplification of trigger distribution.



▲ Fig. 3 8 × 8 MIMO configuration with NI PXI VST.

Distributing the necessary clocks and triggers to achieve multi-device synchronization can be challenging because of the latencies and timing uncertainties caused by skew and jitter. A PXI-based platform for modular instruments is well suited to address these complexities. The PXI architecture allows designers to implement advanced multi-device synchronization by using unique features of PXI, such as the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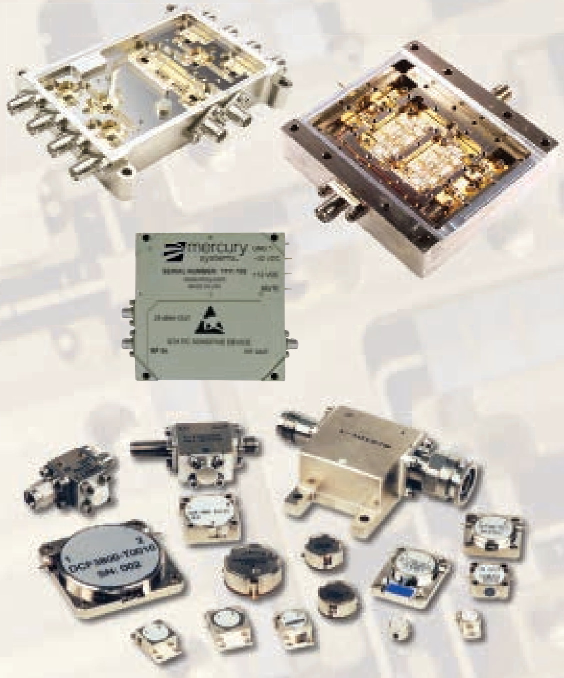
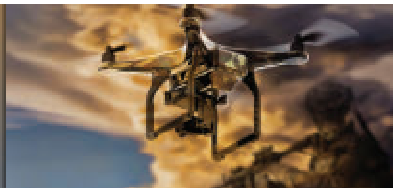




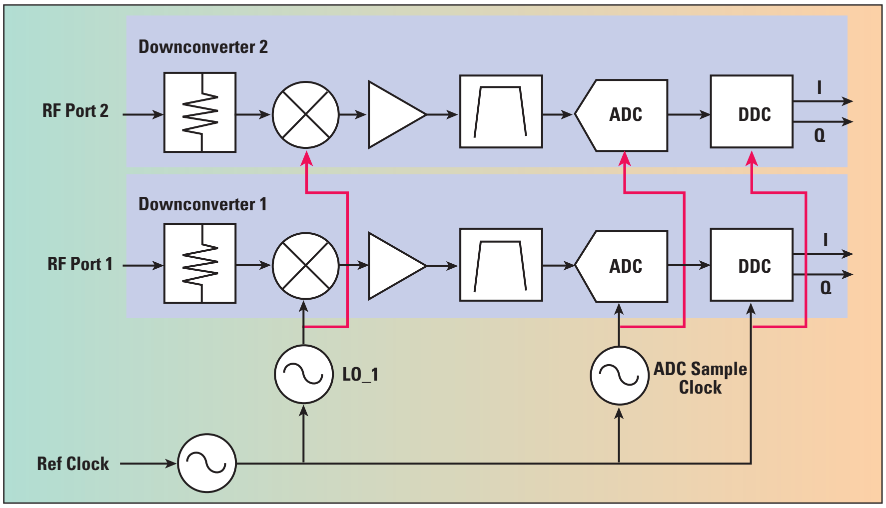


Fig. 4 2-channel phase-coherent RF vector signal analyzer.

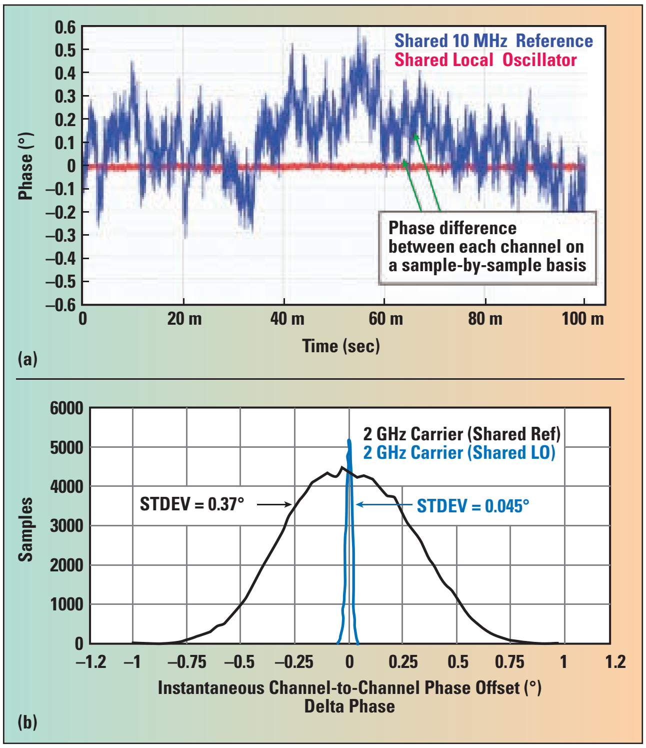


Fig. 5 Comparing shared LO vs. 10 MHz reference: channel-to-channel skew (a) and histogram of channel-to-channel phase offset (b).

trigger bus, star trigger and a common system reference clock.

One method of synchronization is NI-TClk, in which another clock domain is used to enable alignment of sample clocks and the distribution and reception of triggers.[3] Designers of multichannel phase-coherent test systems can use this method to align the sample clocks that are not aligned initially, despite being phase-locked to a common reference clock, and to enable the accurate synchronous triggering of the individual devices.

Figure 3 shows an 8 x 8 MIMO configuration of eight vector signal transceivers (VST), each capable of generating and acquiring 1 GHz instantaneous RF bandwidth in a single 18 slot chassis, tightly synchronized with a typical skew less than 500 ps using NI T-Clk and a shared PXI reference clock.

ACHIEVING PHASE COHERENCE AND ALIGNMENT

Most traditional RF instruments, analyzers or generators allow reference clocks (usually 10 MHz) and occasionally a start trigger to be shared. While sharing these clock signals is sufficient to guarantee simultaneous signal acquisition and generation, it does not guarantee phase coherence. For example, consider the case where only a 10 MHz reference clock is shared between two vector signal analyzers.

In this scenario, the two analyzers will independently derive their local oscillators from a common 10 MHz clock. Over a short interval, signals may appear to have a constant phase difference, but over time the phase of each channel will drift. This is because each LO is derived independently from a 10 MHz reference, and the phase-locked loop (PLL) noise that is introduced when synthesizing each LO will be independent from one channel to the next. As a result, a multichannel RF system with only a shared 10 MHz reference will be characterized by substantial channel-to-channel phase skew.

A better approach to phase coherence and alignment is to derive a single LO for all channels from a single PLL, as shown in ***Figure 4***. When the LO is directly shared, each downconverter shares the same phase noise.[4]

In ***Figure 5a***, observe the channel-to-channel skew when using two different synchronization approaches. The blue trace shows the phase difference over time when each analyzer shares only a 10 MHz reference clock and does not share the LO. The red trace illustrates the phase difference between each channel when the local oscillator is shared directly between each downconverter signal chain. Note from the graph that sharing the LO directly enables significantly tighter phase alignment than when merely sharing a 10 MHz reference.

Another way to measure the benefit of sharing the LO directly is to look at a histogram of the channel-to-channel phase error, as shown in ***Figure 5b***. In the case, where only the 10 MHz reference is shared, a relatively wide spread of phase variation (greater than one degree for six sigma confidence) is seen. In the case where the LO is shared directly, the same confidence level is within 0.2 degrees.

REAL-TIME IN-LINE PROCESSING

Real-time processing is important for many aspects of testing electronic warfare systems. For test applications involving beamforming or direction finding, such as passive radar, it is important to calculate channel matrices in real-time, since channel characteristics change rapidly. Moving RF samples to a host processor would be slow, consuming both data processing capability and bus bandwidth. Instead, the samples can be moved to the on-board FPGAs or transferred through the high-bandwidth PXI bus to additional FPGA co-processors for in-line signal processing.

For many test applications, it can be equally important to store and play back signals. Storage of waveforms al-

lows for in-depth observation of multichannel data, and enables the capture of spurious signals that may not occur for very long or often. Storage can also be valuable for retaining evidence of RF activity at specific geographies and times for surveillance of unauthorized signals or sporadic jamming. Real world signal capture can also be used to verify whether future communications systems will be resilient to real world scenarios.

The PCI Express architecture enables these requirements by supporting peer-to-peer transfers between multiple devices so that data can be continuously transferred and processed in real-time, or stored to disk for extended periods and post-processed. Such a system gives researchers and developers the ability to acquire and store information from multichannel RF sources for careful observation or offline processing. Later, in the lab, the data can be manipulated and played back as a stimulus signal for validating algorithms, channel models, hardware configurations and other aspects of real world systems.

Whether stationed in a lab or deployed in the field, size, weight and power (SWaP) are important considerations for measurement equipment in electronic warfare applications. With the increasing complexity and computational power requirements of advanced EW systems, designers are optimizing for SWaP requirements by creating multifunction systems that leverage the advancing technology and modular nature of the PXI platform.

