Vol. 60 • No. 4

April 2017

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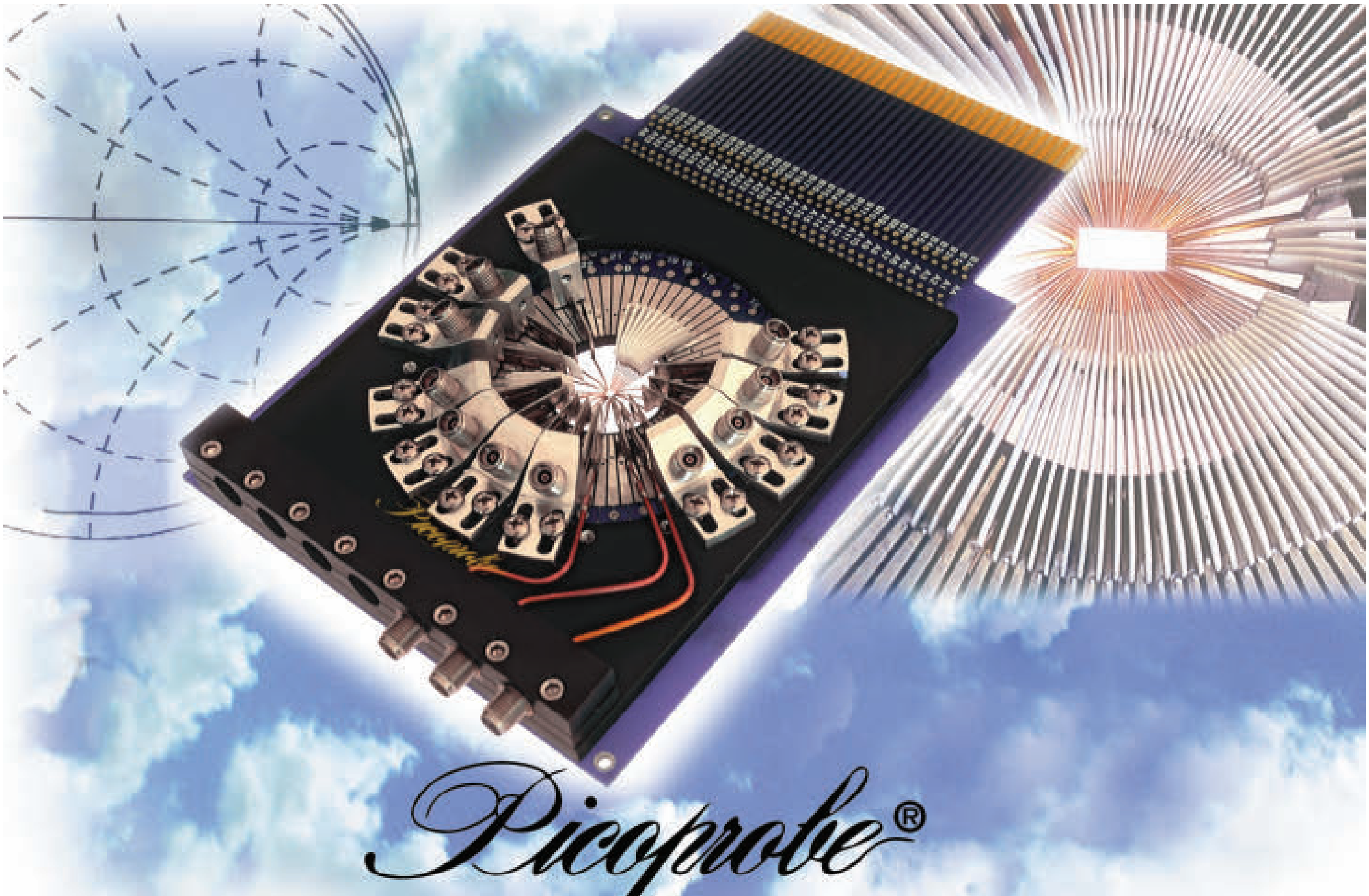

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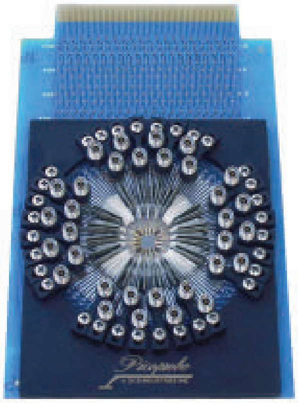

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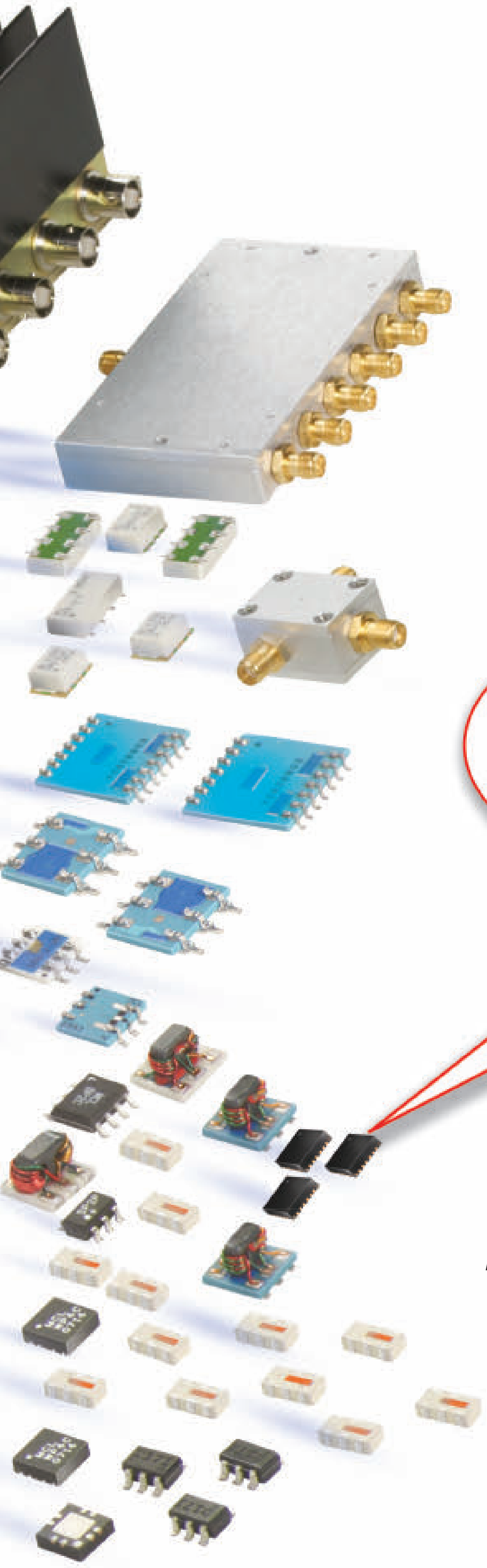

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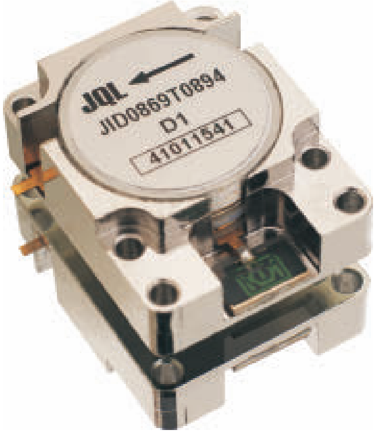

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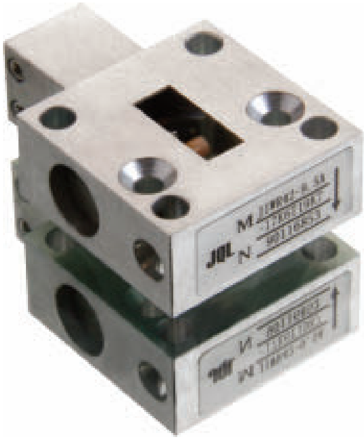

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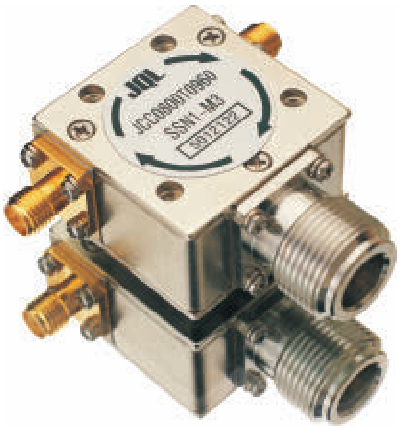

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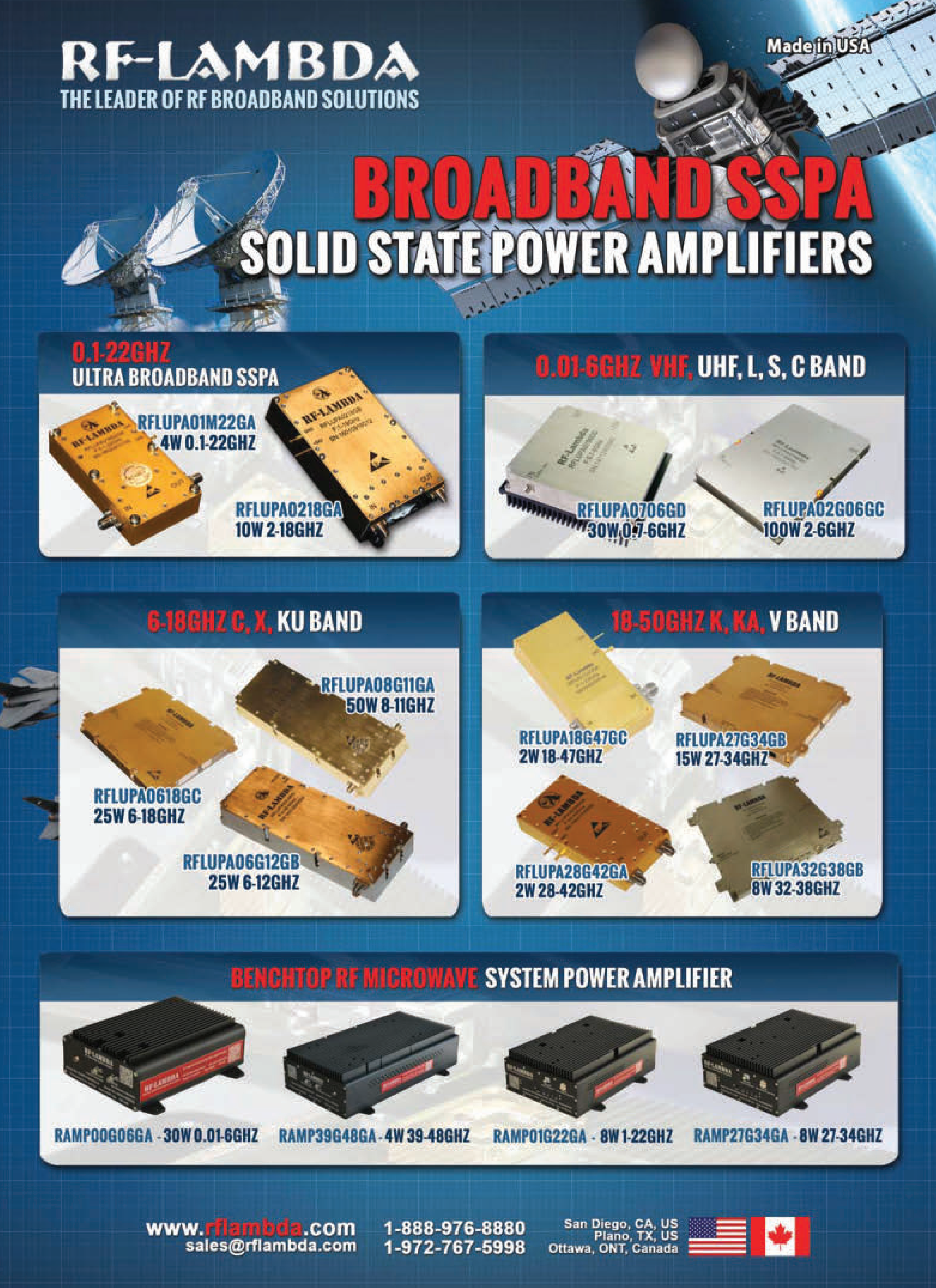

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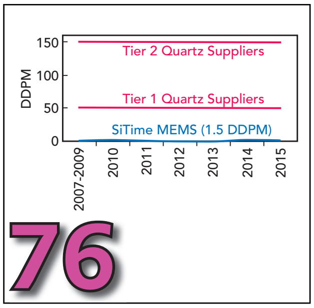

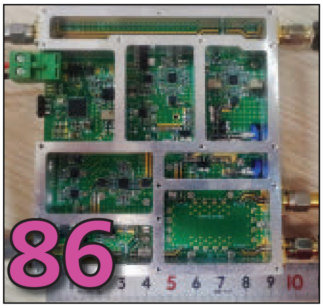

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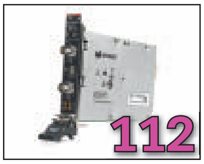

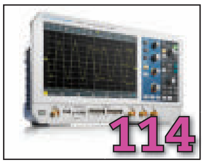

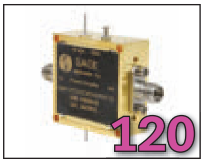

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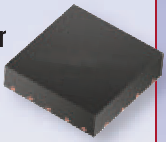

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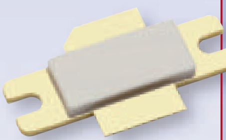

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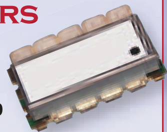

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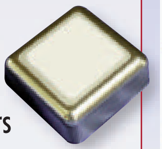

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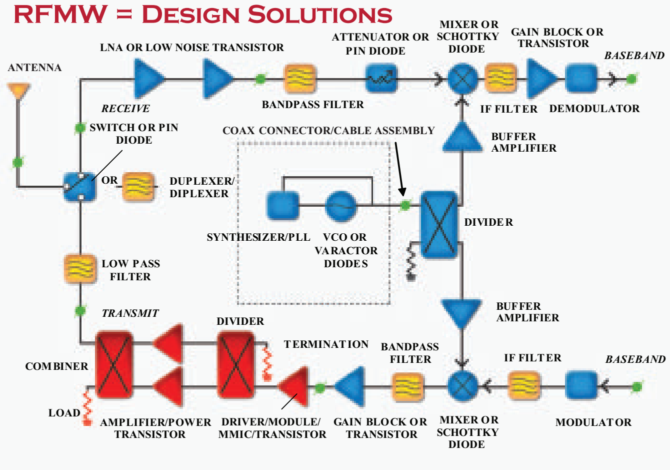

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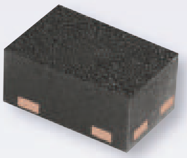

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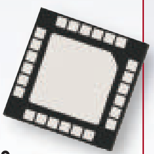

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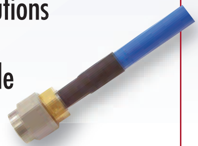

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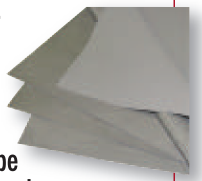

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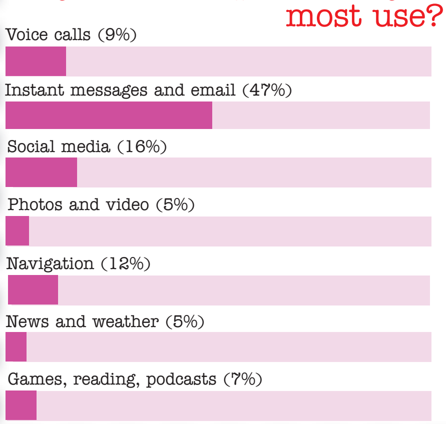

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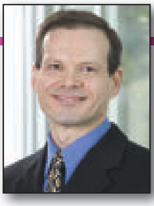

With the Infineon acquisition scuttled by U.S. government concerns, Wolfspeed will remain with Cree. **Jim Milligan**, director of RF, discusses this unexpected change and Wolfspeed's technology and product plans.

David Vye, director of technical marketing for the AWR group of National Instruments, discusses the increasing complexity of RF/microwave design and how improvements in simulation are helping designers get products to market faster.

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Editor's Note: Exactly one decade ago, Alexander Chenakin wrote about the state of the synthesizer market and future directions in Microwave Journal. *The article has been referenced by many authors that followed and most of his projections were proven correct over time. Now he is back with another look at the current design trends in synthesizers and more future directions for another decade of inspiration.*

Frequency Synthesis: Current Status and Future Projections

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There is persistent pressure on the RF/microwave industry to deliver higher performance, higher functionality, smaller-size, lower-power-consumption and lower cost synthesizers.[1-18] Although all synthesizers exhibit significant differences as a result of specific applications, they share basic fundamental design objectives as depicted in ***Figure 1***. The ideal synthesizer should preferably be broadband with fine frequency resolution that allows addressing a larger number of potential applications. Aside from frequency coverage and resolution, phase noise and spurs are critical parameters that impose the ultimate limit in the system's ability to resolve signals of small amplitude. Another key parameter that impacts overall system performance is frequency switching speed. The time spent by the synthesizer transitioning between frequencies becomes increasingly valuable since it cannot be used for data processing. Modern synthesizers tend to be faster due to the ongoing increase in the data rates of RF/microwave systems. Another challenge is size and cost reduction. These requirements—wide frequency coverage, small step size, fast switching speed, adequate spectral purity, small size and low cost—are the key drivers in the development of modern frequency synthesizers.

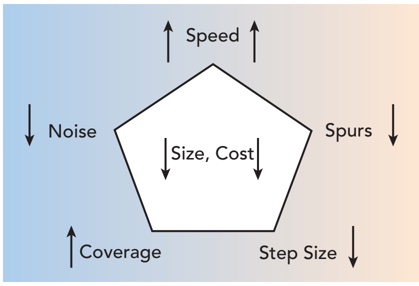

Fig. 1 Synthesizer design challenges.

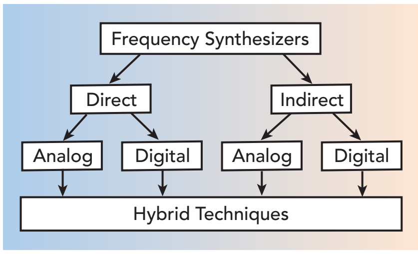

Fig. 2 Frequency synthesizer classes.

ARCHITECTURES

Synthesizer characteristics depend heavily on a particular architecture, which can be classified into a few main groups as indicated in ***Figure 2***. Direct architectures are intended to create the output signal directly from available reference signals either by manipulating and combining them in the frequency domain (direct analog synthesis) or by constructing the output waveform in the time domain (direct digital synthesis). The indirect methods assume that the output signal is regenerated inside the synthesizer in such a manner that the output frequency relates (e.g., is phase-locked) to the input reference signal. Similarly, indirect synthesis can be accomplished with analog and digital techniques. A practical synthesizer, however, is usually a hybrid design that combines various techniques to take advantage of the best aspects of each.

INDIRECT SYNTHESIS

For decades, an indirect phase-locked loop (PLL) synthesizer was

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(and still remains) the most common and most popular technique. A generic single loop PLL (see ***Figure 3***) includes a tunable voltage-controlled oscillator (VCO) that generates a signal in a desired frequency range. This signal is fed back to a phase detector through a frequency divider with a variable frequency division ratio N. The other input to the phase detector is a reference signal divided down to a desirable step size. The phase detector compares the signals at both inputs and generates an error voltage, which following filtering (and optional amplification) slews the VCO until it acquires the lock frequency given by $f_{OUT} = Nf_{PD}$, where f_{PD} is the comparison frequency at the phase detector input. Thus, frequency tuning is achieved in discrete frequency steps equal to f_{PD} by changing the division coefficient N.

This simple PLL synthesizer exhibits various limitations and tradeoffs. The main impact on synthesizer performance is caused by the large division ratios required to provide a high frequency output with a fine resolution. Note that any noise generated by PLL components is degraded at a 20logN rate, where N is the division ratio. In conventional integer-N PLLs operating with small step sizes, the division ratio is large because the step size must be equal to the comparison frequency at the phase detector. As a result, significant phase noise degradation occurs. Furthermore, the synthesizer switching speed is a function of its loop bandwidth and, therefore, is limited by the phase detector comparison frequency. Increasing the loop bandwidth may lead to higher reference spurs due to insufficient loop filter rejection or even loop instability. Thus, this simple single loop architecture suffers from mutually exclusive design goals. It is usually utilized in non-demanding applications or when low cost is the major concern.

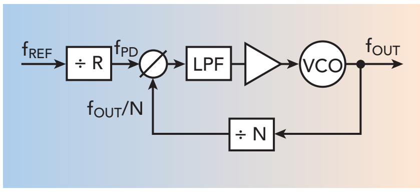


Fig. 3 Single loop PLL synthesizer.

Fractional-N Synthesizer

Fractional-N synthesizers break this coupling between frequency resolution and other characteristics by using fractional division ratios, allowing a higher comparison frequency for a given step size. Fractional ratios are possible by alternating two (or more) division ratios (let's say, N and N+1) and averaging the output frequency over a certain period of time. Another way to look at this process is to calculate the number of pulses delivered by such a complex divider for a given time interval. Obviously, the average division coefficient will be between N and N+1 depending on how many pulses are processed by each individual divider. The biggest concern associated with this scheme is that the instant frequency at the fractional-N divider output is not constant. An abrupt change in the division coefficient leads to a phase discontinuity that produces a voltage spike at the phase detector output. Since the frequency division change occurs periodically at the same rate, it appears as discrete spurs in the synthesizer's output spectrum. Suppression of the resulting spurs requires that the PLL filter bandwidth must be sufficiently small, which may affect phase noise and speed performance.

There are many techniques to reduce fractional-N spurs.[19-21] In general, this can be accomplished by adding or subtracting a voltage at the phase detector output during the frequency division change. Another method is based on using a multi-modulus divider that allows a larger number of division coefficients. In this case, we should expect a larger number of spurs of smaller amplitude. The multi-modulus divider is often accompanied by a delta-sigma modulator that allows randomizing frequency spurs and pushing them towards higher offset frequencies where they can be filtered by the loop filter. In spite of various improvements, the main disadvantage of the fractional-N technique is the excessive spurious levels produced by phase errors inherent in the fractional division mechanism.

A clever method to reduce fractional spurs is to utilize a variable

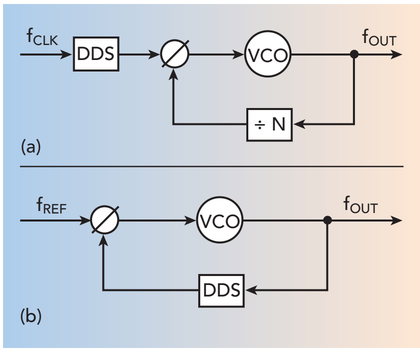


Fig. 4 Using a DDS as a fine resolution high frequency reference (a) or fractional divider (b) within a PLL synthesizer.

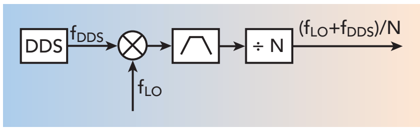


Fig. 5 Up-converting and dividing a DDS signal.

reference. The technique is based on the fact that spur location in a fractional-N synthesizer is a function of its particular division ratio and output frequency. Therefore, for a given output frequency one can move (and then filter out) an undesired spur by changing the reference frequency and corresponding division ratio. This involves thorough frequency planning and also requires an additional frequency synthesizer (to be used as a reference). Furthermore, although the division ratio is reduced, it can still be high enough to affect PLL performance.

Direct Digital Synthesis (DDS) Within a PLL Synthesizer

The DDS is another effective solution to provide a very fine frequency resolution without a common penalty of the phase detector comparison frequency reduction. The DDS can serve as a fine resolution, high frequency reference or be employed as a fractional divider as illustrated in ***Figure 4***. While a DDS provides excellent frequency resolution, its spurious levels are usually quite high. Moreover, the spurs further degrade because of the PLL multiplication mechanism. Although the two schemes in Figure 4 look different, they both affect DDS spurs in the same manner. In both cases, the overall loop division coefficient is defined by the ratio between the

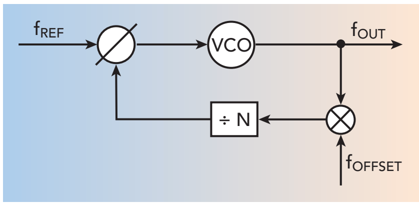


Fig. 6 Frequency offsetting improves PLL performance.

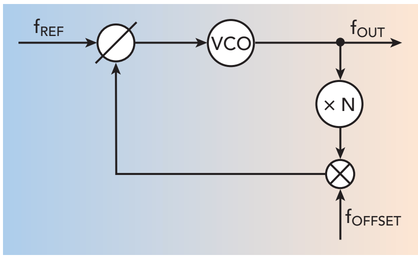


Fig. 7 Inserting a multiplier into the PLL feedback path.

VCO output and phase detector comparison frequencies. The DDS spurs can be reduced by utilizing many techniques, for example, using a variable clock (as described above for the fractional-N synthesizers) or up-converting and further dividing down the DDS signal as illustrated in ***Figure 5***. Note that the up-converted relative DDS bandwidth is reduced and often needs further extending as required by a particular frequency plan. This can be achieved through various methods; for example, by using variable (versus fixed) frequency division coefficients.

Frequency Offset and Multiplication Within a PLL Synthesizer

The synthesizer's main characteristics can be drastically improved using frequency conversion (mixing) within the synthesizer feedback path as shown in ***Figure 6***. The idea is to convert the VCO output to a much lower frequency with the aid of a mixer and an offset frequency source. In certain scenarios (e.g., when the operating frequency range is narrow) it is possible to eliminate the feedback frequency divider completely. In this case, the loop division coefficient equals one, and no phase noise degradation occurs. Moreover, one can further reduce PLL component residual noise impact by inserting a frequency multiplier into the feedback path instead of a divider as depicted in ***Figure 7***.

Multi-Loop Synthesizer Schemes

The main disadvantage of the simple frequency offset schemes is limited frequency coverage. Widening the output frequency bandwidth for a fixed offset frequency leads to a higher IF at the mixer output. This requires a divider with a larger division coefficient, thus defeating the idea of this method. The offset frequency signal should preferably be as close as possible to the RF output frequency in order to keep the division ratio at a minimum. This can be accomplished in multi-loop schemes by utilizing a wideband offset signal (see ***Figure 8***).

Use of a Mixer Chain in the Feedback Loop

A clever solution is to utilize a chain of mixers within PLL feedback path as illustrated in ***Figure 9***. Individual offset signals can be obtained from a common high frequency variable reference using dividers and/or multipliers. In this case mixer intermodulation products coincide with phase detector comparison frequency harmonics and thus can be easily filtered out by a loop filter.[22]

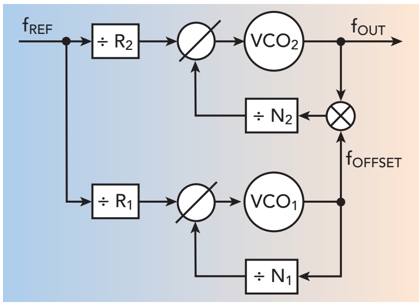
DIRECT SYNTHESIS

Direct Analog Synthesizer

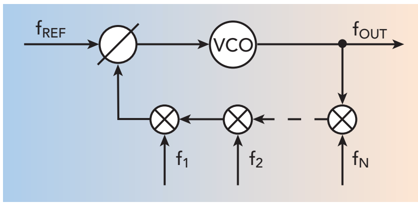
Direct analog synthesis is a totally different ball game. As the name suggests, the desired signal is created directly (i.e., without regeneration) by mixing base frequencies followed by switched filters, as conceptually shown in ***Figure 10***. The base frequencies are normally obtained from a common reference by frequency multiplication, division and/or mixing. The key advantage of the direct analog technique is extremely fast switching speed, ranging from micro- to nanoseconds. Since direct analog synthesis assumes no closed loops, switching speed is limited only by propagation delays of the switches and their control circuits as well as filter settling.

Another distinct advantage is the ability to generate low phase noise due to use of components with negligibly low residual noise. Phase noise depends mainly on the noise of the available fixed-frequency sources and can potentially be very low. The main disadvantage is limited frequency coverage and step size. The number of output frequencies can be increased by using a higher number of base frequencies and/or mixer stages, however, this rapidly increases the design complexity and overall component count.

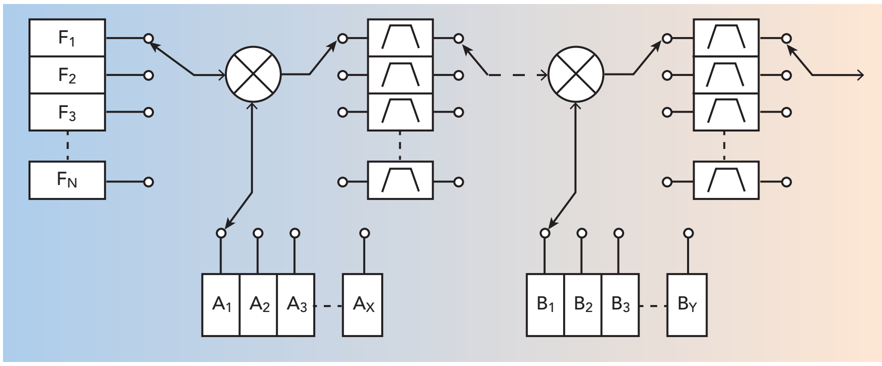
Another serious problem is the large amount of mixing products that must be filtered. These include the undesired mixer sideband, LO leakage and intermodulation prod-



▲ Fig. 8 Multi-loop synthesizer.



▲ Fig. 9 Mixer chain in the PLL feedback path.



▲ Fig. 10 Direct analog synthesizer.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ucts. Depending on a particular frequency plan, filtering close-in spurs can be a challenging task. This is a non-trivial consideration requiring certain design effort and careful frequency planning. Although a large variety of mixing and filtering schemes are possible, they tend to be hardware intensive if a small frequency step and wide coverage are required. Therefore, while direct analog synthesis offers excellent tuning speed and phase noise characteristics, its usage is limited to applications where fairly high cost can be tolerated.

Direct Digital Synthesizer

In contrast to traditional concepts, direct digital synthesizers utilize digital signal processing to construct an output signal waveform in the time domain piece-by-piece from a reference clock frequency. Initially a digital representation of a desired signal is created using a phase accumulator and lookup table (see ***Figure 11***). Then it is reconstructed with a digital-to-analog converter (DAC) to create a sinusoid or any other desired shape. The waveform construction process is completed with a lowpass filter to remove unwanted spurious components. This process is extremely fast, limited mainly by the speed of the digital control logic. This results in very high switching speeds, comparable with direct analog schemes. The DDS also provides reasonably low phase noise even showing an improvement (limited by its residual noise floor) over the phase noise of the clock source itself. The most valuable DDS feature, however, is its exceptionally fine frequency resolution determined by the length of the phase accumulator; sub-Hz levels are easily achieved.

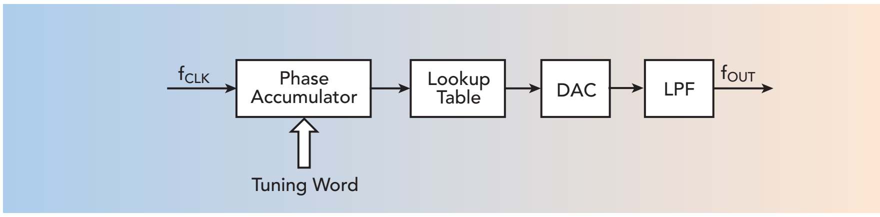

Fig. 11 Direct digital synthesizer.

The main disadvantage is limited usable bandwidth. While DDS starts working from nearly DC, its highest frequency is limited by the Nyquist criteria to one half of the clock frequency. Working in higher Nyquist zones is possible, however, performance degrades very quickly. Another serious problem is a relatively high spurious content due to a number of factors inherent in the DDS technique, such as bit truncation, quantization and DAC conversion errors.

DDSs are available as specialized fully-integrated chips or can be built using separate field programmable gate array (FPGA) and DAC ICs. The latter allows constraining the digital part within FPGA, thus, isolating its EMI-induced spurs. Today's FPGAs have sufficient capacity to build quite complex multicore phase accumulators and lookup tables with negligible spur levels due to bit truncation. As a result, the major spur sources are normally on the DAC side due to its nonlinearities and quantization noise. DAC-free solutions are also possible (for example, using digital-to-time conversion)[23], although, they are currently not common.