MULTICHANNEL PHASE-COHERENT TEST SYSTEM

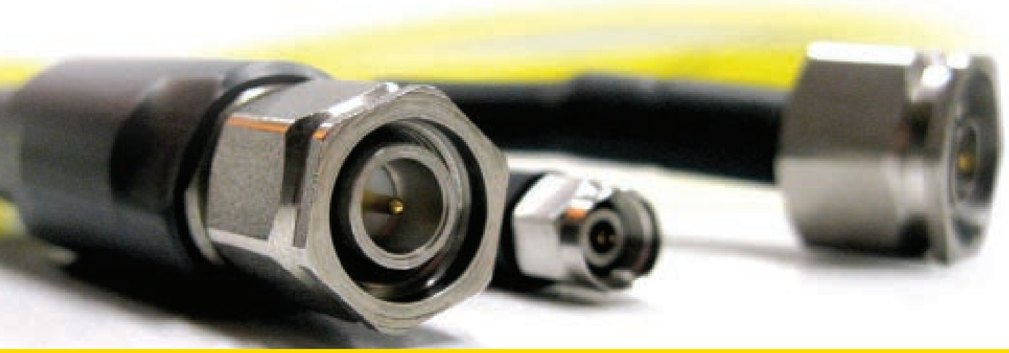
The next section looks at building a test system that can address the challenges and requirements of testing and verification of multichannel phase-coherent RF systems. This test system is built on a platform-based approach of modular hardware and software-defined instrumentation.

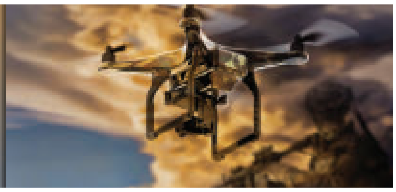
Figure 6a shows the configuration of an NI two-channel phase-coherent test system, which is configured in the PXIe-1085 chassis, an 18-slot chassis with built-in 10 MHz reference clock, PXI Trigger bus and star trigger for PXI modules. For RF instrumentation the PXIe-5840 VST is used in a 2 x 2 MIMO configuration.

Following are the steps to develop a multichannel phase-coherent test system.

Step 1: The first step is to configure the two VSTs to share a common PXI reference clock derived from the PXIe-1085 chassis via software, and to physically share the LOs between the generators and the analyzers, as shown in ***Figure 6b***. The VSTs natively support NI-TClk technology, which ensures that all the channels start acquisition/generation simultaneously and can achieve a channel-to-channel skew typically less than 500 ps. We further enhance this by performing an in-system calibration which will further reduce skew another order of magnitude to less than 50 ps.

Step 2: Now that the VSTs are synchronized, the next step is to ensure the phase and amplitude coherence. For the sake of this example, there is multichannel phase coherence between the analyzers at first. In this step, one of





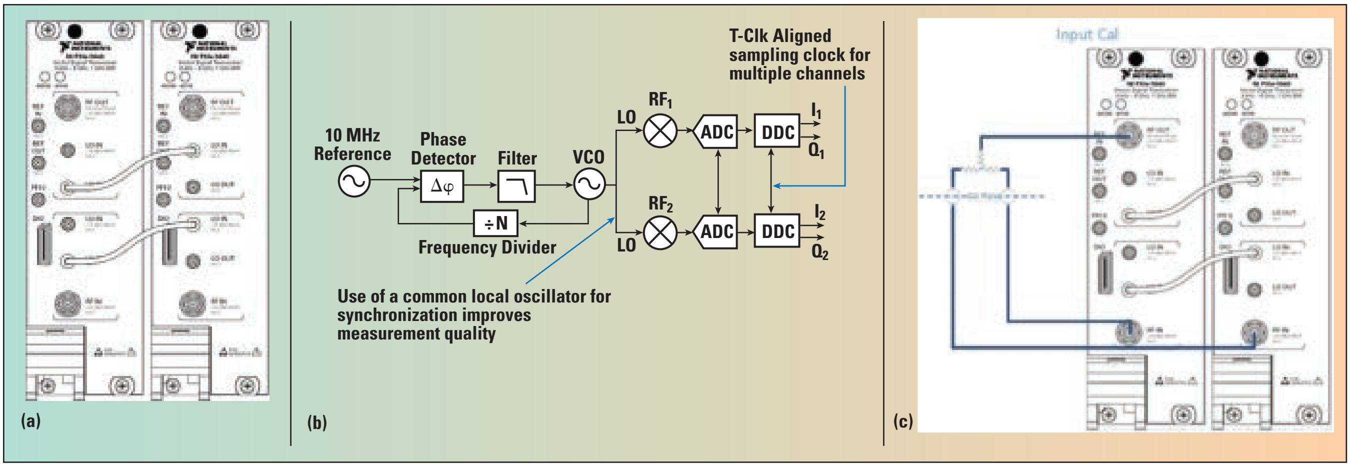


Fig. 6 Two-channel phase-coherent test configuration (a), configuration with shared LO, common reference clock and T-Clk alignment (b) and calibration setup (c).

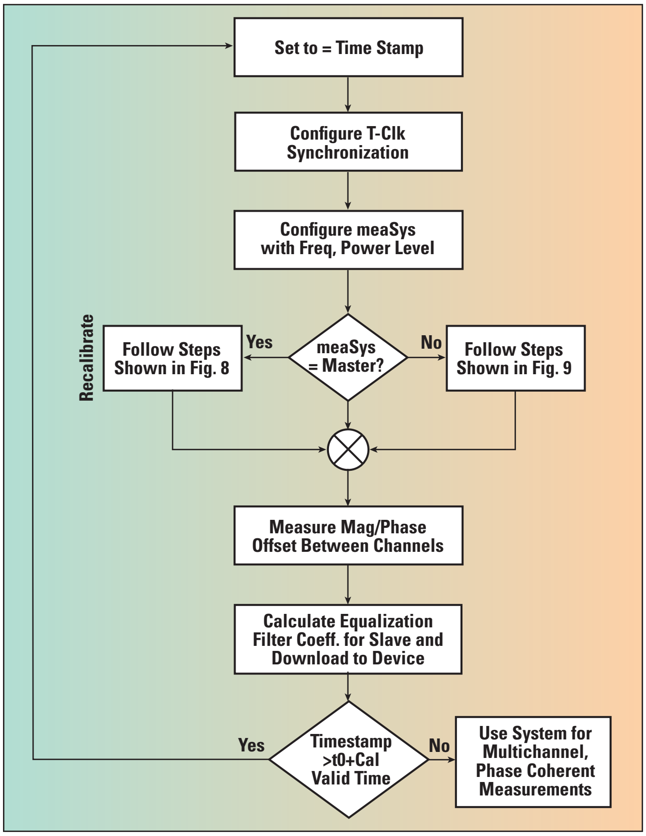


Fig. 7 Multichannel phase-coherent calibration process.

the two VSTs is used as the source of the continuous wave signal that will be used as the calibration tone. The signal from the source is split using a two-way splitter, and fed to the RF input ports of the two VSTs, as shown in ***Figure 6c***.

Step 3: The next step is to apply the FPGA-based real-time calibration process for fine-alignment of phase and amplitude between the two VSTs.[5] This calibration process is implemented with the on-board Xilinx Virtex 7 FPGAs of the VSTs using LabVIEW FPGA. ***Figures 7***, ***8*** and ***9*** describe the steps involved in the calibration process. This algorithm is scalable from two-channel to eight-channel configurations. MeasSys represents the multichannel phase-coherent acquisition system, Timestamp represents the initial time instance of measurement, freq represents frequency of CW tone and cal Validtime represents the duration of time after which the system needs to be recalibrated.

Step 4: Now that the system is ready for multichannel phase-coherent measurements, the next step is to configure a multichannel phase-coherent generation system. ***Figure 10*** shows the hardware configuration for this step, where the two VSTs are simply connected in the loopback mode with shared LOs and a common reference clock.

Step 5: The next step is to apply the real-time calibration process for the fine-alignment of phase and amplitude difference between the generator. Repeat the process described in Step 3 to achieve a multichannel phase-coherent generation system.

Step 6: Now, the next-generation system for testing a multichannel phase-coherent RF system is ready for use. This can be simply verified by connecting the two VSTs in a crisscross method, as shown in ***Figure 11***, and then observing the stability in phase and amplitude difference over time.

The multichannel phase-coherent test system was tested in a chamber with regulated temperature conditions. The phase and magnitude difference was calculated between the two channels after applying the calibration algorithm, and the measurements were taken at three different frequencies of 3, 4 and 5 GHz, as shown in Figures 10 and 11. Note that the plots, ***Figures 12*** and ***13*** show the average phase and magnitude difference between two channels. The results suggest that the

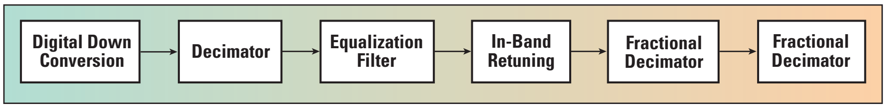


Fig. 8 DSP architecture with equalization filter.

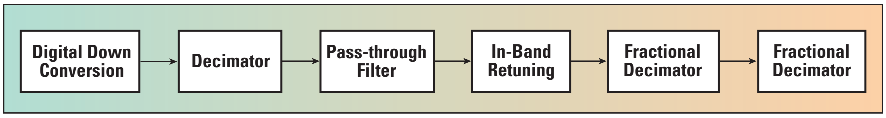
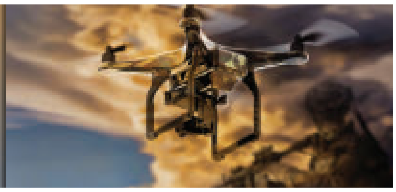
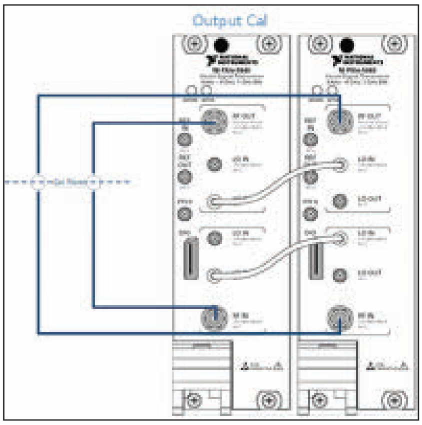


Fig. 9 DSP architecture with pass-through filter.



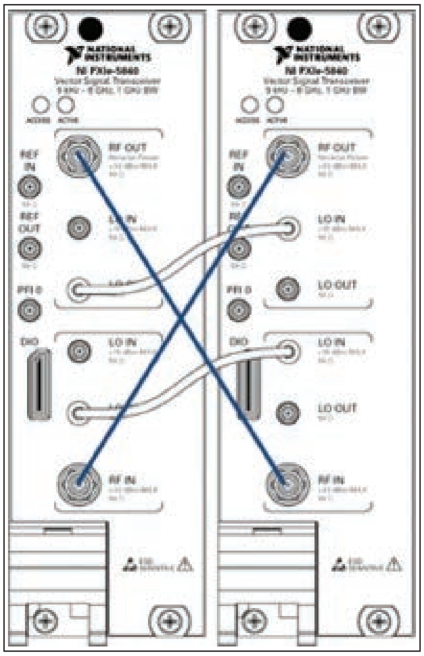


▲ Fig. 10 Calibration setup for phase-coherent generators.

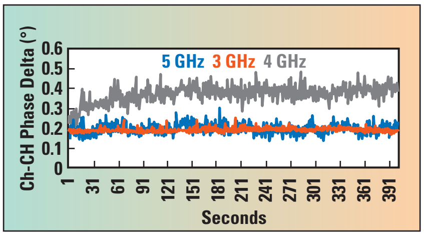
next-generation multichannel phase-coherent test system built as described effectively achieved a phase difference with less than ±1 degree variation, and magnitude difference within 0.05 dB variation sustained over time.

CONCLUSION

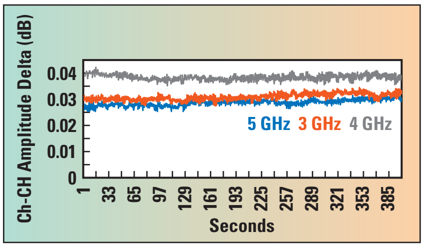
With multichannel phase-coherent systems becoming more common in electronic warfare and radar applications, the need to efficiently test and deploy such systems is becoming increasingly significant. Further, it is a critical requirement for a test and measurement setup to offer equal or better precision in phase and amplitude alignment in the multichannel RF systems.



▲ Fig. 11 Verification of phase coherence after calibration.



▲ Fig. 12 Average channel-to-channel phase difference vs. time.



▲ Fig. 13 Average channel-to-channel amplitude difference vs. time.

This article considered the challenges and requirements of testing a multichannel phase-coherent system, presented a next-generation test system that addressed these challenges using a platform-based approach and outlined a software-defined FPGA-based calibration process that allows for sustained phase coherence with an internal calibration mechanism.

Results were presented to demonstrate the stability in phase and amplitude variations of the multichannel phase-coherent test system. With the scalable and modular nature of the PXI platform, the proposed architecture for the two-channel phase-coherent VST system can be further scaled to achieve 4 x 4 or 8 x 8 phase-coherent test systems with a consistent precision in phase and amplitude variations.■

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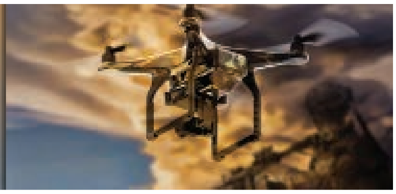


INVITED PAPER

Airborne Spectrum Monitoring For Network Verification and Security

Thomas Elliott and Russel Lindsay
Anritsu Corporation, Morgan Hill, Calif.

The growing demand for wireless data in our society has facilitated new and evolving technologies to provide coverage around the globe. Millions of antennas have been and will be installed in every environment, from atop mountains to city streets and building roofs. They are even in orbit.

Maintaining and building on this network, especially as we transition to 5G, will require antenna and coverage testing in places with limited or restricted access for mobile carriers, installers, field engineers and field technicians. It also poses a new challenge for security and defense agencies tasked with monitoring communications traffic for nefarious transmissions. To locate, track and identify signals within this sea of communications, agencies will have to expand their tools and capabilities.

Traditional signal hunting has required a large amount of labor-intensive searching at the ground level. Typically, handheld spectrum analyzers with a horn antenna or a mobile interference hunting solution that combines a handheld spectrum analyzer, antenna and specialized software loaded on a tablet are used. To deliver on the promise of higher data rates and constant coverage, network testing must evolve and go places it has never gone before.

TESTING GOES AIRBORNE

Advances in test technology have led to the development of ultraportable spectrum analyzers that are small and light enough to be connected to a standard drone. This configuration can make measurements in hard-to-reach places and/or do basic coverage mapping, all using off-the-shelf equipment. The same configuration is also useful in military spectrum monitoring and security/defense applications. It must be noted that country-specific government regulations concerning commercial drone usage must be followed during such tests.

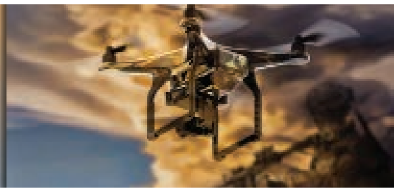
Performance is another factor. The advancing technology has allowed for smaller packages in test solutions without sacrificing the ability to conduct highly accurate tests, which is necessary to locate interference in today's crowded RF spectrum. Ultraportable analyzers with frequency coverage of up to 110 GHz and that have high dynamic range of greater than 100 dB at 110 GHz are necessary to simultaneously measure strong and weak signals on today's networks.

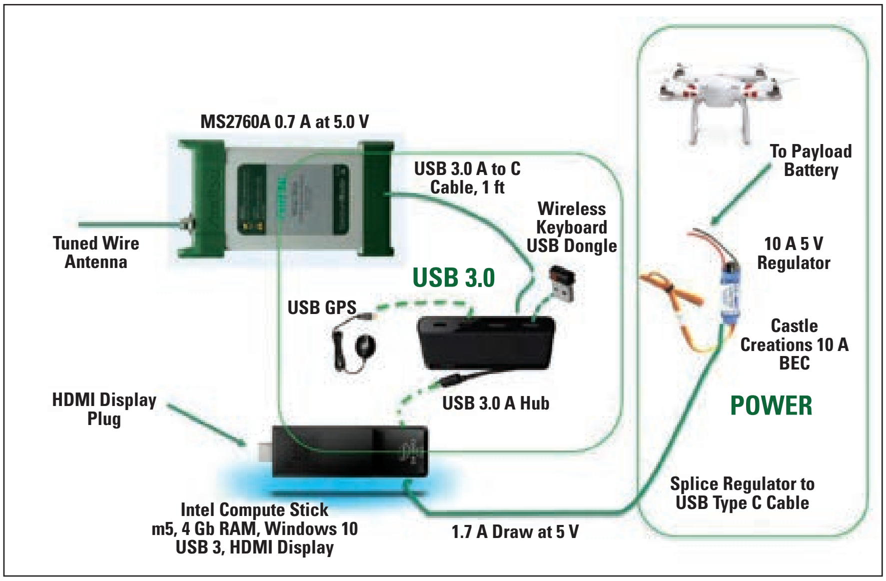
A drone test configuration was put to practice in a recent test to prove out the concept. A commonly available 500-size photo drone, DJI Phantom 2 Vision, without a camera was selected. For the purpose of the demonstration, the lack of a camera saved cost, reduced potential failures and allowed for a larger payload to be assembled.

The off-the-shelf drone had a number of automatic features typical of its class that proved advantageous for testing applications. These included:

- **Auto-height hold**—allowing the drone height to be somewhat independent of payload
- **Auto-leveling**—making the drone somewhat indifferent to center-of-gravity concerns
- **Auto-position-hold**—helping the drone be independent of wind (within limits).

The drone manufacturer does not list a payload specification, but many users have done tests and posted results online, which provided a guideline. The general consensus is that maximum payload is approximately 28 oz (785 g) to achieve up to 14 minutes of flight time. The total





▲ Fig. 1 Flight payload configuration.

weight of the payload used was less than 20 oz.