Until recently, the DDS technique was rarely used alone at microwave frequencies. However, the rapid development of high frequency ICs enables DDSs working directly at microwave frequencies with quite impressive characteristics such as microhertz resolution, nanoseconds-range switching speed and built-in modulation. The extension of DDS usable bandwidth (together with its spur content reduction) is the key improvement required by the industry.

EVOLUTION AND FUTURE PROJECTIONS

A synthesizer is traditionally expected to generate a continuous wave signal within its operating frequency range. Its amplitude may vary with frequency within

certain limits. However, newer designs bring more functionality such as amplitude leveling and control. The output level can be calibrated and controlled using either open-loop (lookup table) or more sophisticated close-loop automatic level control (ALC) schemes. Furthermore, these days the industry demands more complex waveforms ranging from traditional analog modulation (amplitude, frequency, phase and pulse) to complex vector formats such as IQ modulation. These modulation capabilities together with amplitude control and harmonic rejection can now be built not only in bulky test and measurement signal generator boxes, but also in smaller form factor modules. Key performance characteristics (such as phase noise, spurs and switching speed) are approaching those of dedicated test and measurement signal generator solutions as well.

With respect to phase noise performance, synthesizer designers rely primarily on 100 MHz ovenized crystal oscillator (OCXO) technology. Today's commercial OCXOs achieve -170 to -176 dBc/Hz (and better) at 10 kHz offset and 100 MHz output. This can potentially translate to -130 or -136 dBc/Hz at 10 GHz assuming the synthesizer circuitry is "ideal." Although nothing is ideal, all current developments are striving for ideality. At low frequency offsets (100 Hz and below), a 10 MHz OCXO performs better. Furthermore, its short-term stability is also better compared to a 100 MHz oscillator. Hence, a synthesizer design usually provides the capability to lock its output to a 10 MHz reference. Similarly, high frequency oscillators (such as SAWs and DROs) perform better at high frequency offsets such as 100 kHz and above.[24-29] A combined reference source containing several oscillators locked to each other can be used to achieve the lowest phase noise profile at any frequency offset. Further improvements are possible through the use of higher-Q resonators such as sapphire-loaded cavities or optical methods.[30-33]

CONCLUSIONS

Overall, the indirect, VCO-based PLL synthesizer remains the most popular approach at the moment. Further improvements are expected through reduction of the PLL residual noise floor in order to support megahertz-range loop bandwidths. Fast switching speed (to several microseconds) and low phase noise (around -130 dBc/Hz at 10 kHz offset and 10 GHz output) are common goals for today's designs and those of the near future. Small form factor, extended functionality (such as built-in modulation and amplitude control) and low cost are design targets required by the industry.

The most exciting future developments, however, are likely to be associated with DDS technology, which has tremendous potential for growth. Much of the progress will be brought by extension of DDS usable bandwidth and reduction of its spurious content. Frequency multiplication and/or up-conversion is possible to bring available frequency bandwidth to mmWave frequencies and higher (although the native DDS bandwidth will constantly grow). At some point, direct synthesis is expected to compete with and eventually replace indirect designs by offering amazingly fast, nanosecond-range tuning speed as well as complex output waveforms.

Longer term major breakthroughs are expected in the design and operation of the reference utilizing other physical principles or materials. For example, phase noise around -170 dBc/Hz at 10 kHz offset and 10 GHz output for a sapphire-resonator-based oscillator has been reported.[34] These expectations will dramatically change conceptual approaches for building new synthesizers or even the whole way of thinking about the problem. What performance can be eventually achieved? Only the future will tell. A lot of amazing developments are expected in the coming decades. ■

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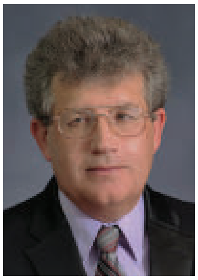

Alexander Chenakin *is vice president of Advanced Technologies at Micro Lambda Wireless Inc. in Fremont, California, where he oversees the development of advanced signal generator products. Dr. Chenakin previously held a range of technical and executive positions at Phase Matrix, National Instruments, Anritsu and other companies. He is well recognized in the field of frequency synthesis and is referred to as the inventor of QuickSyn technology. In 2009, he received ARMMS RF & Microwave Society's best contribution award for his work on fast switching frequency synthesizers.*

Dr. Chenakin's professional achievements have been widely presented in trade publications and international conferences. He has written more than 40 technical articles and holds two U.S. patents. In addition, Dr. Chenakin is the author of an Artech House published textbook about frequency synthesizers. He is a senior IEEE member and has been an invited speaker at several IEEE-sponsored events.

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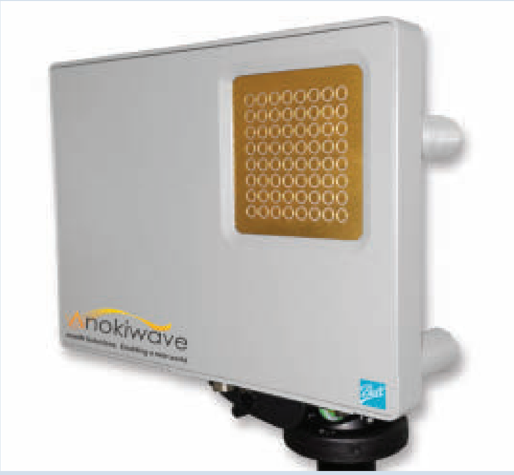

28 GHz Active Array Antenna Enables Rapid 5G Prototyping

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As the telecommunications industry rapidly migrates to the new 5G standard, we can expect unprecedented data speeds, low latency and high reliability communication. To support these advancements, millimeter wave frequency bands are being made available on a global scale for 5G base stations, backhauls, fronthauls and customer premises equipment. The wide contiguous bandwidths available at these newly assigned frequencies enable high data rates. Additionally, the associated short wavelengths allow physically compact electronic steerable (active) antennas to be deployed that offer spatial diversity, spectrum reuse and high antenna directivity (gain) to overcome the higher path loss encountered at millimeter wave frequencies.

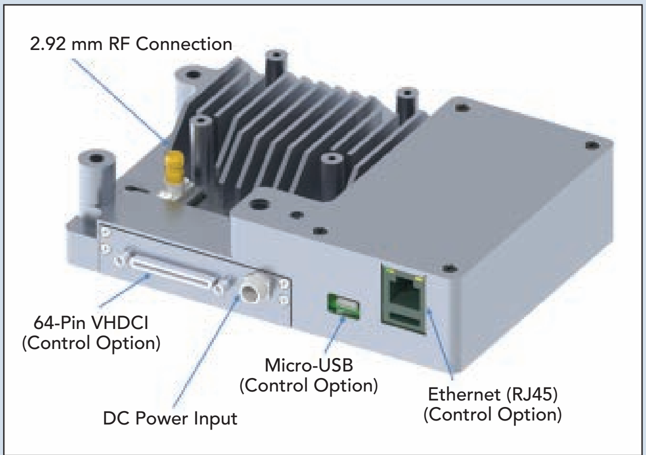


Fig. 1 Control and signal interfaces on the rear panel of the AWMF-0129.

The aerospace and defense industries have been manufacturing active antennas for decades, so the expertise needed for 5G solutions is not new. What is new, and what is now fueling the migration of these types of antennas to the commercial sector, are the advancements in high frequency silicon semiconductors, an IC technology that combines the required beam steering functions—vector (amplitude and phase) modulation and digital interfaces—with the traditional transmit/receive functions, all implemented in highly compact ICs that enable the fabrication of planar antennas, a requirement for cost-effective assembly. Only using silicon in

these active antennas has driven the cost of these antennas down by orders of magnitude, making them suitable for high volume, mass deployment systems like 5G infrastructure.

28 GHz ACTIVE ANTENNA FOR 5G

Anokiwave has developed beam steering ICs for active antennas for more than a decade and recently announced the AWMF-0129, the world's first commercially available active antenna specifically designed for 5G infrastructure. Developed in collaboration with Ball Aerospace, the AWMF-0129 is a 64-element, single polarization 5G, rapid prototype phased array antenna designed to cover the 27.5 to 30 GHz frequency band. A planar antenna, it can be used either as a stand-alone component or combined and synchronized with other arrays to support hybrid beamforming and multiple-input-multiple-output (MIMO) functionality as part of a larger array.

To support 5G beam acquisition and various channel needs, the rapid prototype array supports and provides multiple beamwidths. A wide beam is available to support channel state information measurements, search modes and broadcast channels. Multiple progressively narrower beams can be used for beam acquisition. The narrowest beams allow for interference mitigation, optimizing the signal to noise ratio (SNR), maximizing equivalent isotropically radiated power (EIRP) and range extension. A two-dimensional scan volume of ±60° in both azimuth and elevation is supported. As this is a time-division duplex (TDD) system, the array operates in a half-duplex mode, enabling the same antenna to support both transmit and receive, with distinct transmit and receive beam settings if required.

The array also includes pre-stored beam states that, once loaded, can quickly be accessed in a beam acquisition protocol—an essential specification for any 5G radio physical interface. Each beam state is accessible in under 100 ns, meaning that the beam position of the entire array can be redirected in approximately 10 µs. The embedded digital controller receives a desired "look vector" (beam position coordinates in azimuth and elevation), calculates the required vector modulator settings at each element in the array and communicates with the silicon ICs to steer the beam within the allotted time slot. Completion of this entire operation within a sub-symbol interval (T_s = 13.33 µs) is a critical specification for the low latency requirements of proposed 5G radio systems.

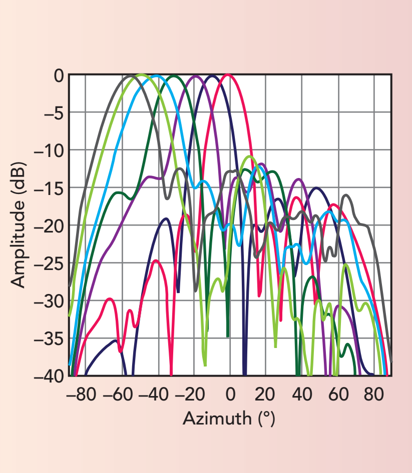
The array specifies an EIRP of greater than +50 dBmi and a G/T—a measure of the noise sensitivity of the antenna—of greater than -8 dB/K at boresight. As green electronics becomes an increasingly high profile consideration, the overall energy efficiency of an array becomes more important. The two key figures of merit for an active antenna are the ratio of EIRP to total DC power dissipation (including all amplification and vector generation, digital controllers, signal telemetry and DC-DC conversion) and the G/T to effective aperture ratio, which is a measure of the noise performance of the array as a function of the effective aperture size. By careful architecture choice and minimizing front-end losses, the AWMF-0129 exceeds other competing approaches and technologies in these two key ratios.

Other features of the array include temperature compensated gain with full

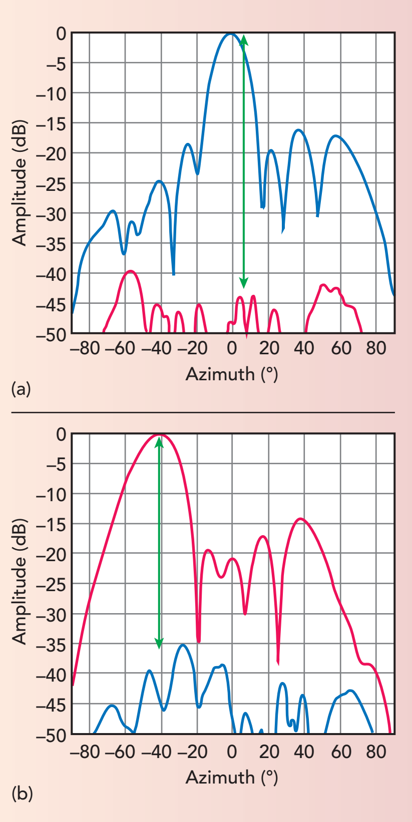
array temperature mapping, temperature sense telemetry and transmit output power measurement at each antenna element reported back to the host system as telemetry. Remote monitoring and control of each antenna with real-time operational data allows for greater flexibility. The active array can be controlled through several interface options, allowing the array to be synchronized with the timing and data requirements of the baseband modem or with other antennas. The interface options are either Ethernet, USB or high speed control low voltage differential signaling (LVDS).

The array measures 10.8 cm × 15.4 cm × 3.12 cm and weighs 500 g. It can be powered from either +12 or +18 V and consumes less than 25 W of DC power which includes the embedded controller for beam steering and array control. ***Figure 1*** shows the rear panel of the array, illustrating the interface ports and array mounting connections.

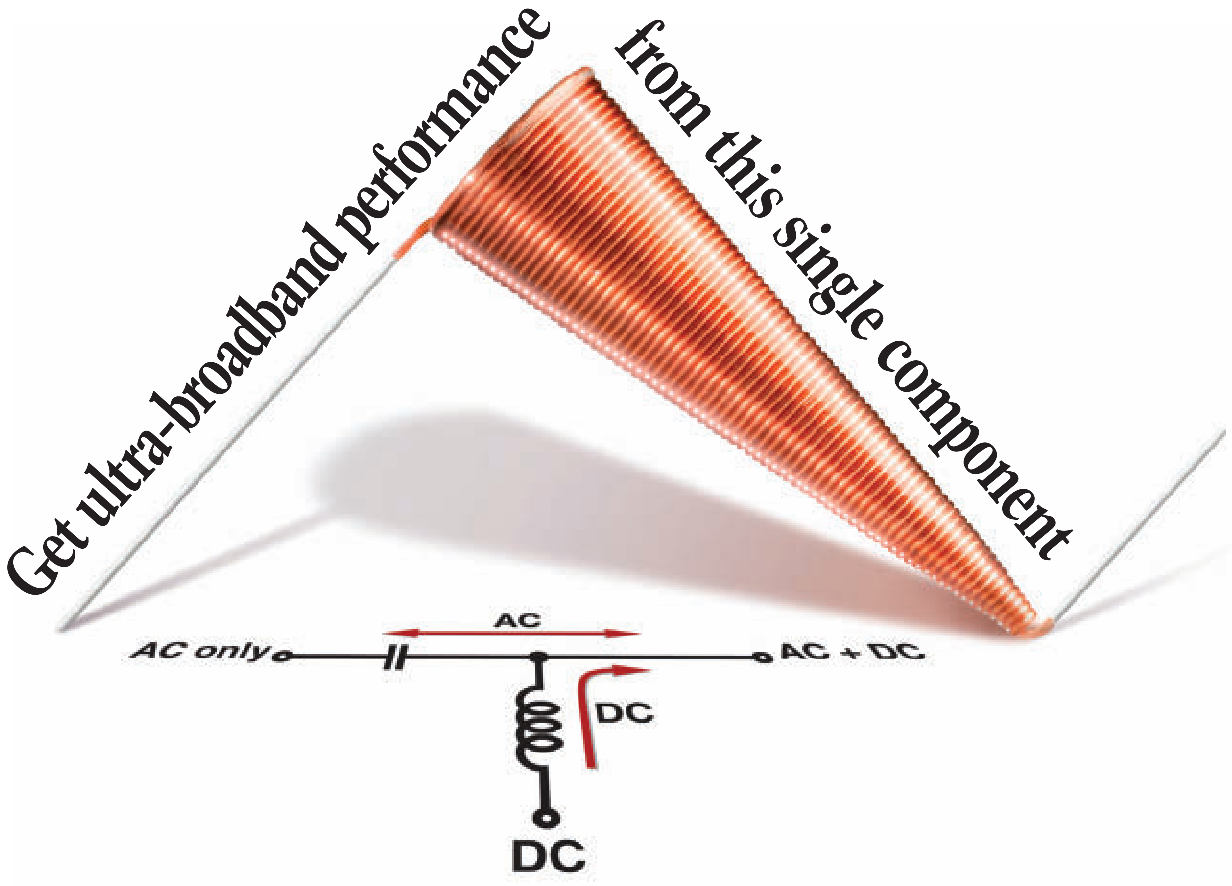
The RF signal interface to the array is directly at the carrier frequency of the physical air interface. This provides an extra degree of flexibility, allowing use in a conventional test setup with external test equipment for channel characterization, evaluation of over-the-air modulated waveform statistics or integration with specific up- and down-conversion blocks for spectral emission evaluation. One of the key challenges with 5G radio development is understanding how frequency



▲ Fig. 2 Receive patterns with the array scanned from 0 to 60°.



▲ Fig. 3 Cross-polarization performance with the receive at boresight (a) and 40° θ (b).



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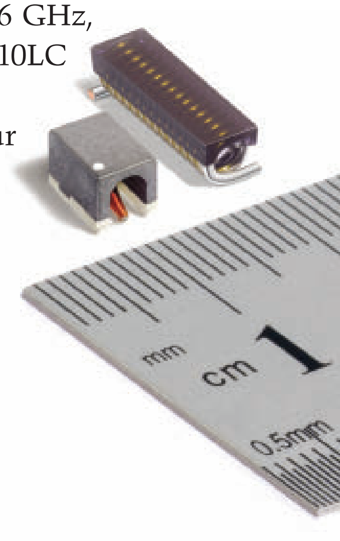

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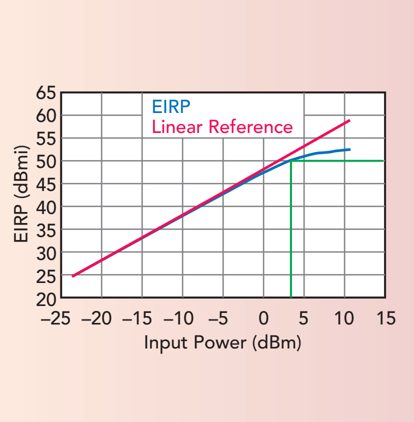

▲ Fig. 4 Measured transmit EIRP vs. input drive. The EIRP at 1 dB compression is ≥50 dBmi.

planning and signal characteristics will impact adjacent channel leakage ratio (ACLR) and spectral mask requirements for out-of-band spurious signals. Direct signal injection and reception at the RF carrier frequency allows the user to perform optimization and evaluation of frequency conversion proposals.

ARRAY PERFORMANCE

Figure 2 shows the far-field antenna pattern of the array in receive mode for scan angles from 0 to 60°. The patterns are well behaved with good sidelobe levels. Co-polarization and cross-polarization antenna patterns of the array in receive mode at both boresight and 40° θ scan are shown in ***Figure 3***. Excellent cross-polarization is observed under both scan conditions, with measured isolation between the polarizations greater than 35 dB. The measured transmit EIRP of the AWMF-0129 achieves ≥50 dBmi at 1 dB compression (see ***Figure 4***).

The AWMF-0129 is the world's first commercially available electronically scanned active array available for fast prototyping and evaluation of millimeter wave environments for 5G applications. Based on highly integrated Si technology that includes embedded functions for remote telemetry and low latency fast beam steering of the entire array, the AWMF-0129 enables real-time active beam steering. By providing full flexibility in the choice of waveform stimulus and timing control, the array is an enabling technology to evaluate and develop multiple products.

VENDORVIEW

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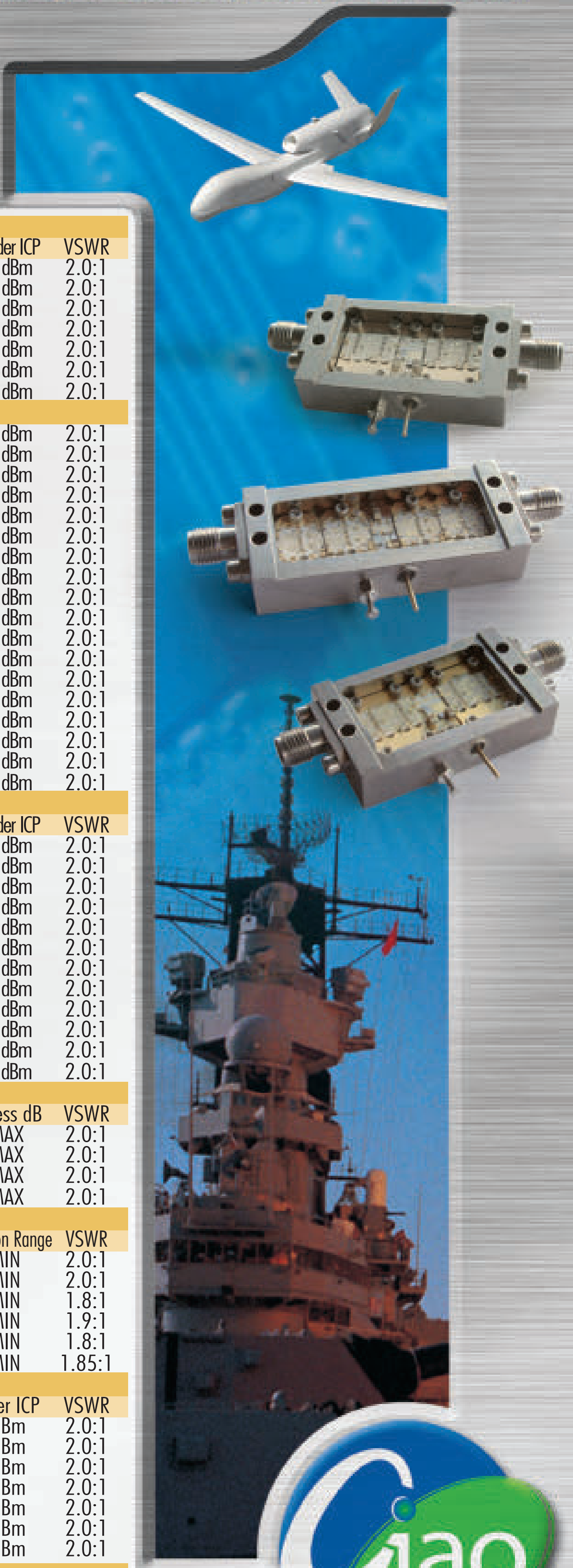

OCTAVE BAND LOW NOISE AMPLIFIERS

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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DARPA Selects SSL for Revolutionary Goal of Servicing Satellites in GEO

In an important step toward a new era of advanced, cost-effective robotic capabilities in space, DARPA announced it has selected Space Systems Loral (SSL), based in Palo Alto, Calif., as its commercial partner for the Agency's Robotic Servicing of Geosynchronous Satellites (RSGS) program. DARPA and SSL seek to develop technologies that would enable cooperative inspection and servicing of satellites in geosynchronous orbit (GEO), more than 20,000 miles above the Earth, and demonstrate those technologies on-orbit. If successful, this research and demonstration effort would open the door to radically lowering the risks and costs of operating in GEO, a harsh and difficult-to-access domain that is critically important for both military and civilian space assets.

Under an agreement drafted jointly by DARPA and SSL, the two entities would share costs and responsibilities for the program. While such public-private partnerships have become common in several domains of research and development—saving taxpayer dollars by requiring commercial partners to invest significantly in projects rather than simply receive government funding—the RSGS public-private effort would be a first for DARPA in the space-servicing domain. As such, the Agency's selection of SSL and the pending agreement have been submitted for review by the Defense Department's Under Secretary of Defense for Acquisition, Technology and Logistics.

With RSGS, DARPA plans to develop a robotic module, including hardware and software, and provide technical expertise and a Government-funded launch. SSL would provide a spacecraft and would be responsible for integrating the module onto it to create a robotic servicing vehicle (RSV) and the RSV onto the launch vehicle, as well as providing a mission operations center and staff.

After a successful on-orbit demonstration of the RSV, SSL would operate the vehicle and make cooperative servicing available to both military and commercial GEO satellite owners on a fee-for-service basis. In exchange for providing property to SSL, the Government would obtain reduced-priced servicing of its satellites and access to commercial satellite servicing data throughout the operational life of the RSV, again at great taxpayer savings. The capabilities that RSGS aims to make possible include:


DARPA Image

- High-resolution inspection
- Correction of some mechanical anomalies, such as solar array and antenna deployment malfunctions
- Assistance with relocation and orbital maneuvers
- Installation of attachable payloads, enabling upgrades or entirely new capabilities for existing assets
- Refueling

In parallel with the RSGS partnership, DARPA also intends to provide the Government-developed space robotics technology to other interested U.S. space corporations. Qualified companies would be able to obtain and license the technology through cooperative research and development agreements.

Separately, to help ensure the long-term sustainability of RSGS and other future space operations—and provide the foundation for a new commercial repertoire of robust space-based capabilities—DARPA recently solicited research to develop and publish consensus operational safety standards for on-orbit rendezvous and proximity operations (RPO) and robotic servicing operations. The awardee would establish and manage the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), which would include both private sector and government technical experts.

Through CONFERS, DARPA aims to establish an industry/government forum composed of experts from throughout the space community. The forum would develop non-binding, consensus-derived technical and safety standards for on-orbit servicing operations, and help create definitions and expectations of responsible behavior in outer space.

Hughes Selected for GA-ASI "Type-Certifiable" Predator B RPA Platform

Hughes Network Systems recently announced that its Defense and Intelligence and Systems Division (DISD) has been awarded a contract by General Atomics Aeronautical Systems Inc. (GA-ASI) to work with the company to provide satellite communications on the "Type-Certifiable" Predator® B (TCPB) Remotely Piloted Aircraft (RPA) system, which provides the basis for the UK's Protector programme. A variant of the proven multi-mission Predator B, the new SkyGuardian™ aircraft will provide a next-generation capability, integrating enhanced safety and reliability systems that will enable RPA flight within civilian airspace, along with an increased payload capacity that will support a wide variety of mission sets.

Working with GA-ASI, Hughes is upgrading the aircraft's satellite communications system with customized

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airborne Hughes HM series modems. The advanced modems will enable a significant increase in data transfer rates, employing an enhanced waveform that ensures resilient and secure communications when operating in challenging environments.

The new aircraft is designed to be compliant with NATO and UK airworthiness requirements, supporting easy integration into segregated and non-segregated civil airspace operations around the world.

Raytheon Demos First Ever Geolocation Capability for Radar Warning Receiver

Raytheon Co. demonstrated, in a recent flight test, single-ship geolocation capability for the ALR-69A(V), a first for any radar warning receiver. The AN/ALR-69A(V)—the world's first all-digital radar warning receiver—enhances aircrew survivability, providing "sensors forward" situational awareness at lower costs than competing systems through simple software modifications.

"Adding single-ship geolocation capability to a radar warning receiver transforms the way pilots execute their missions," said Paul Overstreet, ALR-69A program manager, Raytheon Space and Airborne Systems. "The ALR-69A can now assist with targeting solutions while continuing to identify threats in dense signal environments."

Geolocation capabilities offer aircrews more options, allowing pilots to decide whether to maneuver to avoid the threat or to prosecute it. Before this added geolocation capability, aircrews only had an approximate direction of the arrival of the threat signals. The ALR-69A(V) now provides aircrews precise information on ground-based threat locations and precision-direction finding for airborne threats.

> Single-ship geolocation enhances aircrew survivability.

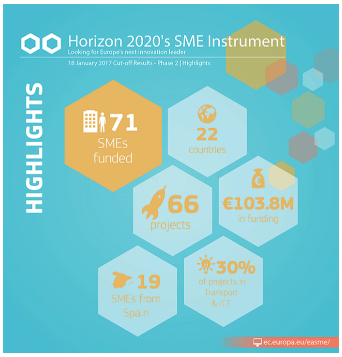
About the ALR-69A(V)

The ALR-69A(V) provides improved detection range and accurate, unambiguous identification in dense signal environments comprised of both threat signals and those from wingmen, coalition partners and commercial operations. Its 360° coverage is provided by four independent Radar Receivers, each covering one quadrant of the aircraft. Raytheon designed the ALR-69A(V) for the utmost in flexibility and growth potential. The modular, open architecture relies on many commercial off-the-shelf (COTS) components that allow for ready expansion or upgrade. The ALR-69A(V) is installed on the U.S. Air Force C-130H, KC-46A and is being tested on the F-16.

European Commission Invest Almost €104 million in SMEs

There are 71 small and medium-sized companies (SME) from 22 countries that have been selected for funding in the latest round of the Horizon 2020 SME Instrument Phase 2. The total amount to be distributed between the SMEs working on 66 projects is €103.82 million. In this phase of the instrument, each project will receive up to €2.5 million to finance innovation activities.

Spanish SMEs were the most successful with 19 companies selected for funding. They were followed by five companies from both Germany and Ireland.



Most projects are in the field of ICT and transport (10 projects each) followed by nine projects in the field of low-carbon and energy efficient systems.

Funding under Phase 2 of the instrument allows companies to invest in innovation activities such as demonstration, testing, piloting, scaling up and miniaturisation, in addition to developing a mature business plan for their product. The companies will also benefit from 12 days of business coaching. Most projects are proposed by a single SME but some companies team-up to elaborate a project.

The European Commission received 1534 project proposals by 18 January 2017, the first cut-off date for Phase 2 in 2017. Since the launch of the programme on 1 January 2014, 641 SMEs have been selected for funding under Phase 2.

Research Programme to Improve Military Communication Systems

Plextek has been appointed by the UK Government's Defence Science and Technology Laboratory (Dstl) to lead the £2 million, four-year Adaptive Communications Transmission Interface (ACTI) research programme.

Under the ACTI programme, the company will lead a team of specialists and experts from academia, to investigate cross-layer processing as a way of enabling Mobile Ad-Hoc Network (MANET) radio systems to utilise directional antenna techniques. An important goal of the programme is to create disruptive technologies that will improve the quality, reliability, data rates and range of military communications systems.

The techniques that have been applied to achieve ad-hoc (infrastructure-less) connections and dynamic routing have been studied for many years under the general banner of MANET. However, the MANET 'multi-hop' approach has so far not delivered the anticipated step change in wireless system performance. Through the use of novel directional antennas, the ACTI programme will address the complex underlying causes of this, including link range and interference within the network by message forwarding. Cross-layer processing techniques will be developed to tackle the difficulties in allocating radio resource at the MAC layer, the complexity of dynamic routing in a mobile scenario and the needs of the IP layers.

> "...operational advantage to our military forces."

A Dstl spokesperson commented: "The ACTI research programme will explore the theory that current systems can benefit from the use of directional antennas. Over the next four years, Plextek, along with its partners, will be developing innovative MANET protocol stack and antenna technology that aims to demonstrate the benefits envisaged."

Peter Doig, Business Manager, Defence at Plextek: "With this research programme we'll be doing some pioneering work on MANET architectures that include directional, steerable antennas which have the potential to tackle some of the underlying matters that have hampered multi-hop MANET networks, with a view to enabling the next generation of military ad-hoc radios to provide an operational advantage to our military forces."

SPYGLASS Project Focuses on PBR/Galileo Combination

The €1.3 million European SPYGLASS (Galileo-based Passive Radar System for Maritime Surveillance) project is coming close to the validation of a prototype of Passive Bistatic Radar (PBR) technology based on Galileo transmissions. Once finalised, the new system could help relevant authorities to assure better maritime surveillance, detection and localisation, even of non-indexed ships.

The SPYGLASS technology uses a single receiver tuned in to Galileo frequencies. The receiver can be installed on a buoy or on a tethered balloon to increase its area coverage. The receiver then records Galileo signals that naturally bounce off moving ships, and processes them to provide estimates of the ship's rela-

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> "...resolve the maritime safety issue..."

tive range and speed.

This technology is low cost, allows for covert operation and reduces environmental impact. If combined with Galileo and its constellation that guarantees constant coverage of any point on Earth by several satellites, PBR technology developed under SPYGLASS has the potential to resolve the maritime safety issue once and for all.

Maritime surveillance is one of the key applications where a fully operational Galileo constellation could truly make a difference, not only through its high precision but also by ensuring European independence in a sector that requires the resolving of Europe-specific challenges.

GSA Confirms LTE Exceeds 25% of Global Mobile Subscriptions

The Global mobile Suppliers Association (GSA) confirms that LTE subscriptions now account for 25.1% of all mobile subscriptions globally. Analysing the latest information, provided to GSA by Ovum, shows growth of 818 million new LTE subscriptions in 2016 compared to 596 million in 2015. LTE and WCDMA are now the only mobile technologies that are growing in subscriptions, although WCDMA subscriptions are experiencing slowing growth. By the end of 2016, LTE subscriptions, according to Ovum data, stood at 1,920 billion compared to 1,102 billion in December 2015.