FLIGHT ASSEMBLY

In addition to the ultraportable spectrum analyzer (Anritsu Spectrum Master™ MS2760-0070), the configuration assembled had other components to fit the requirements of the application. A 10 A battery eliminator circuit (BEC) set to 5.1 V was used as a regulator. Since 5.0 V is the correct voltage for the compute stick used, the regulator was adjusted via a USB programming kit. The compute stick drew about 1 A at 5.0 V, while the ultraportable spectrum analyzer required approximately 0.7 A at 5.0 V. A custom power supply cable was used to transfer the voltage from the BEC to the compute stick. One end of the USB Type-C, cable was cut to expose a red +5 volt wire (Vbus) and a black ground wire (GND). It is advisable to confirm the wiring using a voltmeter and USB Type-C pinout specification before connecting the compute stick. If it is incorrectly connected, irreparably damage to the compute stick could occur.

The lightweight compute stick (weighing 2.1 oz/59 g) came fully configured, with the exception of the operating system. While the compute stick processor and RAM were not exceedingly high, the stick still provided enough performance to make a quality measurement.

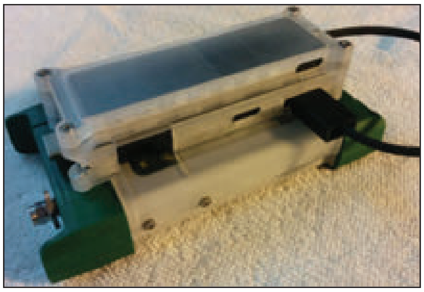
Control PC

A PC with a minimum of Intel i7 processor and 16 GB of RAM was used with the ultraportable spectrum analyzer. This level of computer performance was necessary to maximize instrument performance. The PC had a Windows 10 Professional operating system. One drawback to Windows 10 is that it is not designed to handle sudden power removal, which can happen in this application due to unplugged cables or a dead battery. To help mitigate the problem, a separate payload battery is recommended and was used.

USB Hub

Because the compute stick had only one USB A port, a four-port USB hub was necessary to connect it to the ultraportable spectrum analyzer, USB-based GPS unit and keyboard/mouse. It should be noted that the link between the compute stick and the ultraportable spectrum analyzer must be USB 3.0 compliant. The GPS was USB-powered and Windows compatible. Custom software was written to combine the GPS readings with the RF Channel power results from the ultraportable spectrum analyzer.

A tuned wired flight antenna (with close attention paid to weight) was constructed from semi-rigid coax. The cable was cut to be approximately 3 in long (7.6 cm) and the sheathing was stripped back until the newly constricted antenna resonated at 24 GHz. To tune the antenna, a cable and antenna analyzer was used.

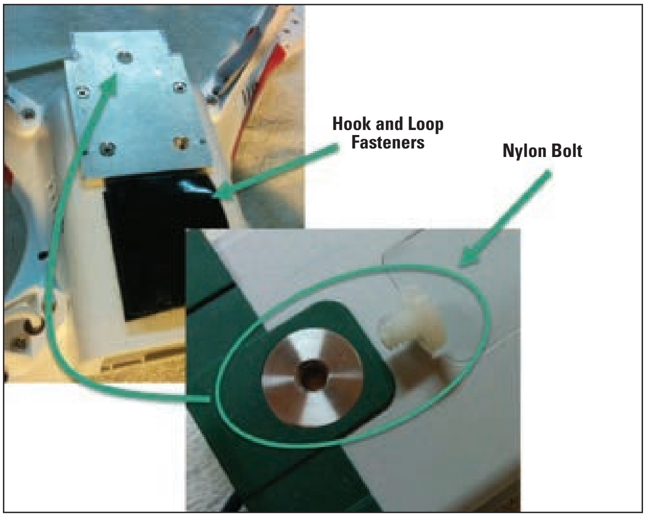


▲ Fig. 2 Flight payload assembly.

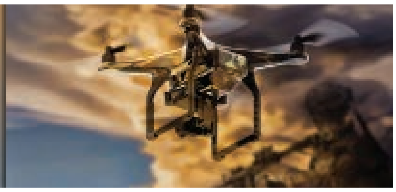
The payload consisted of the ultraportable spectrum analyzer, compute stick, USB hub and GPS (see ***Figure 1***). The first three items were grouped via the 3D printed assembly shown in ***Figure 2***. When mounting the payload to the drone, crash-proofing was a consideration. While it is not possible to completely guard against the most serious impacts, providing a shock-absorbing payload mount was beneficial.

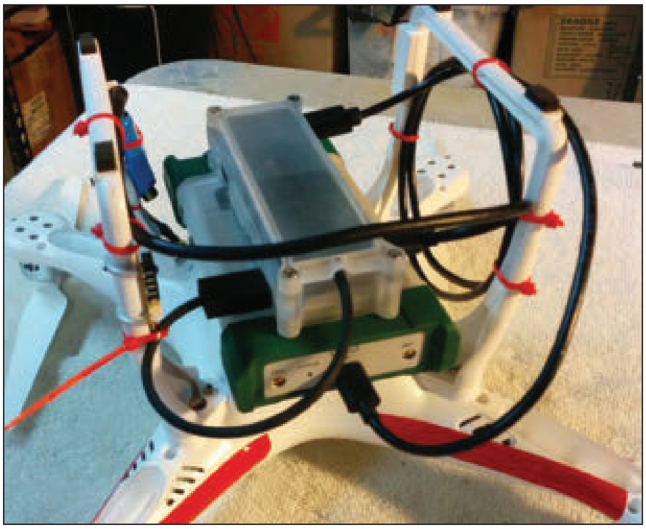
In this test, a custom aluminum plate was developed and mounted on the drone using the bolt holes typically used for a camera (see ***Figure 3***). The plate had a ¼-inch hole drilled for the nylon bolt used for the ultraportable spectrum analyzer. In addition to attaching the payload to the drone, the nylon bolt acted as a mechanical fuse, or break point, for the payload in case of an unplanned rough landing. A hook and loop fastener stabilized the payload and had some give in the event of a crash.

Once the payload was assembled and fastened to the drone, all the ca-



▲ Fig. 3 Flight payload mounting plate.





▲ Fig. 4 Assembled payload secured to the drone.

▲ Fig. 5 Ground package configuration.

bles were connected (see ***Figure 4***). Securing the cables tightly is essential to prevent them from becoming loose or unplugged during flight or a hard landing. In the worst case scenario, improperly connected cables could become caught in the propellers and bring the drone down suddenly. This could have resulted in injury or property damage, as well as the loss of the drone and/or the ultraportable spectrum analyzer.

GROUND PACKAGE

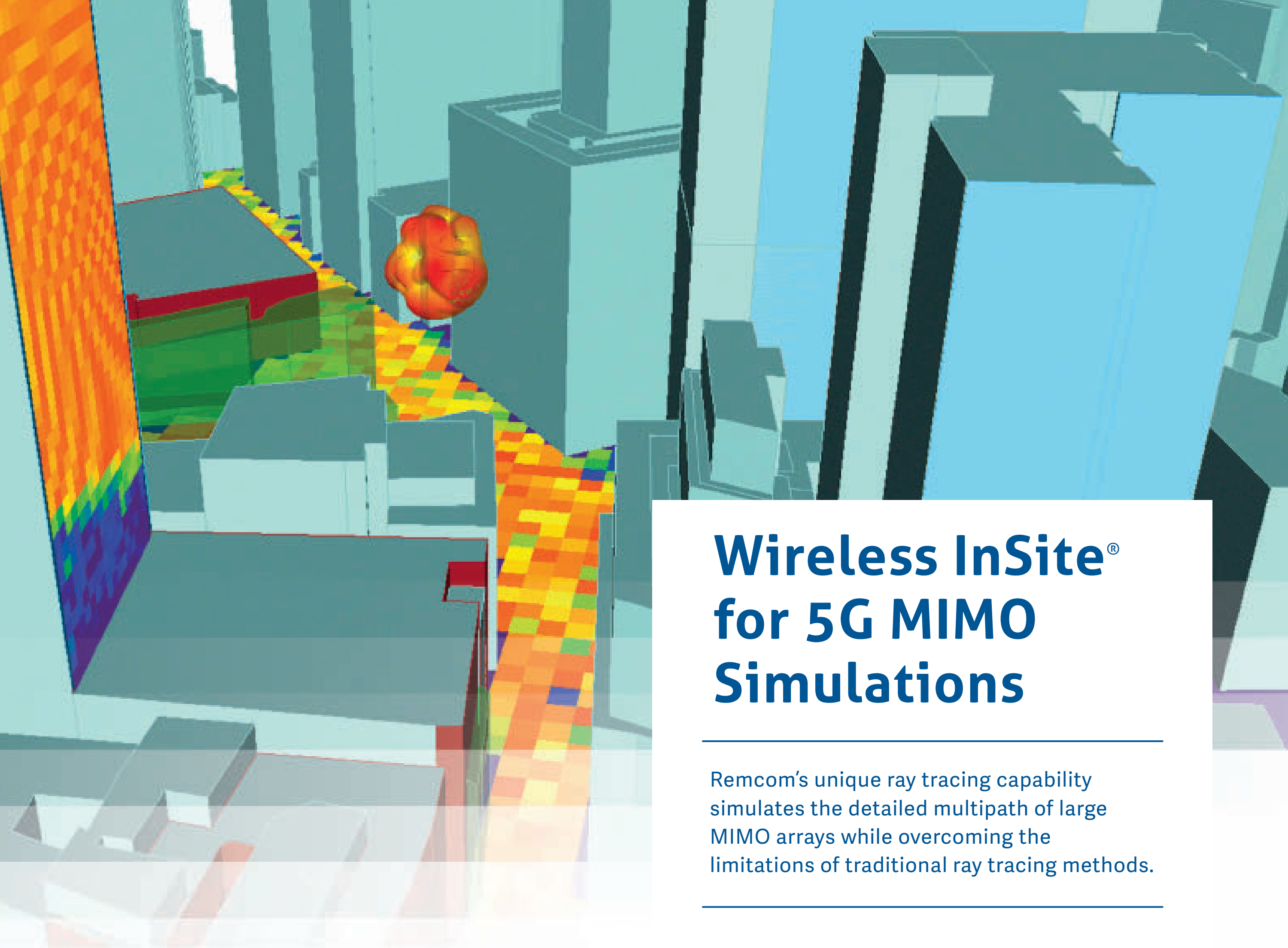
The ground package designed consisted of a control station, display and keyboard, extra batteries and chargers and a transit case (see ***Figure 5***). It is advisable to use a keyboard with an integrated touchpad to eliminate the need for a mouse and necessary added connection. The monitor can be any HDMI compatible display. Battery-power equipment was used to replicate a scenario in which testing needed to be done in a location where outlets were not in the vicinity.