> "...a true mobile broadband customer experience."

The Asia region continues to lead LTE adoption with 59.1% market share although this market share is likely to be impacted in 2017 by accelerating LTE adoption in other regions, especially in the Middle East (LTE subscriptions growing at 166% Year on Year), Eastern Europe (132% Year on Year) as well as Africa and Latin America and the Caribbean (120% Year on Year).

Joe Barrett, President of GSA, said, "Over the past year LTE subscriptions have grown substantially and we are now seeing all regions moving swiftly to adopt LTE as their primary mobile technology to deliver a true mobile broadband customer experience. GSA continues to predict that LTE, LTE-Advanced and LTE-Advanced Pro subscriptions will overtake 3G/WCDMA-HSPA in 2019."

Worldwide Fixed Wireless Households to Surge Past 150 Million

Exponential growth of 4G LTE coverage and capacity is driving wireless service growth for fixed broadband access, while fiber-to-the-home (FTTH), xDSL and cable technologies reach nearly 50 percent of global households. As 5G standardization approaches completion, the technology will significantly accelerate global fixed wireless deployments. ABI Research forecasts worldwide fixed wireless broadband subscribers will grow at a 30 percent CAGR to top 151 million in 2022.

"The arrival of 5G technology will completely transform fixed wireless broadband network deployments," says Khin Sandi Lynn, industry analyst. "Trials show that the technology's superior performance over LTE will allow operators to deploy 5G for fixed wireless broadband service in densely populated areas."

Currently, fixed LTE broadband access is mainly deployed in remote areas where fixed line infrastructure is poor and it is not commercially feasible to deploy fixed networks. While government initiatives, high data transfer rates, and a large capacity are all attractive features for fixed LTE deployments now, fixed wireless broadband deployments will be further accelerated by their 5G successor in the years ahead.

> 5G technology will significantly accelerate global fixed wireless deployments.

United States operators AT&T and Verizon already announced plans to deliver broadband access to businesses and residential customers using 5G fixed wireless networks. The companies aim to begin 5G fixed wireless rollouts later this year.

"Superior capacity offered by 5G technology will benefit operators to deploy fixed wireless access in densely populated areas," concludes Lynn. "This will enable fiber-like broadband service to support bandwidth-hungry applications without the need to install fiber-optic cables to each premise."

22 Mobile Companies Propose Accelerating 5G Standards

On the eve of the 2017 Mobile World Congress, 22 mobile communications companies announced collective support for accelerating the 5G new radio (NR) standardization schedule to enable large-scale trials and deployments as early as 2019. The firms are supporting a proposal for the first phase of the 5G NR specification.

The companies comprising the consortium are AT&T, British Telecom, Deutsche Telekom, Ericsson, Etisalat Group, Huawei, Intel, KDDI, Korea Telecom, LG Electronics, LG Uplus, NTT DOCOMO, Qualcomm Technologies, SK Telecom, Sprint, Swisscom, Telia Company, Telstra, TIM, Vivo, Vodafone and ZTE.

The first 3GPP 5G NR specification will be part of Release 15, the global 5G standard that will use both sub-6 GHz and millimeter wave spectrum. Based on the current 3GPP Release 15 timeline, the earliest 5G NR deployments based on standard-compliant 5G NR infrastructure and devices will likely be in 2020.

> 5G NR would enable large-scale trials and deployments starting in 2019.

The companies propose an intermediate milestone for completing the specification for a configuration called "non-standalone 5G NR," which would enable large-scale trials and deployments starting in 2019. The non-standalone 5G NR specification will use the existing LTE radio and evolved packet core network for mobility management and coverage and add a new 5G radio access carrier to enable certain 5G use cases starting in 2019.

The new proposal and intermediate milestone reaffirms the schedule for the complete standard, including the standalone 5G NR in Release 15.

The companies state they are committed to make forward compatibility a key design principle for the standardization of the first release of 5G NR. This will enable in-band introduction of new capabilities and features in subsequent releases, which will allow unidentified industries and use cases and support the 5G vision to connect everything to everything. According to the companies, the non-standalone 5G NR proposal is consistent with 3GPP's commitment to a flexible evolution and interworking of the radio access network towards 5G NR and the evolution of the core network towards 5G.

RTLS and Asset Tracking Technologies to Catalyze Next-Gen Fleet Telematics, Retail and Manufacturing Solutions

The potential surrounding next-generation RTLS and asset tracking technologies will move from proof of concept to full scale deployments in 2017, laying the foundation for a break out year in 2018.

ABI Research is beginning to see BLE beacon and other next-generation RTLS and asset tracking technology deployments in the transport and logistics, healthcare, retail, manufacturing and commercial buildings verticals. The low-cost, high-accuracy combination is creating new opportunities in applications like pallet tracking, condition monitoring, last mile delivery, inventory, and tools/asset tracking. Beacons, which are also well-suited for consumer asset tracking, will continue to accelerate significantly in 2017 and 2018, as large beacon networks help catalyze the critical end user population.

With a growing number of start-ups having strong IPs infiltrating the market landscape, industry incumbents need to understand who they should collaborate with and what new technology initiatives will start to take form. HID Global recently acquired high-accuracy start-up Bluvision, and Cisco invested in MIST Systems. ABI Research expects to see more investments, partnerships, and acquisitions over the next two years.

While active RFID is starting to look outdated and expensive in comparison to new technologies, passive RFID remains the dominant entity in the RTLS and asset tracking market, particularly with retail migrating to in-store item level tracking. This was a big trend at NRF this year, with Zebra launching its new SmartSense technology, while Intel demonstrated its new Retail Sensor Platform. Though the industry is still three to four years away from passive BLE, startups are working on the problem.

Military Demand for Commercial Satellite Communications Capacity Stabilizing

According to Euroconsult, SatCom military demand for commercial satellite capacity has fallen by an estimated 20 percent from a peak of 12.5 GHz in 2011 following tremendous growth over the previous decade, due in large part to lower usage by the U.S. DoD.

Looking forward, heightened global instability and security concerns are translating into prospects for an acceleration in defense spending globally, presenting opportunities through modernization of communications systems aboard military assets. Launches of next generation commercial satellites and procurements of next generation military satellite systems in the 2020-2022 time-frame represent potential game-changers for the milsatcom ecosystem.

"While military satcom requirements still carry a relatively high degree of uncertainty, these developments could combine to see satellite capacity demand in the segment surge by upwards of 60 percent over the coming decade," said Brent Prokosh, senior consultant. "Bottom-up analysis of fundamental demand drivers within leading military application segments reveals positive signs looking forward."

Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Gowanda Components Group (GCG) announced that its capabilities for the design and manufacture of RF and microwave filters are expanding in connection with the acquisition of **Microwave Circuits** from AMTI in Lynchburg, Va. Terms of the deal were not disclosed but GCG has stated that Microwave Circuits' production facilities will remain in Beltsville, Md., and sales and technical support will remain in Lynchburg. This is the fifth acquisition for GCG within the last five years.

COLLABORATIONS

Rohde & Schwarz mobile network testing, powered by **SwissQual**, and **Samsung** have signed an agreement effective immediately that allows access to the RF trace information on Samsung's flagship mobile devices. This enables Rohde & Schwarz mobile network testing to continue to offer commercially available firmware in the future when integrating the latest commercial phones into their benchmarking, optimization and monitoring solutions. Thanks to the agreement, all products from Rohde & Schwarz mobile network testing will be able to support all the latest Samsung devices, enabling customers to continue to receive measurement results that reflect the real end-user behavior and perception.

Keysight Technologies Inc. announced that it is collaborating with **ZTE** to assist them in the test and measurement of critical 5G key technologies, including mmWave communications, new PHY, Massive MIMO and BTS beamforming prototypes. Keysight will help ZTE accelerate 5G product time to market by providing industry-leading products and solutions, for example, UXA mmWave signal analyzers, AXIe modular ultra-broad bandwidth signal generation and analysis systems, and system level prototype solutions. ZTE is a world leading comprehensive telecommunication solution provider as well as a proactive participant and contributor of 5G communications.

National Instruments, **University of Bristol**, **Lund University**, and one of the world's leading providers of communications services, **BT**, announced a collaboration on Massive MIMO trials for next generation, highly efficient 5G wireless connectivity. Massive MIMO is a crucial component of future networks, and this partnership is helping 5G become more of a reality through indoor and outdoor testing—which is huge, given the industry's desire to prove 5G technology can work in a real-world environment. As lead users, both Lund University and the University of Bristol worked closely with NI to implement, test and debug this framework prior to its product release.

NEW STARTS

GLOBALFOUNDRIES (GF) announced plans to expand its global manufacturing footprint in response to growing customer demand for its comprehensive and differentiated technology portfolio. The company is investing in its existing leading-edge fabs in the United States and Germany, expanding its footprint in China with a fab in Chengdu, and adding capacity for mainstream technologies in Singapore. In the United States, GF plans to expand 14 nm FinFET capacity by an additional 20 percent at its Fab 8 facility in New York, with the new production capabilities to come online in the beginning of 2018.

Bird continues to set the industry standard in RF communications with its latest response to the growing requirements worldwide for integrated systems. In January 2017, Bird aligned its entire array of products under the Bird brand. The company started the year with a keen focus on marketing all of its products under the Bird brand as the reliable, trusted and recognizable choice for customers. The branding move capitalizes on the momentum that has ensued over the past 75 years since J. Raymond Bird founded the company and jump started the RF communications industry.

Smiths Interconnect, a division of Smiths Group plc, announced it is unifying its technology brands of EMC Technology, Hypertac, IDI, Lorch, Millitech, RF Labs, Sabritec, TECOM and TRAK under the single brand identity of 'Smiths Interconnect'. This brand transition supports a recent strategic reorganization focused on creating a more agile structure that can better anticipate and respond to customers' evolving needs. Individually, the technology brands represent state-of-the-art solutions across the connectors, microwave components and microwave subsystems markets.

Aerospace Radar Technology is a new veteran-owned start-up radar company in Long Beach, Calif. They are registered with SAM, System for Award Management with the Federal Government and represent many years of high level experience in military and aerospace radar for surface, airborne and space borne applications. Their staff has been at the forefront of such programs as Navy point defense radar, very low grazing radar, terrain avoidance radar, autonomous vehicle radar, bistatic radar, space borne surveillance radar, BMDO (Ballistic Missile Defense Office) comparative radar performance study, launch range safety instrumentation and infrared remote sensing.

Quantum Microwave Components LLC, a company that manufactures and distributes components for the microwave industry, officially launched in December 2016. Under the leadership of president Andy Cobin, the company offers the industry's lowest noise figure LNAs from 300 MHz to 115 GHz. Two new mmWave LNAs just released include the V-Band 45 to 77 GHz with a NF of 1.8 dB and DC power of 1.8 V at 35 mA, and the W-Band 65 to 115 GHz with a NF of 3.2 dB and DC power of 1.5 V at 35 mA. Quantum Microwave

For More Information For up-to-date news briefs, visit mwjournal.com.

is located at 759 Chief Justice Cushing Highway, Suite 382, Cohasset, Mass., 02025, and can be reached at (857) 499-0071. Visit www.QuantumMicrowave.com to see their full line of products.

ACHIEVEMENTS

Qorvo®, a leading provider of innovative RF solutions that connect the world, has earned continued Trusted Source Category 1A accreditation through 2018 from the U.S. Department of Defense (DoD). The company is one of only five accredited suppliers for both gallium nitride (GaN) and gallium arsenide (GaAs).

Custom MMIC announced its most recent product releases have pushed their standard product portfolio over the 100 product mark. Custom MMIC is a leading developer of GaAs and GaN monolithic microwave integrated circuits (MMIC), serving the high performance and high reliability needs of military, space, aerospace and industrial applications.

Response Microwave Inc. (RMI), a global specialist in the supply, design and manufacture of RF/microwave connectivity and control component solutions, is celebrating its 15th year of business. With industry roots dating back to the 1980s, RMI has experienced consistent growth and created a reputation for high performance and quality products at fair and reasonable price levels. RMI thanks their loyal customer base for affording them the opportunity to support you, as well as their dedicated internal employees and field sales team for being an integral part of the company's success.

SemiGen Inc., an ISO and ITAR registered RF/microwave assembly, automated PCB manufacturing and RF supply center, has released a technical brief shedding light on the benefits to RF/microwave OEMs in partnering with a U.S.-based contract manufacturer. The electronics contract manufacturing industry has seen over 100 billion dollars of growth within five years, mostly due to an increased demand in filling the supply chain's gap. With design talent often burdened for assembly and test, OEMs can find themselves with little available resources.

imec, the world-leading research and innovation hub in nano-electronics and digital technologies, announced that their 200 mm gallium nitride-on-silicon (GaN-on-Si) e-mode power devices with a pGaN gate architecture showed no degradation after heavy ion and neutron irradiation. The irradiation tests were performed in collaboration with Thales Alenia Space, a leader in innovative space systems. The results demonstrate that imec's 200 mm GaN-on-Si platform delivers state-of-the-art GaN-based power devices for earth as well as for space applications. GaN-on-silicon transistors operate at higher voltages, frequencies and temperatures than their silicon counterparts. This makes them the ideal candidates for power conversion devices as they show less power losses in electricity conversion.

Around the **Circuit**

PEOPLE

▲ *Jim Hisert*

Indium Corp. has named **Jim Hisert** applications manager. Hisert is responsible for exploring and leveraging the use of indium in various forms and applications. He will use this information to identify new markets for existing products and identify new opportunities. Hisert has worked for Indium Corp. for over 10 years in various roles, including as an applications engineer and a manufacturing engineer. He has presented at industry organizations and technical seminars globally, and has authored technical papers on numerous topics, including thermal management, semiconductor-grade flux technology, solder materials testing and sputtering target bonding.

▲ *Cees Links*

Qorvo® announced that company executive **Cees Links** has been recognized for his significant contributions to the Wi-Fi industry with the prestigious Design News 2017 Golden Mousetrap Lifetime Achievement Award. Presented February 7th in Anaheim, Calif., the award honors an individual whose career has been devoted to innovation in the advanced design and manufacturing industry. Links, general manager of the Qorvo Wireless Connectivity business, is considered a pioneer in wireless data, advancing and integrating the worlds of mobile computing and continuous networking.

REP APPOINTMENTS

Southwest Microwave, a global leader in the development of high-performance millimeter wave and RF interconnect solutions, announced that **Interconn Technical Sales** is their new manufacturer's representative for Washington, Oregon and British Columbia. Headed by Alex Guletsky and Tom McKenna, with a combined 70 years of experience serving leading OEM T&M customers across all major markets including semiconductor, medical, military/aerospace and telecommunications, Interconn has a long history of providing highly-engineered connector, cable, cable assembly and electronic components solutions.

PLACES

Peregrine Semiconductor announced the opening of their new Austin, Texas development center. Now open, Peregrine's Austin office will accelerate the development of UltraCMOS® products for mobile applications including power amplifiers, low-noise amplifiers and switches. This new office is staffed with 13 experienced RF integrated circuit (RFIC) developers and is seeking candidates for further expansion. The Austin office will be led by 25-year industry veteran, David Bockelman. Most recently, David served as senior R&D manager at Avago Technologies/Broadcom and was previously the vice president of engineering at Javelin Semiconductor.

Pasternack, a U.S.-based supplier of RF, microwave and millimeter wave products, announced the opening of a customer fulfillment center in Suzhou, China to provide same day shipment of urgently needed products throughout China. The new fulfillment center allows Pasternack to better serve Chinese engineers and technical buyers by providing them immediate access to both industry standard and hard-to-find RF and microwave products, all backed by 24/7 support from a team of experienced RF engineers and technical experts. Up to 1,500 square meters of floor area has been dedicated to stocking the industry's largest offering of RF components and cable assemblies to ensure 99.4 percent in-stock availability.

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INVITED PAPER

An Alternative to Using MMICs for T/R Module Manufacture

John Walker, William Veitschegger, Richard Keshishian
Integra Technologies Inc., El Segundo, Calif.

Phased array radars have several advantages over conventional radars that use rotating antennas: phased arrays can transmit multiple beams simultaneously, place a null in the direction of a side-lobe jammer and can have a planar or conformal topology. Phased arrays can be one, two or three dimensional, but in every case they consist of an array of individual antenna elements with each element driven by a transmit/receive (T/R) module. In the simplest case of a passive phased array, the T/R module consists of just a cascade of a phase-shifter and an attenuator which are adjusted for each element to steer the beam, with a passive feed network connecting the T/R modules to a central transmitter and receiver.

However, the full benefits of a phased array radar are not realized in this case since the losses of the feed network, particularly for an array with many elements, significantly degrades the system noise figure and transmitter output power. For the best performance it is necessary to use a fully-active T/R module which has both a low noise and high power amplifier located inside it. Numerous different architectures have been proposed for a T/R module but ***Figure 1*** shows a basic generic one.

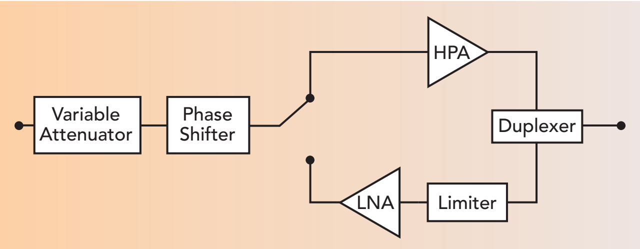


Fig. 1 Generic T/R module.

Until recently, most solid-state phased arrays have used GaAs MMICs for the high power amplifier (HPA), but the advent of GaN on SiC transistors and MMICs, with their higher efficiency and power output, means that most solid-state radars in the future will use GaN. However, there are two issues that need to be considered when using GaN on SiC in a T/R module, one economic and the other technical. Dealing with the economic issue first, GaN on SiC is more expensive than GaAs. This arises from the use of smaller substrate sizes (4" typically for GaN compared with 6" for GaAs), and because the substrate is SiC rather than GaAs. A large fraction of a GaN HPA MMIC real estate is occupied by the passive circuit elements rather than the active device, which exacerbates the cost issue. Various solutions to this problem have been proposed such as realizing all of the passive circuitry on separate GaAs substrates

and butt-joining them to the GaN transistor power bars.[1] At X-Band and above there really is no alternative to the use of either a pure GaN MMIC or a hybrid GaN/GaAs MMIC solution since the elements' size requirements cannot be greater than λ/2 apart (to prevent grating lobes),[2] which means that there is no space for any form of packaged device.

However, at S-Band and below it is possible to consider the use of packaged devices such as a conventional pre-matched GaN on SiC transistor or a transistor that is fully matched to 50 Ω inside the package. It is this latter solution which forms the focus of this article, and the economic benefits for the radar manufacturer will be shown.

The technical issue associated with using GaN on SiC transistors in T/R modules arises from the fact that they have a very high power density, which limits the VSWR withstand capability. A glance at the datasheet of any commercially available pulsed GaN on SiC transistor will quickly show that the VSWR withstand capability is typically in the 3:1 to 5:1 range, but it is well known that the T/R modules will see a poor VSWR at some beam directions due to mutual coupling[3] between the antenna elements. If a T/R switch is used as the duplexer in the T/R module then this poor VSWR will be applied directly to the GaN HPA less any improvement arising from the insertion loss of the T/R switch itself, and this can lead to HPA failure.

Using a three-port circulator, as the duplexer does not help much either since the limiter will reflect all of the power directly into the HPA, again less any improvement arising from the insertion loss of the circulator. It might be thought that the solution to this VSWR withstand problem is to use a balanced amplifier. While balanced amplifiers have several advantages such as presenting excellent input and output terminal VSWRs even when designed for lowest noise figure or maximum output power, it is readily shown[4] that they do not offer any improvement to the VSWR withstand capability. A solution to the poor VSWR withstand capability of GaN is to use a non-reflective limiter such as a four-port circulator.

TRANSISTORS MATCHED TO 50 Ω

Transistors that are fully matched to 50 Ω are 100 percent tested at full rated output power by the transistor manufacturer under the exact pulse length and duty cycle conditions that the radar requires. This is difficult if not impossible to do with MMICs using an RF-on-wafer probe tester when the power exceeds a few watts. Furthermore, fully matched transistors can be supplied in gain and phase matched blocks if required. Assembly costs are also reduced compared with using MMICs since only one assembly operation is required, namely solder attach of package and leads which can both be undertaken at the same time, whereas MMICs require solder die-attach first followed by wire bonding. T/R assembly yield is also higher since with MMICs the wire bonds form part of the matching network whereas in a 50 Ω transistor the matching is all contained within the package.

T/R assembly yield is also higher since tuning is eliminated compared with using pre-matched transistors. In effect, some of the assembly, tuning and manufacturing costs associated with producing a T/R module are passed from the T/R module manufacturer to the transistor

▲ Fig. 2 S-Band (3.1 to 3.5 GHz) 135 W GaN transistor internally matched to 50 Ω. Package size is 0.4" × 0.4".

manufacturer and this is reflected in a slightly higher price for a fully matched transistor compared with a standard pre-matched one. ***Figure 2*** shows an example of a 135 W S-Band transistor that is internally fully matched to 50 Ω.

Transistors fully matched to 50 Ω also have several other advantages compared to MMICs. For example, it is quick and easy to alter the frequency range or the power output of the device if required, whereas for a MMIC a new mask set is required followed by a new wafer fabrication, both of which make it expensive and time-consuming. The bond wires used as inductors in the matching networks have much higher Q than the distributed components used in MMICs, which results in less power loss and higher efficiency.

Another key advantage is that U.S. government export restrictions are much less severe for a 50 Ω transistor than a MMIC. For example, in S-Band radar applications in the 3.1 to 3.5 GHz band, the maximum power output for a MMIC is restricted to 40 W if an EAR99 classification is required, whereas for a 50 Ω transistor the limit is 115 W. Finally, although a packaged 50 Ω transistor is clearly larger than a bare MMIC, that disparity is largely eliminated when comparing packaged MMICs with a 50 Ω transistor. For comparison the 50 Ω transistor shown in Figure 2 measures 0.4" × 0.4" whereas a packaged MMIC such as Qorvo TGA2813-SM for the same frequency range has outside dimensions of 0.35" × 0.28". The MMIC part only delivers 100 W saturated output power whereas the 50 Ω transistor delivers 150 W saturated output power. Admittedly, the MMIC is a two-stage amplifier and so has more gain.

OPTIMUM LOAD IMPEDANCE

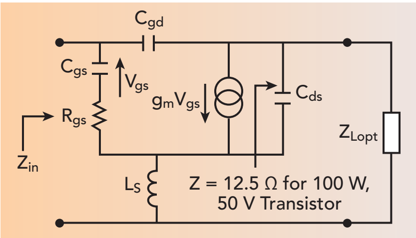
If 100 W per element is required in the phased array, then no matter whether a MMIC or discrete transistor is used for the HPA, the output device will require to see a resistive load of 12.5 Ω at the internal current generator plane based on standard load-line theory of $V^2/2P$ for a GaN device operating from a typical drain voltage of 50 V.[5] This is the load impedance that is required for maximum linear output power (i.e., no waveform clipping) for a transistor that has a constant value of g_m for all values of gate-source voltage above the threshold voltage.

The above analysis also assumes a transistor without any source inductance, feedback capacitance or output capacitance. Real transistors of course have all three elements present and this modifies the load impedance that must be connected to the transistor to achieve the same output power. An analytic expression has been derived[6] for the optimum load for a transistor with finite values for L_s, C_{gd} and C_{ds} and is given by:

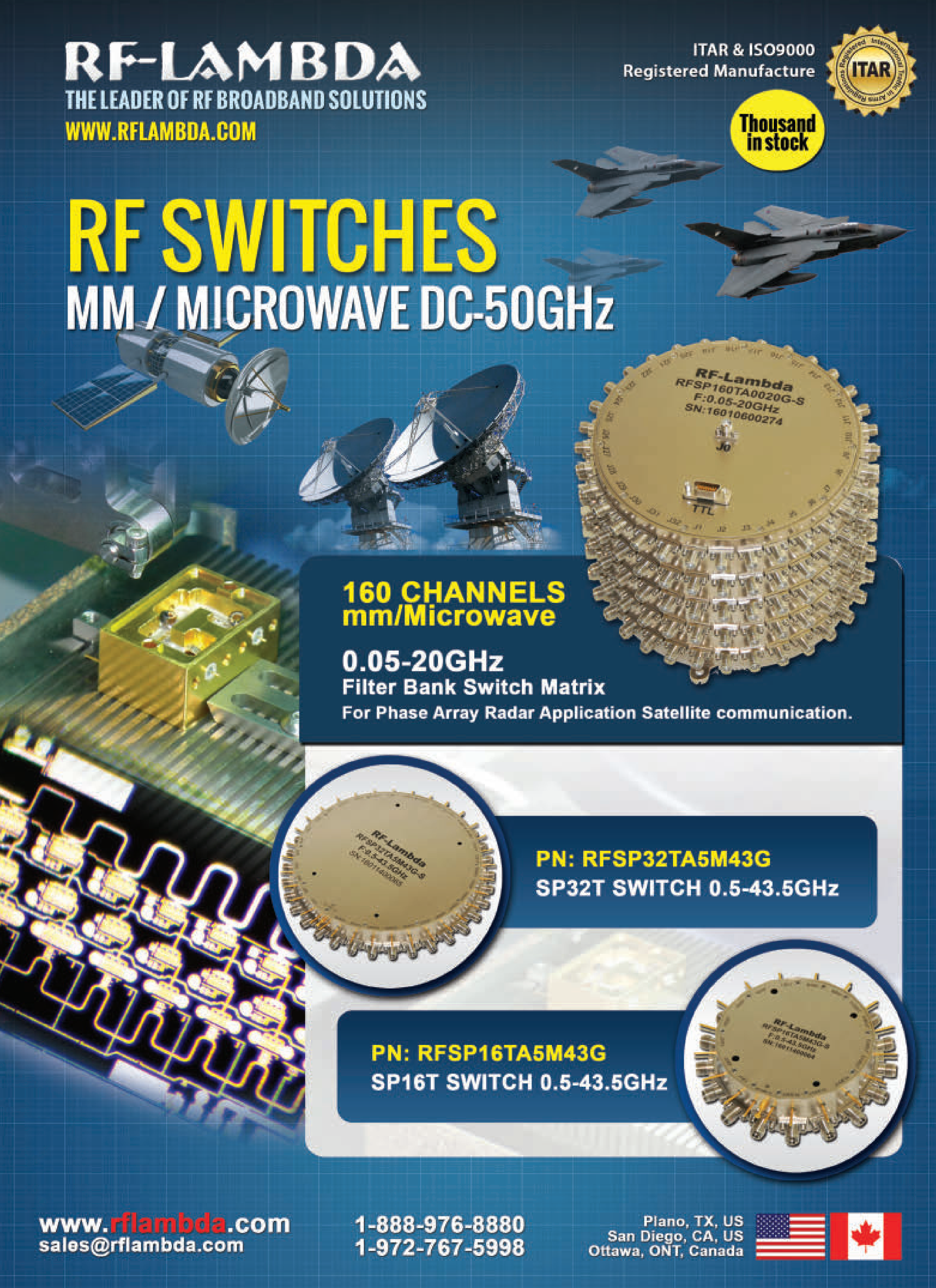
$$Z_{Lopt} = \frac{R_{Lopt} - \omega^2 L_s \left(R_{Lopt} C_{ds} - C_{gs}/g_m\right) - j\omega L_s}{1 - j\omega\left[C_{gd}/g_m + R_{Lopt}\left(C_{gd+Cds}\right)\right]} \qquad (1)$$

where R_{Lopt} is the value for optimum load impedance for the situation where L_s, C_{gd} and C_{ds} all have zero value, i.e., 12.5 Ω in this case. ***Figure 3*** shows a simplified equivalent circuit for a GaN transistor. The source of the transistor can be connected to ground with bond wires or via holes but, regardless of which method is used, the transistor will have a finite value of source inductance.

A 3D electromagnetic analysis was performed of the grounding structure for the transistor shown in Figure 2, which showed that L_s =0.03 nH. Even though 0.03 nH has a reactance of only 0.57 Ω at 3 GHz, it will be shown that this is the dominant effect controlling the value of the transistor's input impedance.



▲ **Fig. 3 Simplified equivalent circuit of a GaN transistor. For a 100 W, 50 V S-Band transistor, typical values are C_{gs} = 30 pF, C_{gd} = 1 pF, C_{ds} = 9.6 pF, g_m = 4 S, R_{gs} = 0.45 Ω, L_s = 0.03 nH.**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TechnicalFeature

Using the values for these elements given in Figure 3 then Z_{Lopt} at the drain terminal of the die is now a 10.7 Ω resistor in parallel with an inductance of 0.20 nH instead of just a pure 12.5 Ω resistor. Transforming the external 50 Ω load down to 12.5 or 10.7 Ω requires only a 4:1 impedance transformer, which is relatively easy to implement, the problem lies in trying to place a shunt inductor of value 0.20 nH immediately adjacent to the transistor die and the fact the package inherently forces a series inductance to be present in front of the 10.7 Ω load.

For these reasons transistor manufacturers normally work with a series load configuration with the first element being the inevitable series drain bond wire inductance. For the transistor being considered here then transforming the parallel RL load to a series, one requires that the device sees a load impedance of 1.75 Ω in series with a 0.20 nH inductor. The transformation of 50 Ω down to 1.75 Ω requires a 25:1 impedance transformer which is much harder to realize. For the transistor being described here this is achieved using a series LCL matching network inside the transistor package, and this network transforms the external 50 Ω load resistance down to Z_{Lopt} and so no matching is required on the PCB, i.e., the external RF circuit is simply a 50 Ω transmission line with a drain bias network attached.

CLASS OF OPERATION

Transistors designed for radar applications are invariably operated in almost pure class B with the transistor conducting for only half of the RF cycle (I_{dq} < 50 mA for the example shown) rather than class A. ***Figure 4*** compares the class A and B situations. Fourier analysis of the current waveform in Figure 4 for class B operation shows that the drain current is given by:

$$i_D = g_m v_{gs,peak} \left(\frac{1}{\pi} + \frac{1}{2} \sin \omega t + \text{even harmonics} \right) \quad (2)$$

while in class A the drain current would be simply:

$$i_D = g_m v_{gs,peak} \sin \omega t \quad (3)$$

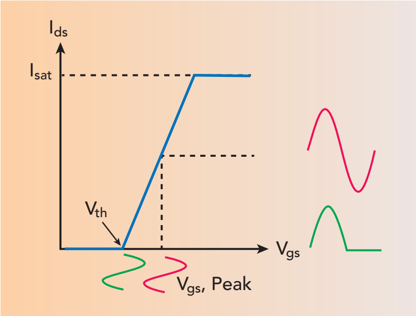

Fig. 4 Voltage and current waveforms for ideal class A and B amplifiers.

Comparing Equations 2 and 3 shows immediately that g_m must be replaced by $g_m/2$ in Equation 1 for class B operation.

Although the transistor is biased in almost pure class B mode as far as DC is concerned, it is questionable whether it actually operates in the classical class B mode from an RF point of view. Fourier analysis of the drain current waveform shows that it has components at DC, the fundamental frequency and at even harmonics of the fundamental frequency. The harmonics must be terminated in a short-circuit in order to have a pure sinusoidal output. For a transistor with a large output capacitance then this requirement is satisfied by the transistor's own internal output capacitance.

For the transistor under consideration C_{ds} = 9.6 pF so the output capacitance presents a reactance of 2.8 Ω to the second harmonic rather than a short-circuit. Also, the transistor has an LCL low-pass network connected to the drain pad on the die to provide some pre-matching inside the package, which will also present a reactive impedance to the second harmonic. Without access to device waveform measurement data it is difficult to be precise on exactly how the transistor operates, but this does not invalidate the general conclusions about the input impedance that are discussed next.

INPUT IMPEDANCE

The resistive part of the input admittance Y_{in} has both an intrinsic and an extrinsic component. The intrinsic component is a result of the finite value of gate-source resistance R_{gs} in Figure 3, which is comprised of the source Ohmic contact resis-

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tance and the channel resistance formed by the GaN layer between the source contact and the depletion region under the gate. However, the channel resistance in a GaN transistor is extremely low since the electrons flow in a two-dimensional electron gas. For the 135 W S-Band GaN transistor shown in Figure 2, R_{gs} is in the region of 0.45 Ω. However, since $1/\omega C_{gs} >> R_{gs}$ it will be shown in what follows that the value of R_{gs} makes very little contribution to the overall value of the resistive part of Y_{in} as it is masked by the much larger reactance of the gate-source capacitance.