Communication between the ground and airborne drone was achieved via a remote desktop connected to the compute stick from a separate laptop. The two PCs were connected via a basic USB pocket router. Once the compute stick and the laptop were linked to the pocket router, they were on the same network and it became much easier to connect applications between them.

It also allowed for remote monitoring and control of the ultraportable spectrum analyzer. The remote display is shown in ***Figure 6***. To do so, the analyzer software was installed on the laptop and compute stick. With the software open on the laptop, auto-connect was turned off, then the IP address of the compute stick was entered. Using the pocket router, the ultraportable spectrum analyzer could be monitored and controlled from distances as far as 100 meters. Other routers may allow for wider range.

POWER CONSIDERATIONS

The proof of concept discussed here used the drone flight battery as a voltage source for the payload. A link to the compute stick had to be established so it could be powered



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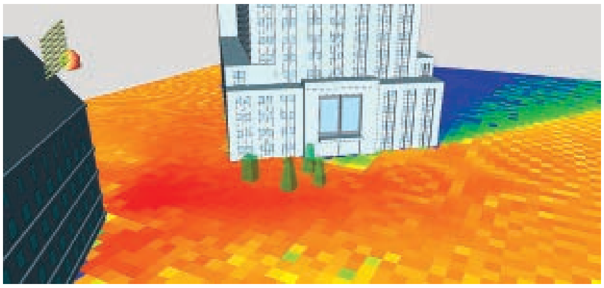

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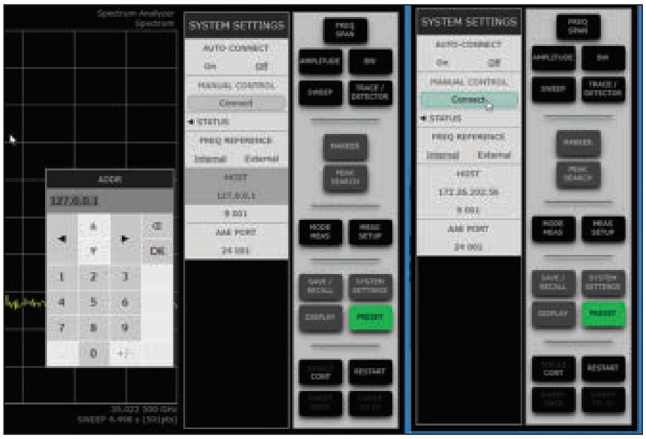

Fig. 6 Remote display.

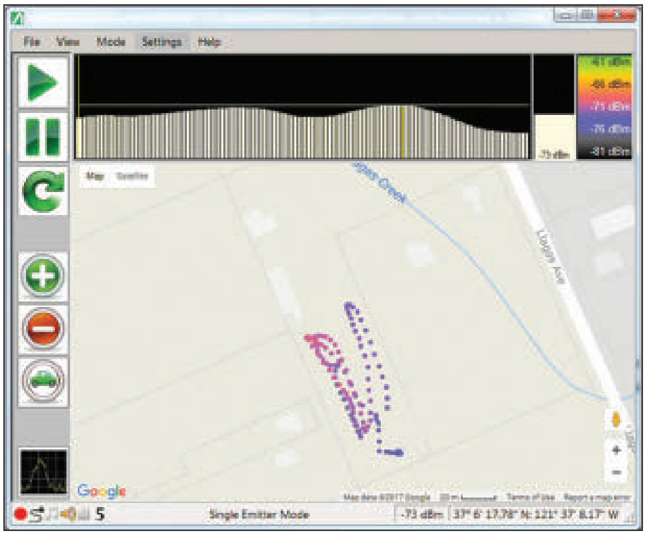

Fig. 7 RF channel power measurements with GPS location data.

down every time before changing the flight battery. If the flight battery had been drained completely, it is possible that the drone would power down on its own.

While the compute stick held up fairly well to the inadvertent sudden power downs it experienced, there was no guarantee that it would have recovered. As a precaution, we installed a separate payload battery—allowable because of the light weight of the ultraportable spectrum analyzer. A two cell 1300 mAh LiPo battery would last about 40 minutes if it was drawn down to 80 percent of its capacity. These batteries are available online and weigh approximately 3.5 oz (100 g). A dedicated LiPo charger is required for these batteries.

It is recommended that two or three extra batteries and chargers be included in the ground kit. Battery charging time is typically 30 to 45 minutes for each, so a set of three or four flight batteries will allow for hours of flight operations. If the drone is flown in an area without AC (mains) power, a method to charge batteries from a vehicle must be considered. Another option is to have enough batteries to complete the project.

RESULTS

Figure 7 shows the results of the drone test configuration proof of concept. The flight results display mapped RF power at 24 GHz. RF channel power measurements were plotted in a mapping tool, showing power versus time (along the top of the display), a power scale (in the upper right) and the GPS referenced measured data. The drone flight originated in the lower right corner of the map, with the dark purple bread crumbs indicating lower power. The drone flight pattern scanned the available area and identified that the strongest signal was in the upper left of the mapped area. When that area was investigated by personnel on foot using a handheld spectrum analyzer, the signal source was quickly found.

CONCLUSION

It is possible and practical to fly and operate an ultraportable spectrum analyzer connected to one of the many off-the-shelf drones on the market today. With the current move toward 5G and the high frequency range anticipated for backhaul, the ability to position a 110 GHz spectrum analyzer in the air will have many uses, some known and many not anticipated. This is also useful for military, defense and security applications as well as spectrum monitoring or hunting. The experiment conducted proves this approach as an effective solution to address a growing network verification challenge.■


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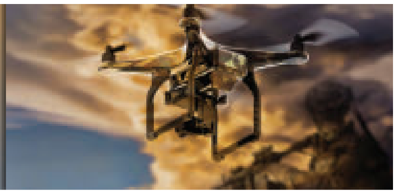
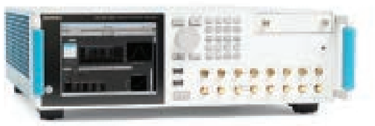
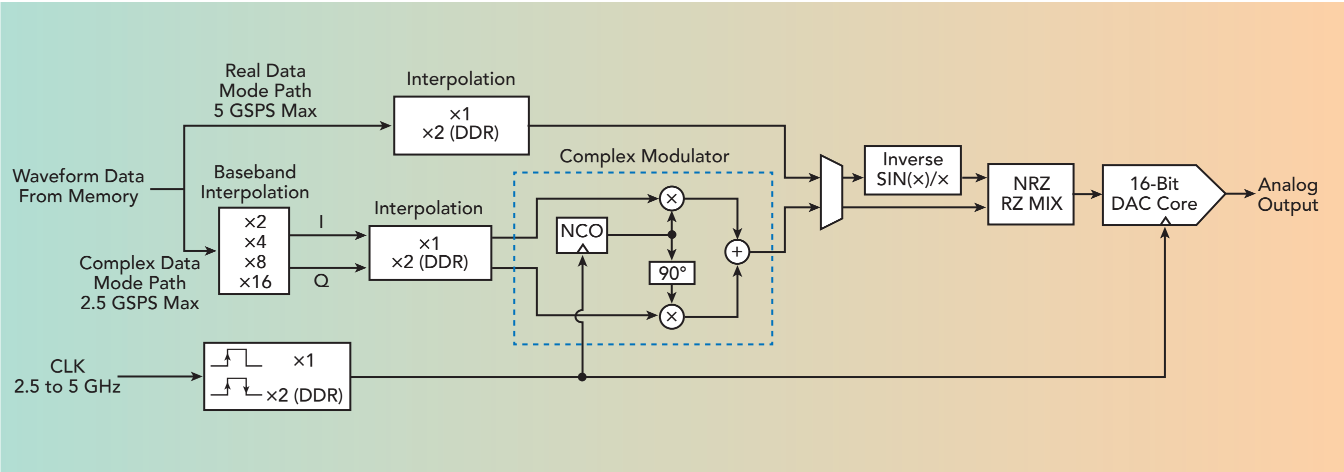




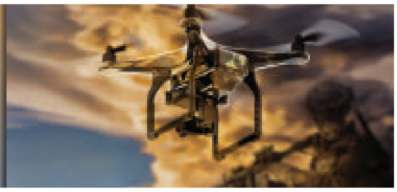
AWG Launches New Era in RF Signal Generation

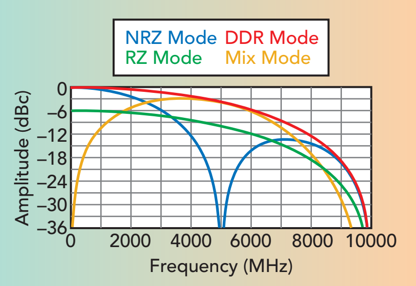
Tektronix Inc.
Beaverton, Ore.

Tektronix has long been a leading manufacturer of arbitrary waveform generators (AWG) that offer an easy and flexible way to generate the signals needed in radar and electronic warfare, general microwave and RF design, advanced research and high speed digital applications such as high speed serial and optical communications. The company is expanding its lineup with the AWG5200 series that offers an impressive set of capabilities not previously available in one instrument, including a standard sampling rate of 5 GSPS (up to 10 GSPS with interpolation), 16-bit vertical resolution, 2 GS waveform memory per channel and up to eight channels per unit, with support for synchronizing multiple units. The AWG5200 series includes a flexible waveform generation plug-in suite with comprehensive coverage for a wide



▲ **Fig. 1 Simplified block diagram of the DAC used in the Tektronix AWG5200.**





▲ **Fig. 2 Several DAC modes enable the AWG5200 to output signals at the cleanest portion of the DAC bandwidth and frequency roll-off positions.**

variety of standards and digital modulation techniques. It also lowers the cost of ownership for complex multi-signal environments, starting at a list price of about $11,000 per channel for an eight-channel instrument.

At the heart of the AWG5200 series instruments are new high performance, digital-to-analog converters (DAC) that offer a mix of speed and resolution in a fully-integrated product package (see ***Figure 1***). With its powerful DAC cores, the AWG5200 can directly generate complex modulated RF EW signals with carriers up to 4 GHz, without external RF conversion. The 16-bit vertical resolution is the best available for a fully-integrated AWG, compared to alternatives at 14-bit resolution. Driven in part by the demand for lower cost and smaller size devices for telecommunications and military systems, the DACs used in the AWG5200 incorporate signal processing and modulation in addition to signal generation functions. In the past, a separate system handled the signal processing and created the waveform, and the digital information was fed to the DAC. Now, the more advanced high speed DACs have signal processing blocks built in. The more useful of these digital signal processing blocks include complex (I/Q) modulation, numerically controlled oscillators (NCO) and conditioning functions such as finite impulse response (FIR) filters and digital interpolation. This enables direct generation of complex RF signals in an efficient, compact and more affordable way. The AWG5200 series offers several DAC modes that enable users to output signals at the cleanest portion of the DAC BW and frequency roll-off positions. Options include NRZ, DDR, RZ and mix modes (see ***Figure 2***).

HAVE IT YOUR WAY

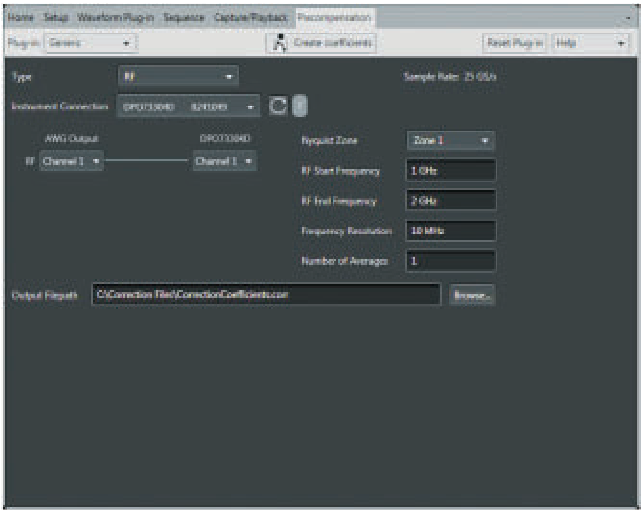
An increasingly important requirement for RF and radar designers is high fidelity, tightly synchronized, multi-channel signal generation to stimulate receivers for design, troubleshooting and operational testing. This is especially true for occupied spectrum measurements, where designers are trying to simulate a spectrum that is filled with RF/microwave signals from military and commercial radar and radios, as well as countless consumer devices. For this application, the more test sources the better.

The AWG5200's eight independent channels provide less than 10 ps channel-to-channel skew. Each of the AWG5200's channels have independent path outputs, individual amplification, separate sequencing, up-conversion and dedicated memory, and they can be controlled independently without crosstalk or limitations on any channel's performance. The only common factor is that all channels share a common clock or, if the user chooses, an external reference clock can be used.

This level of independence and flexibility, with 16-bit resolution, less than 2 µs latency and -70 dBc spurious free dynamic range, make the AWG5200 an excellent source for

- Generating complex, real world environments
- Testing phased arrays
- Simulating objects of interest
- Replacing older equipment with new commercial off-the-shelf solutions.

For applications such as testing phased-array antenna systems or multiple-input-multiple-output (MIMO) antenna arrays, up to four AWG5200s can be synchronized to create a total of 32 test signals.



▲ **Fig. 3 The RF Generic waveform creation plug-in is a software package that digitally synthesizes modulated baseband IF and RF/microwave signals.**

From a practical standpoint, a major benefit of the AWG5200 is that it makes signal generation much more manageable, by eliminating the need for large racks of specialized—and costly—signal generation equipment. The growing library of plug-ins for creating waveforms for RF testing makes creating signals for conformance or margin testing fast and straightforward. Plug-ins include generic pre-compensation, multi-tone and chirp, orthogonal frequency division multiplexing (OFDM), radar and "RF Generic." The latter, shown in ***Figure 3***, digitally synthesizes modulated baseband, IF and RF signals and supports a wide range of modulation schemes. Users can, of course, design their own waveforms using a variety of tools and techniques and automate tests using MATLAB scripts. The AWG5200 is also code compatible with previous generation Tektronix AWGs, meaning any existing waveforms and scripts can be employed.

The AWG5200 has a 6.5 inch touch screen display that offers intuitive menu-driven operation, with familiar front panel controls and keypad. It can also be controlled by an external PC using Ethernet or a direct USB connection running SourceXpress software. It includes a removable hard disk drive for quickly changing test setups or meeting security requirements.

PRICING AND AVAILABILITY

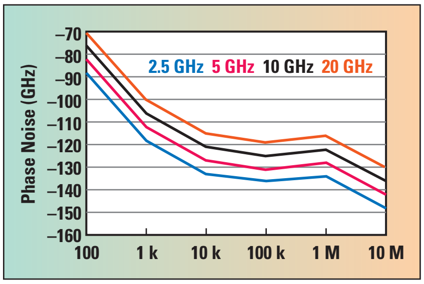
The AWG5200 is available now. The eight-channel instrument with 2.5 GSPS and up to 10 GSPS performance has a starting price of $82,000 (U.S. MSRP). Two- and four-channel models are also available.

Tektronix Inc.
Beaverton, Ore.
www.tek.com/AWG5200

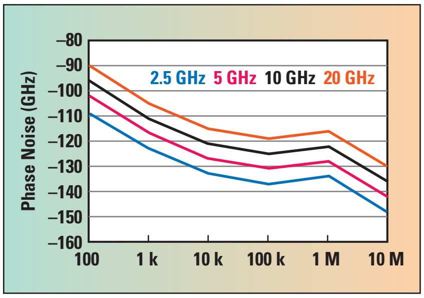
20 GHz Ultra-Low Phase Noise Synthesizer

Syntonic Microwave
Campbell, Calif.

Syntonic Microwave's RF tuner and IF-to-IF converter product lines require the very best signal sources—beyond what could be found on the market. So Syntonic set out to build the highest performing microwave synthesizer and make it available to the market. The result is the DS-3000 family, comprising the DS-3001 with a temperature compensated crystal oscillator (TCXO) and the DS-3002 with an oven controlled crystal oscillator (OCXO). The compact design continuously tunes from 100 MHz to 20 GHz in 1 Hz steps. Fast tuning is accomplished through high speed internal switching and settling, with tuning via four-wire SPI or USB interfaces. The DS-3000 series provides low cost, signal generator class performance and high-reliability for both commercial and military applications—well-suited for challenging and difficult environments.



▲ Fig. 1 Phase noise performance of the DS-3001.



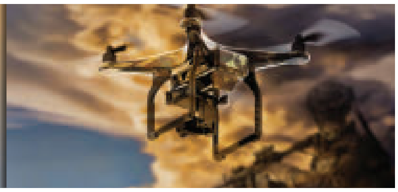
▲ Fig. 2 Phase noise performance of the DS-3002.