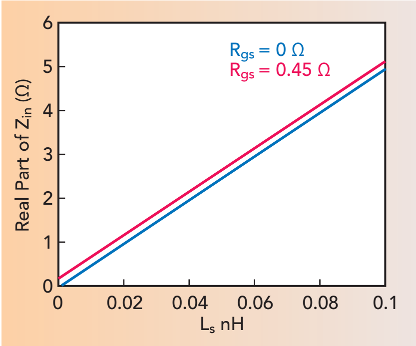
The extrinsic contributor to the resistive part of the input admittance Y_{in} arises from the finite value of the gate-source feedback capacitance, C_{gs}, and source inductance, L_S, which cause a portion of the resistive load impedance to appear at the input. If the effect of R_{gs} is ignored for the reason just given, and it is also temporarily assumed that L_s = 0, then straightforward circuit analysis shows that the input admittance with an arbitrary value of load resistance R_L connected at the output is given by:

$$Y_{in} = \frac{\omega^2 C_{gd}^2 R_L \left(1+g_m R_L\right)}{1+\left(\omega C_{gd} R_L\right)^2} + j\omega \left(C_{gs} + C_{gd}\left(\frac{1+g_m R_L}{1+\left(\omega C_{gd} R_L\right)^2}\right)\right) \quad (4)$$

Since $1>>(\omega C_{gd}R_L)^2$ then this expression simplifies to:

$$Y_{in} = \omega^2 C_{gd}^2 R_L \left(1+g_m R_L\right) + j\omega\left(C_{gs} + C_{gd}\left(1+g_m R_L\right)\right) \quad (5)$$

The reactive term is, of course, the well known Miller effect[6] whereby the effective input capacitance is not simply C_{gs} + C_{gd} but the increased value C_{gs} +$(1+g_mR_L)C_{gd}$. However, since g_m must be replaced by $g_m/2$ in Equations 4 and 5 for class B operation, the Miller effect is halved in class B compared with class A. This fact doesn't seem to be mentioned in most books and articles on RF amplifier design. The factor of two reduction in the g_m value for class B operation is also the reason why class B amplifiers have less gain (theoretically 6 dB lower but not quite as bad as that in practice) than class A amplifiers.



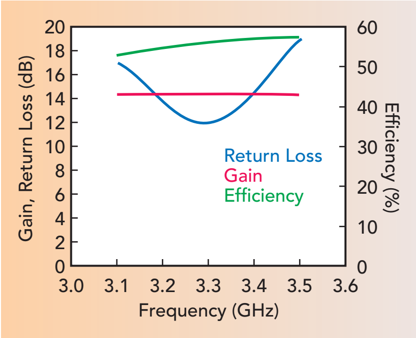
▲ **Fig. 5 Computed value of the real part of Z_{in} vs. source inductance L_s when terminated in Z_{Lopt}, given by Equation 1.**

For a transistor with finite values of both C_{gd} and L_s it has been shown[6] that the input impedance when terminated in Z_{Lopt} is given by:

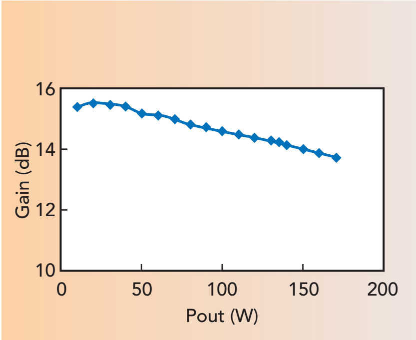
$$Z_{in} = \frac{L_S g_m}{C_{gs} + C_{gd}\left(1+g_m R_{Lopt}\right)} - j\frac{1+\omega^2 L_S C_{ds} g_m R_{Lopt} - \omega^2 L_S C_{gs}}{\omega\left(C_{gs}+C_{gd}\left(1+g_m R_{Lopt}\right)\right)} \quad (6)$$

The optimum source impedance is simply the complex conjugate of Z_{in}. It can be seen immediately from Equation 6 that the real part of Z_{in} is linearly dependent on the value of source inductance, thus controlling its value is critical to obtain a high production yield for a transistor fully matched to 50 Ω at the input. ***Figure 5*** shows the computed value of Z_{in} as a function of the value of source inductance for the situation where R_{gs} = 0 and R_{gs} = 0.45 Ω. It can be clearly seen that the finite value of gate-source resistance makes very little difference to the value of the real part of Z_{in} which justifies the earlier assumption that it can be neglected in the analysis.

To match a transistor having a real part of Z_{in} in the region of 1.5 Ω (the measured value is actually a lot less than this) to 50 Ω over the frequency range 3.1 to 3.5 GHz entirely within the package is a daunting task. It requires a matching network with more sections than the simple three-section one used at the output. ***Figure 6*** shows the input return loss and associated gain across the



▲ Fig. 6 Measured performance of the Integra Technologies IGT3135M135S transistor, with I_{dq} = 25 mA, V_{ds} = 46 V, a 300 μs pulse length and 10% duty cycle.



▲ Fig. 7 Gain vs. output power for the IGT3135M135S transistor, with I_{dq} = 25 mA, V_{ds} = 46 V, a 300 μs pulse length and 10% duty cycle.

TABLE 1
AMPLIFIER HARMONIC PERFORMANCE

Frequency (GHz)	Second Harmonic (dBc)	Third Harmonic (dBc)	Fourth Harmonic (dBc)
3.1	-38	-57	-65
3.3	-46	-62	-66
3.5	-56	-67	-69

band. The data is taken with a fixed output power of 135 W. The typical input return loss is better than 12 dB across the band with 14 dB gain and >55 percent drain efficiency.

Figure 7 shows the gain vs. output power from which it can be seen that the transistor is operating at 1 dB gain compression at 135 W output power. Finally, the harmonic performance is given in ***Table 1***. Incorporating lumped element matching within the package at both input and output helps to suppress harmonics and is a major advantage compared with using external distributed matching. The harmonic performance given in Table 1 is better than would be achieved with a MMIC that uses on-chip distributed matching.

CONCLUSION

This article described the economic and technical benefits of using a transistor fully matched to 50 Ω rather than a MMIC in T/R modules used in phased array radars. Values for the impedances at the gate and drain terminals of the transistor die have been given and, despite the fact that the resistive part of the input impedance is about 1 Ω, it has been shown that it is still possible to produce a transistor that is matched to 50 Ω over a 400 MHz bandwidth centered on 3.3 GHz with an input return loss better than 12 dB.■

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INVITED PAPER

MEMS Oscillators Enable Resilient Outdoor Small Cells

Jim Holbrook
SiTime, Sunnyvale, Calif.

The unabated demand for mobile services and increased bandwidth is driving the need for network densification in urban environments. The deployment of small cells is helping to address this growing demand. Small cells, as the name implies, are smaller, lower power base stations with output power in the range of 200 mW to 10 W and coverage from 10s of m to 2 km. According to the Small Cell Forum, 14 million small cells have been deployed as of May 2016, and over 5 million are expected to ship in 2017. China Mobile is leading the way, with an expected tender for 1 million units. Small cells will also play an important role in the roll-out of 5G, using the short range of millimeter wave frequencies.

Outdoor small cell deployments pose special challenges because of obvious factors such as weather, which can involve both extreme temperatures and rapid temperature changes, and vibration transients from trains, wind and heavy vehicles. State-of-the-art MEMS oscillator technology is ideally suited to meet these outdoor deployment challenges.

EVOLUTION OF MEMS OSCILLATORS

For over 75 years, quartz oscillators have served the electronics industry in applications that require precise frequencies with part-per-million accuracy. They have served the industry well despite certain intrinsic weaknesses. Because of these weaknesses and the economic scale of the silicon IC infrastructure, all-silicon MEMS timing devices have begun to replace quartz oscillators. In 2006, the first MEMS-based oscillator was released, and it demonstrated superior performance under shock and vibration, as well as the absence of sudden frequency jumps at certain temperatures (i.e., activity dips and micro jumps). Since the initial release of MEMS oscillators, the technology has improved considerably—temperature compensation and the phase-locked loop (PLL) — to reduce jitter and phase noise.

Today's MEMS oscillators are the result of years of technology refinement and millions of dollars in investment. The latest MEMS timing technology delivers low noise/low jitter clocks with unmatched resilience to environmental stresses, including shock, vibration, airflow and fast temperature transients. This performance enables more reliable and higher performance in all applications, including small cells.

MEMS Reliability

In MEMS resonator design, the designer has complete control over the lateral shape of the resonator and can control resonant


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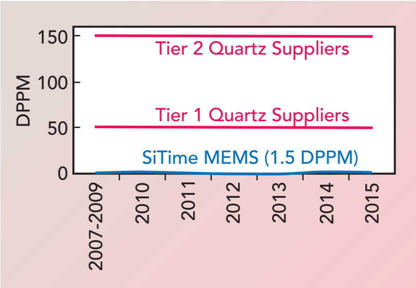
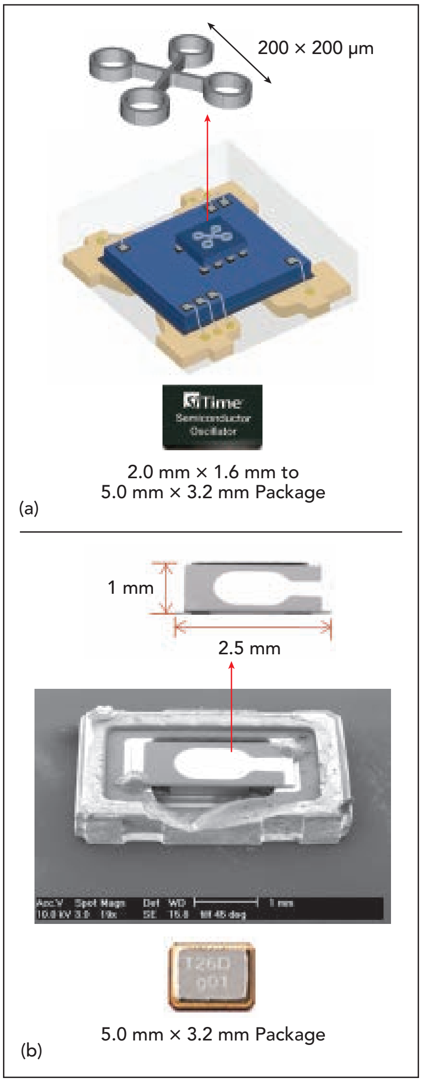
modes. MEMS are designed to be free of spurious mode crossings with the fundamental mode, making them free of resonator-induced activity dips. The MEMS has a single mechanical structure of pure silicon, with a tensile strength of 7 GPa—which is 14× higher than titanium (i.e., 330 to 500 MPa). During oscillation, the resonator moves less



▲ **Fig. 1 MEMS vs. quartz oscillator DPPM.**



▲ **Fig. 2 Typical MEMS (a) and quartz (b) oscillator assemblies.**

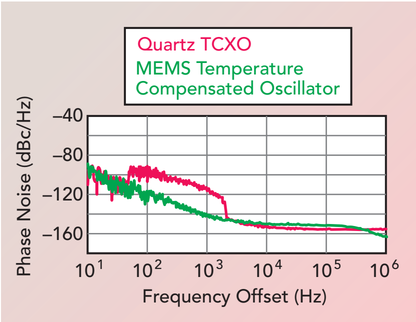
than 1 percent of the gap distance between the sidewalls. Acceleration of over 1 million g would be required to force the resonator to contact the sidewall, where g = 9.8 m/s^2, the acceleration due to gravity at sea level.

During MEMS manufacturing, a proprietary process cleans the resonator and hermetically seals it in a vacuum to eliminate aging mechanisms. This process is the basis for the very high reliability of MEMS oscillators. For example, SiTime has shipped over 625 million MEMS oscillators with no field failures attributable to the MEMS resonator. ***Figure 1*** compares the reliability of MEMS oscillators to quartz oscillators. The MEMS data shows 30× lower defective parts per million (DPPM).

Reliability is an important consideration for any design and is especially vital for equipment deployed outdoors. Better reliability improves the quality of service and reduces maintenance cost and the total cost of ownership.

Vibration Performance

MEMS-based oscillators are very resistant to a variety of environmental stresses, including shock and vibration. MEMS resonators have approximately 1000 to 3000× lower mass than quartz resonators (see ***Figure 2***). This means that a force on a MEMS structure from shock or vibration will result in much lower acceleration than its quartz equivalent, within a much lower frequency shift. This benefit is illustrated in ***Figure 3***, which compares the phase noise of a MEMS temperature compensated oscillator to a best-in-class quartz temperature compensated crystal



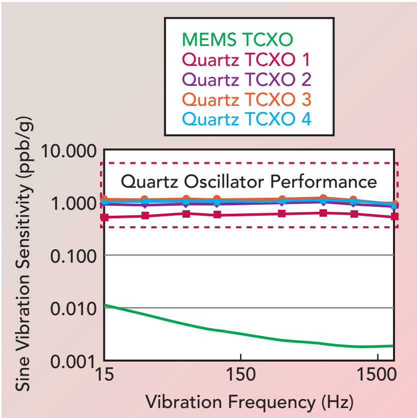
▲ **Fig. 3 Phase noise of 20 MHz temperature compensated MEMS oscillator and TCXO with 15 Hz to 2 kHz random vibration.**

oscillator (TCXO). The random vibration magnitude was 7.5 g root mean square (rms) over a frequency band from 15 Hz to 2 kHz. The MEMS oscillator has approximately 20× lower phase noise in this frequency range, which is a significant benefit to systems facing this type of environmental stress. Maintaining good phase noise performance in the presence of vibration is very important for small cells, helping to eliminate dropped calls and maintain high data throughput.

Another test of vibration sensitivity is the frequency shift per g of sinusoidal acceleration. The most common measure is part per billion (ppb) frequency shift per g of acceleration (ppb/g). ***Figure 4*** compares the vibration sensitivity of a temperature compensated MEMS oscillator to four quartz TCXOs. The sensitivity of the MEMS oscillator ranges from 15 to 150× lower, depending on the vibration frequency. With the MEMS oscillator, no vibration-induced spurs are detected above the random noise floor.