Multi-loop synthesis techniques are employed in the microwave frequency plan to give the DDS-based DS-3001 and DS-3002 their excellent phase noise performance, which is also enabled by the high quality, high performance system reference. Excellent spurious suppression is also a natural outcome of Syntonic's synthesis methodology. The phase noise and spurious performance are consistent with the most demanding test equipment and carrier receiver/transmitter requirements. As shown in ***Figure 1***, the architecture achieves excellent phase noise from near-in to very wide offsets. At 10 GHz, for example, the typical phase noise ranges from –76 dBc/Hz at 100 Hz to –136 dBc/Hz at 10 MHz.

Users requiring the best in phase noise and frequency stability will find the DS-3002 version of the synthesizer pushes the performance bar to new levels in these two categories. The phase noise of this model is especially improved at the near-in offsets from the carrier, with improvement of greater than 20 dBc/Hz (see ***Figure 2***). At 10 GHz, the typical phase noise ranges from -96 dBc/Hz at 100 Hz to -136 dBc/Hz at 10 MHz. The DS-3002 is well-suited to applications such as instrumentation and carrier transmission/reception with higher-order modulation signals. The frequency stability of the DS-3002 is also better than that of the standard model, with the stability of the overall output at ± 0.1 ppm over the -20°C to +70°C temperature range and less than 1 ppm aging per year.

The high-stability, low noise, accurate system clock provides two separate outputs for synchronizing and daisy-chaining, enabling users to serve both 100 MHz and 10 MHz to downstream and upstream equipment. This provides a fully synchronous component and system profile. ***Figure 3*** shows the phase noise performance of the 100 MHz output for both DS-3000 models. The DS-3002 has better phase noise below 10 kHz offset from the carrier. The internal reference will auto-lock to an external 10 MHz reference when present.

The DS-3000 can be operated from a Windows PC using Syntonic's graphical user interface (GUI), which is supplied with each purchase (see ***Figure 4***). The GUI gives full control of the synthesizer, including scan, sweep and step. Auto-routines can be executed, and users have a "list mode" for pre-loading up to 5,000 list entries for switching and settling using known frequency



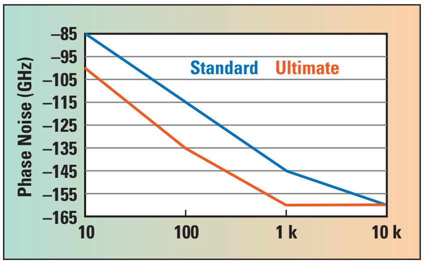
steps. List management is handled either directly through the customer interfaces or via an external Excel or CSV file, which is more convenient for long lists.

The synthesizers are biased with 9 to 15 V and typically consume 10 W (DS-3001) and 12 W (DS-3002). Two ports are available for providing bias: a 14 pin multi-connector and a separate DC input. This enables the synthesizer to be quickly powered for benchtop operation, which means that just a DC connection and USB cable are required for instant and complete control. A unique feature of the 14 pin multi-connector is the locking hardware, making the synthesizer suitable for rugged environments with shock and vibration. The size of each synthesizer is 6.5 in × 4 in × 0.7 in.

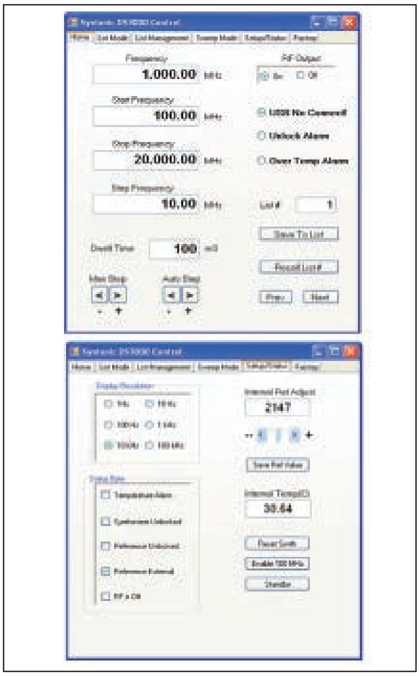
The experience using both synthesizers has been optimized to match the interface environment expected of today's microwave signal generators: an executable GUI running on a PC or laptop, a SPI machine interface for embedded applications and hundreds of features baked into the design, which makes the units easy to use.

Formed in 1990 to supply phase-locked oscillators and satellite converters, Syntonic Microwave has developed a strong heritage in the defense market, supplying Lockheed Martin, Northrop Grumman, Raytheon, Harris, Exelis, L3 Communications, DRS and various U.S. government facilities, research institutes and universities.

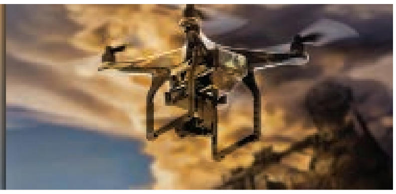
Syntonic Microwave
Campbell, Calif.
https://www.syntonicmicrowave.com/synthesizers/ds3000-microwave-synthesizer/



▲ Fig. 3 Phase noise of the 100 MHz reference outputs of the DS-3001 and DS-3002.



▲ Fig. 4 Two of the GUIs used to control the synthesizer.



17 to 40 GHz Block Up- and Down-Converters

Norden Millimeter has developed a new generation of broader bandwidth block up- and down-converters, developed to extend the frequency range of ELINT, COMINT, threat detection, interferometer and test systems. These new converters cover 17 to 26.5 and 25.5 to 40 GHz, providing 1 GHz overlap at the transition between bands and with 18 GHz systems.

Both converters provide 10 to 15 dB gain, with ± 2.5 dB maximum drift over temperature. The up-converter has independent input IF and output RF attenuation that provide greater than 60 dB gain control. The up-converter's output attenuation reduces both the output signal and noise floor, maintaining the signal-to-noise ratio. The up-converter's noise figure is 21 dB and has a 1 dB compression point of 10 dBm. The down-converter has 16.5 dB noise figure and a 1 dB compression point of 2 dBm. Both the up- and down-converters have an IF range from 2.3 to 17.7 GHz and require an external 14.4 GHz LO. They are powered with ±15 and 5 V and operate from −20°C to +70°C.

These two new products add to Norden's existing frequency converters, which convert 18 to 26.5, 26.5 to 40, 40 to 60 and 60 to 80 GHz to 2 to 18 GHz. The existing converters offer variable gain, 30 MHz to 18 GHz bypass paths and common IF input/output. The units are offered in commercial, military and airborne hermetic cases, as well as VPX configurations. Norden's converters have passed the stringent environmental tests required for military airborne platforms.

Norden can customize converter designs to meet demanding applications, working closely with customers on system specifications and high-reliability solutions that meet system requirements. Norden also offers commercial off-the-shelf options that reduce cost and lead times.

Norden Millimeter Inc.
Placerville, Calif.
www.nordengroup.com

400 MHz to 18 GHz Voltage Variable Attenuators

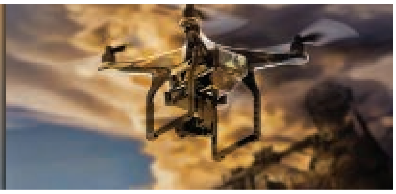
Fairview Microwave's new line of voltage variable attenuators (VVA) offer up to 60 dB of attenuation across a broad range of frequencies from 400 MHz to 18 GHz. The VVA product line is comprised of six models that provide low insertion loss and wide dynamic range, as well as exceptional VSWR over all attenuation levels. CW input power is rated up to +23 dBm. Fairview's PIN diode-based VVAs deliver accurate control and broadband flatness, allowing the output level to be continuously adjusted by changing the analog voltage on the input control line.

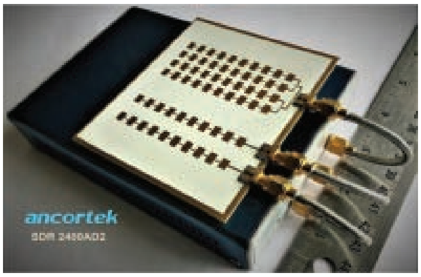
RF components used in most communications systems require precise power levels to achieve peak performance, and these power requirements can vary from one component to the next. This results in the need to fine-tune the attenuation to make up for fluctuations in received signal levels or best match the input power to a sensitive circuit. For these situations, a VVA is required to ensure optimal performance. Fairview Microwave's VVAs are ideal for use with variable gain amplifiers (VGA), feed-forward amplifiers, power level control and automatic level control (ALC) circuits.

The rugged coaxial packaged assemblies are designed to meet MIL-STD-202 environmental test conditions, including humidity, shock and vibration. Package interface options include SMA female connector to 15 PIN D-sub female, 15 PIN Micro-D female or RFI pins. For added flexibility, the SMA connectors are field replaceable. Each model is powered by +12 V DC.

Fairview Microwave's VVAs were designed for electronic warfare, instrumentation, point-to-point and point-to-multipoint radios, broadband telecom, fiber optic, VSAT, SATCOM, military radios, radar, sensors and R&D applications.

Fairview Microwave
Allen, Texas
www.fairviewmicrowave.com





24 GHz Software-Defined Radar Fits In A Pocket

Ancortek Inc. has developed a 24 GHz, lightweight, short-range, software-defined radar (SDR) that fits in a coat pocket. Without modifying any hardware, the software-defined architecture of the SDR 2400AD2 enables operating modes, waveforms, bandwidth and processing functions to be changed to adapt to different scenarios and applications. With dual receiving channels, the radar provides multiple modes: direction of arrival (DOA), dual receive antenna (DRA), clutter cancellation by displaced phase center antenna (DPCA) and radar interferometry. The SDR 2400AD2 can be used for indoor activity monitoring, gesture sensing, 3D interferometric synthetic-aperture radar (InSAR) and interferometric inverse synthetic-aperture radar (InISAR) imaging.

The RF module in the SDR is a high performance coherent transmitter and receiver. Using an Infineon SiGe MMIC, the radar transmits FMCW, FSK or CW waveforms in the 24 to 26 GHz band, with typical output power of 16 dBm and phase noise of –96 dBc/Hz at 1 MHz offset. The module uses a fractional-N phase-locked loop (PLL) to achieve high linearity frequency modulation and improve target detection and range resolution.

The digital processor module has four, 40 MSPS analog-to-digital converters to support the two receive channels, with an FPGA for signal processing to maintain design flexibility. A high speed USB peripheral controller enables data transfer up to 480 Mbps. A user-friendly graphical user interface (GUI) allows easy control of signal waveforms, bandwidth, sampling rates, stream filtering, display parameters and I/Q data recording and export.

Ancortek Inc.
Fairfax, Va.
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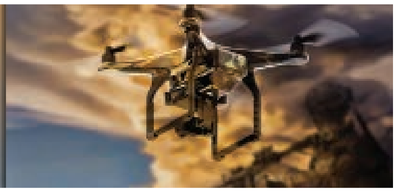

SOLID-STATE AMPLIFIER SOLUTIONS

CTT announced a new 48-page product catalog: Solid-State Amplifier Solutions for Military and Commercial Applications. The new catalog features over 830 amplifier products, of which over 365 are all new. Product offering includes new GaN power amplifier technology for narrowband, wideband and ultra-wideband applications. Many new GaAs-based power and low-noise amplifier designs are also listed, including new Ka-Band, low-noise amplifiers. The catalog also includes application information and case outline drawings. Visit CTT's website for a free download.

VENDORVIEW

CTT Inc.
www.cttinc.com

DIRECT GPS-OVER-FIBER

HUBER+SUHNER's Direct GPSoF solution perfectly addresses the power supply challenges within a GPS system by making use of the company's newly developed Power-over-Fiber technology. This new technology not only enables system improvements by eliminating all copper within the link, but also reduces the amount of hardware within the system by integrating the GPS-over-Fiber transmitter into the antenna's radome. The key benefits are Power-over-Fiber enabled GPSoF transmitter, truly copperless link (no EMI, RFI and EMP) and less hardware as transmitter integrated into antenna radome.

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NEW PRODUCT CATALOG

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

K&L Microwave
www.klmicrowave.com

T26 CABLE ASSEMBLIES

T26 series is high reliable and durable test cable up to 26.5 GHz, ideal for high precision and frequent tests. The cable construction is very rugged, which can be qualified by over 150,000 harsh flex cycles without changes in electrical performance till to 26.5 GHz. T26 series can be built with a wide range of stainless steel connectors, such as 3.5 mm, SMA and N types.

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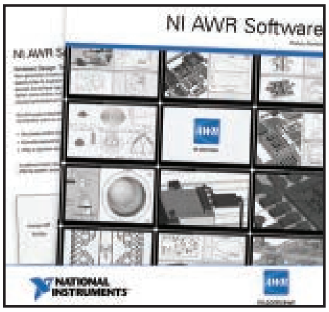
NI AWR SOFTWARE PRODUCT PORTFOLIO



The new NI AWR Software Product Portfolio brochure highlights the breadth of software tools available for high-frequency EDA offered by National Instruments (formerly AWR Corporation). The brochure includes NI AWR Design Environment, inclusive of Microwave Office, Analog Office, Visual System Simulator, AXIEM and Analyst™, as well as Analyst-MP, AntSyn™ and AWR Connected™. These products enable engineers to meet the design challenges of next-generation wireless devices, communications infrastructure and aerospace/defense electronic systems. The portfolio is now available for download from the company's website.

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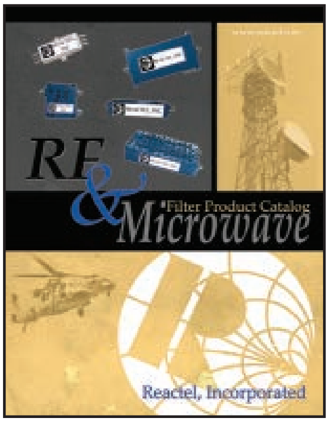
FILTERS, MULTIPLEXERS AND MULTI-FUNCTION ASSEMBLIES



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www.reactel.com

RLC CATALOG UPDATED

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

RLC Electronics Inc.
www.rlcelectronics.com

HIGH-END ANALOG RF AND MICROWAVE SIGNAL GENERATOR

The R&S SMA100B with a frequency range up to 20 GHz is the most powerful analog signal generator on the market. It delivers signals with the lowest possible phase noise and the highest output power with extremely low harmonics. Engineers no longer need to compromise between output power and a spurious free dynamic range. The R&S SMA100B is designed for the RF semiconductor, wireless communications and aerospace and defense industries. The R&S SMA100B RF and microwave signal generator is now available.

VENDORVIEW

Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com/ad/press/purest-signal

NEW MULTIPORT DESIGNS

Spectrum Elektrotechnik GmbH is developing circular and rectangular Multiport Connectors using all kinds of different dimensions, as needed, containing from 4 and up to 80 coaxial cables assemblies. The circular Multiports are using the MIL-DTL 38999 shells of series I and III, operating up to 65 GHz. The rectangular Multiports are available in many different shapes, starting with narrow widths of only 7 mm for 8 coaxial cable assemblies. Spectrum's Multiport-Family is continuously increasing; please ask for the Rev.2 catalog.

Spectrum Elektrotechnik GmbH
www.spectrum-et.org/NEW_WEB2/index.asp

The 2017 Defence, Security and Space Forum
At European Microwave Week

Wednesday, 11 October

A focused Forum addressing the application of RF and microwave technology to The Internet of Space.

Vast areas of the globe are without sufficient Internet connectivity. Commercial and societal progress as well as safety and security are linked to access to the information superhighway, while military missions require reliable and secure datacommunication pathways. This one-day Forum highlights The Internet of Space – Technologies and Applications, a new class of satellite communication services being developed to address these needs.

Programme:

08:30 – 10:10 **EuRAD Opening Session**

10:50 – 12:30 **The Internet of Space – Technologies and Applications**
Two keynote speakers from the industry will present their view on key applications and the related technologies needed for the realisation of the **Internet of Space**. The presentations will cover commercial as well as military applications.

- The World's Largest Satellite Constellation 'OneWeb' – Redefining Satellite Communications
  Wolfgang Duerr, Airbus DS Inc.
- The Connections are Key: The Implications of the Internet of Things on Military Technology –
  Joe Mariani, Deloitte

12:40 – 13:40 **Strategy Analytics Lunch & Learn Session**
This session adds a further dimension to the topics by offering a market analytics perspective, illustrating the status, development and potential of the market for the **Internet of Space**.

14:20 – 16:00 ***Microwave Journal* Industry Panel Session**
This session offers an industrial perspective on the key issues to be addressed in the defence, security and space sector. In accordance with this year's Defence, Security and Space theme the panel will investigate the opportunities for applications of the **Internet of Space** as well as address the technological challenges.
The presentations are:

- *The Internet of Space – Technologies and Applications – Mark Lombardi, Keysight Technologies*
- *Internet of Space, Past, Present, & Future – Timothy Boles, MACOM*
- *Leveraging Technology to Develop Solutions for IoT to the IoS – Roger Hall, Qorvo*
- *New Approaches in End-To-End Payload Testing – Yassen Mikhailov, Rohde & Schwarz*

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16:10 - 17:50 **Defence, Security & Space Executive Forum**

High level speakers from leading Defence and Space companies present their views and experiences on the upcoming technologies and applications in the civil and military domains. They will be complemented by speakers from a government agency, consulting company and a start-up, who will offer their views on research needs, trends and New Space opportunities and challenges. Speakers at the Forum will include:

- *Siegbert Martin, TeSat SpaceCom*
- *Wolfgang Duerr, Airbus DS Inc.*
- *Matthias Spott, eightyLEO*
- *Joe Mariani, Deloitte*
- *Siegfried Voigt, DLR*

17:50 - 18:30 **Cocktail Reception**

The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates

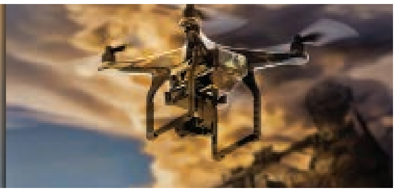
Registration fees are €20 for those who registered for a conference and €60 for those not registered for a conference

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

Organized by:

Microwave Journal   EuMA

MILITARY MICROWAVES
AD INDEX



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