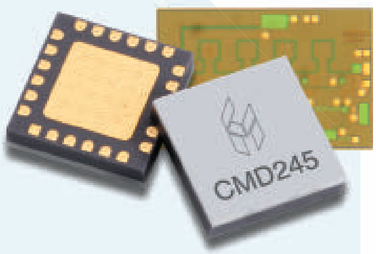
DUAL MEMS OSCILLATOR

Vibration resistance and reliability have been intrinsic advantages of MEMS oscillators since early generations were developed. Recent advances in technology, such as a dual MEMS architecture employed in the Elite Platform MEMS oscillator families from SiTime, provide additional benefits: resilience to fast temperature ramps and low phase noise. Before quantifying these benefits, it will be instructive to provide a brief overview of the dual MEMS architecture to explain how



▲ **Fig. 4 Comparison of vibration sensitivity at 4g acceleration.**


Quadrature Axis
In-Phase Axis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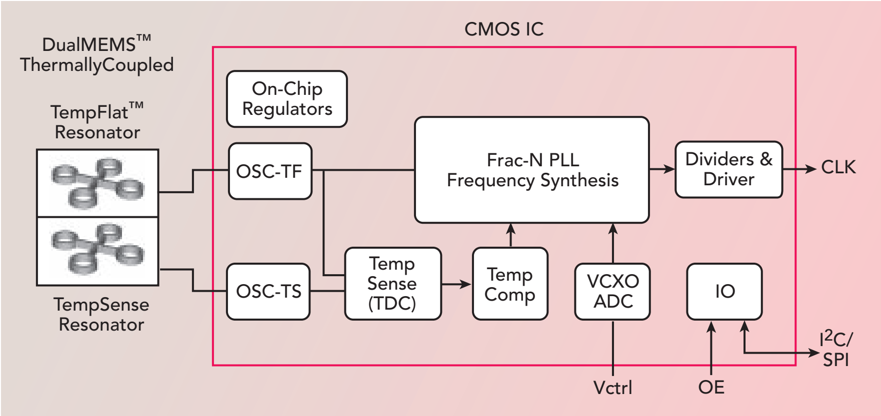
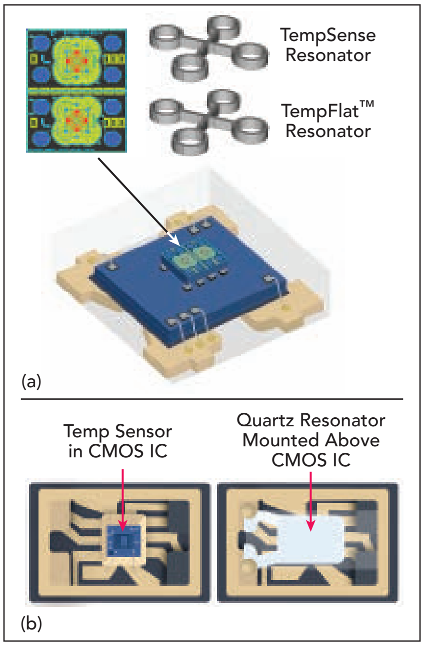


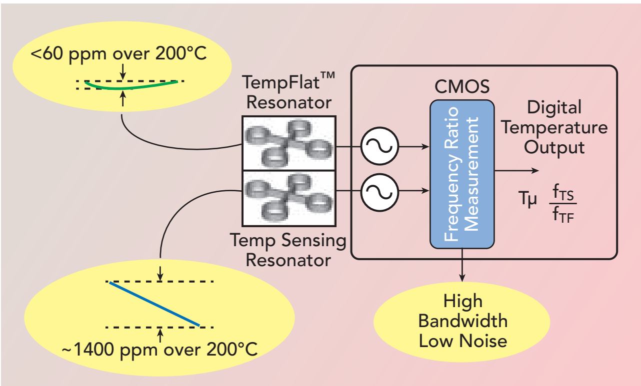
▲ **Fig. 5** **DualMEMS oscillator block diagram.**

these advantages are achieved. ***Figure 5*** shows a block diagram of the DualMEMS™ oscillator. Shown at the left of the block diagram are the two MEMS that comprise the temperature sensor and resonator. One resonator, the TempSense (TS) resonator, is used as a temperature sensor, exploiting its relatively steep but linear -7 ppm/°C frequency vs. temperature slope. The second, which provides a reference clock to the downstream PLL, is designed to have a relatively flat frequency vs. temperature slope and is called the TempFlat™ (TF) resonator. The ratio of frequencies of the TF and TS resonators provides an extremely accurate reading of the resonator temperature, with 30 μK resolution. Another key feature is the tight thermal coupling between the TF and TS resonators, which are fabricated on the same die and separated by only 100 μm. This results in virtually no thermal lag between the TF and TS resonators. Simulations have shown only 52 mK temperature offset between the TF and TS resonators when exposed to heat flux.



▲ **Fig. 6** **Comparison of MEMS (a) and quartz (b) oscillator assemblies.**

By contrast, the temperature sensor in quartz TCXOs is integrated in an IC that sits below the quartz resonator, on the substrate of the ceramic package (see ***Figure 6***). This spatial separation between the temperature sensor and the resonator results in a thermal lag between the two elements, which introduces significant frequency error when subjected to fast thermal transients.



▲ **Fig. 7** **MEMS temperature to digital converter.**

Another key element of the MEMS temperature compensation architecture is the temperature to digital converter (TDC) (see ***Figure 7***). This circuit block generates an output frequency which is proportional to the ratio of the frequencies generated by the TF and TS resonators. The TDC has a 30 μK temperature resolution and bandwidth to 350 Hz. These features enable excellent phase noise close to the carrier and Allan deviation (ADEV) performance. ADEV measures low frequency jitter and wander. More precisely, ADEV is a two sample deviation of fractional frequency values measured continuously with time. It quantifies how much the average frequency changes over a certain time interval, called the averaging time or tau, and can be specified in a table format or as a plot vs. averaging time. With the TDC, the ADEV is less than 10^{-10} with 1 s averaging.

The high bandwidth of the TDC and the tight thermal coupling between the TF and TS resonators result in minimal frequency error when the temperature compensated MEMS oscillator is subjected to fast temperature transients. ***Figure 8*** shows the performance of the DualMEMS architecture responding to fast thermal transients, compared to a ±50 ppb carrier-grade quartz TCXO. When a heat gun is applied simultaneously to the two oscillators, the quartz TCXO deviates up to 450 ppb from the nominal temperature, exceeding its datasheet specification by 9×. The change of the MEMS oscillator is barely noticeable, well below the specification of 100 ppb. Resilience to rapid temperature transients is important for small cell quality of service during changing environmental conditions.

The fractional-N PLL is another important architectural element of the design. The PLL multiplies the reference clock from the TF resonator and, in combination with the output divider, generates the desired output frequency. The PLL and the TDC are critical to the overall phase noise of the oscillator output. The PLL was designed with a high quality factor (Q-factor) voltage-controlled oscillator (VCO) to minimize phase noise and on-chip crosstalk that can manifest as output spurs. The fractional feedback divider in the PLL uses sigma-delta modulation to provide very fine frequency resolution, with noise shaping to

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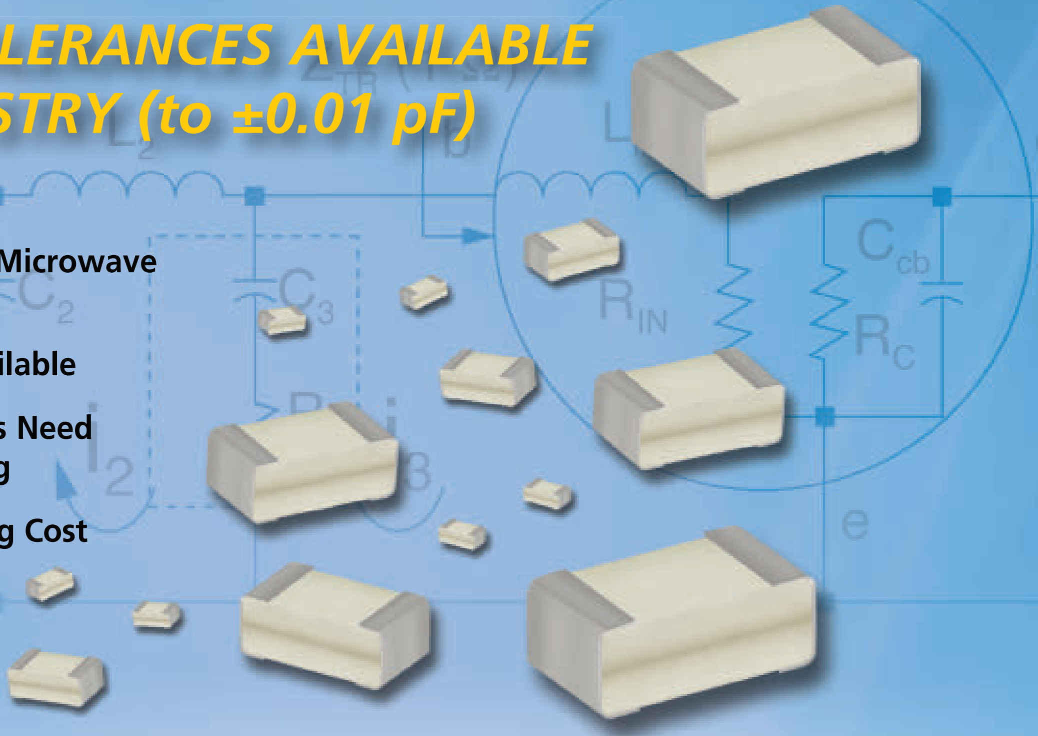

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THE ENGINEERS' CHOICE®   www.atceramics.com minimize spurs and random noise. ***Figure 9*** shows the phase noise of two MEMS-based oscillators compared to the specification for a typical LTE small cell. The MEMS oscillators have significant margin.

Airflow can cause changes in frequency and is another potential cause of performance degradation for outdoor small cells. Airflow can cause die temperature changes by changing the heat flow from the oscillator. Rapid, turbulent airflow can have an even more pronounced effect and, in extreme cases, can cause vibration effects. To show this, ***Figure 10*** plots the ADEV of quartz TCXO and MEMS oscillators in the presence of airflow, using averaging times from 1 to 1,000 s. The MEMS oscillators have 2 to 38x better ADEV performance using averaging times between 1 and 100 s.

ADEV is a time domain measure of frequency stability. The main advantage of ADEV over standard de-

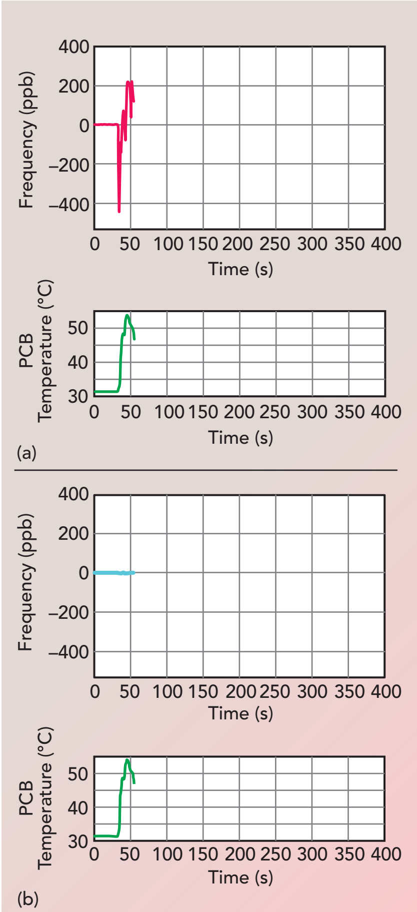

Fig. 8 Frequency deviation of a quartz TCXO (a) and temperature compensated MEMS oscillator (b) when subjected to a fast temperature ramp.

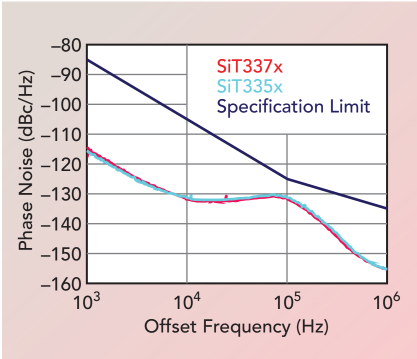

Fig. 9 MEMS oscillator phase noise vs. small cell specification for a 122.88 MHz reference clock.

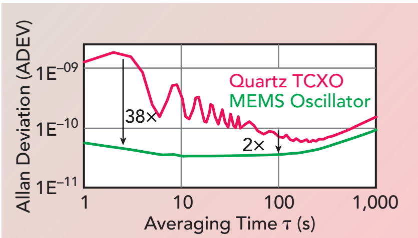

Fig. 10 ADEV performance of MEMS and quartz oscillators with airflow.

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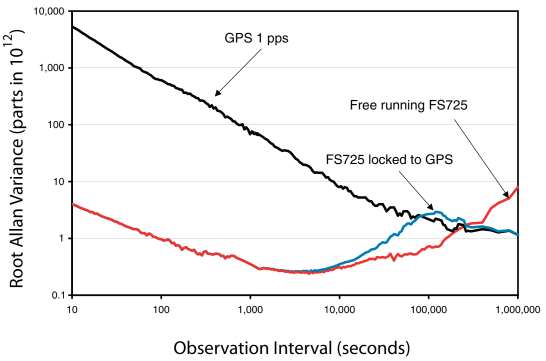
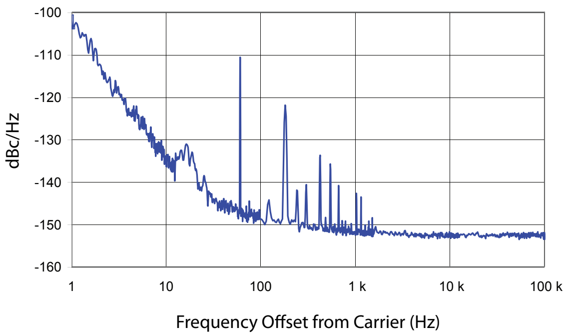


FS725 Single Sideband Phase Noise



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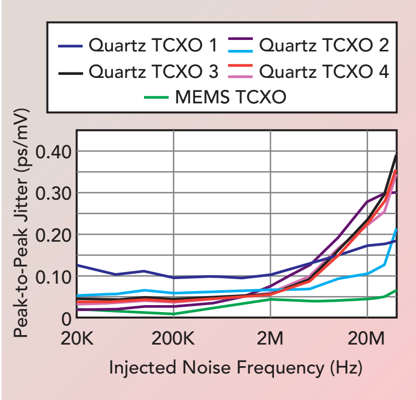
viation is that it converges for most noise types. Therefore, it is widely used for characterizing the frequency stability of oscillators. Good ADEV performance is particularly important for telecom-grade oscillators, and MEMS oscillators excel at ADEV performance.

In addition to external environmental stresses such as vibration, ambient temperature and airflow, internal system stresses are also present. Power supply noise can result from crosstalk with nearby data lines and switching regulators. To maintain system performance, it is important for the oscillator to maintain good phase noise and jitter performance in the presence of noise from the power supply. Power supply noise rejection (PSNR) is the ratio of jitter observed at the output, in picoseconds, divided by the amplitude of injected jitter on the supply pin, in millivolts. Normally, sinusoidal jitter is injected onto the supply voltage with a 50 mV amplitude. ***Figure 11*** shows the peak-to-peak jitter of a MEMS oscillator compared to quartz oscillators from six different suppliers across the noise frequency range from 20 kHz to 40 MHz. The MEMS oscillator excels in PSNR. The low jitter is due to multiple on-chip low-dropout regulators, which isolate the critical components such as the VCO and MEMS oscillator.



▲ **Fig. 11 The PSNR of MEMS and quartz oscillators.**

CONCLUSION

MEMS oscillator technology has improved significantly during the past decade, including the key elements that comprise a high performance oscillator: the resonator, temperature compensation circuitry, PLL and on-chip voltage regulators. Building on the intrinsic advantages of shock and vibration resistance, state-of-the-art MEMS timing technology delivers best-in-class dynamic performance—resilience to system and environmental stresses. Compared to quartz oscillators, MEMS oscillators offer better frequency stability and aging, with no activity drops. They are up to 80 percent smaller and consume up to 90 percent lower power. MEMS oscillators are ideal for meeting the challenges of outdoor small cells. With additional investments in MEMS oscillator technology, refinements will continue to improve phase noise and frequency stability, making MEMS-based timing the solution of choice for the next several decades.■

Low Complexity, High Performance RF Self-Interference Cancellation for Full-Duplex Radios

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The in-band full-duplex technique is regarded as a potential solution for significantly enhancing spectrum efficiency in the next generation communication system (5G). The biggest challenge in achieving full-duplex communication is overcoming self-interference from the simultaneous use of the same frequency band for transmission and reception. A novel RF cancellation circuit with direct RF correlative detection is automatically adjusted in real-time to optimize cancellation. Measured results show that the cancellation circuit provides greater than 50 dB of Tx-to-Rx isolation over a 50 MHz bandwidth. Moreover, the design is an independent module which can readily be cascaded for MIMO scenarios.

The 4th generation communication system (4G) has begun commercialization and is reaching maturity. Technical solutions and standards for the next generation communication system (5G) are now attracting the attention of developers around the world.[1] Future support for the explosive growth of data traffic and the massive increase in the number of interconnected devices is the main driver behind 5G; thus, developments to fully exploit potential spectrum resources and to enhance spectrum efficiency are essential.

In-band full-duplex communications has been widely regarded as a potential solution to improve the spectrum efficiency of wireless systems.[2,3] Current systems employ either time division duplexing (TDD) or frequency division duplexing (FDD) to achieve bidirectional communication. In these systems, high Tx-to-Rx isolation is realized with different time slots or frequency bands for transmission and reception. Using the in-band full-duplex communication technique, however, a radio can simultaneously transmit and receive over the same frequency band, enabling a wireless network to double its spectrum utilization.

There have been several recent attempts to build this type of full-duplex transceiver[4-7] but, its practical realization is still subject to many challenges. The main one is strong self-interference from the transmit side of the node. Therefore, the principal objective for a full-duplex design is to suppress self-interference as much as possible.

The block diagram of a basic full-duplex transceiver with RF and digital cancellation is shown in ***Figure 1***. Compared to a traditional transceiver, an additional RF or analog cancellation circuit is used to eliminate self-interference. About 63 dB of Tx-to-Rx isolation across an 80 MHz bandwidth was obtained in the analog domain by Bharadia et

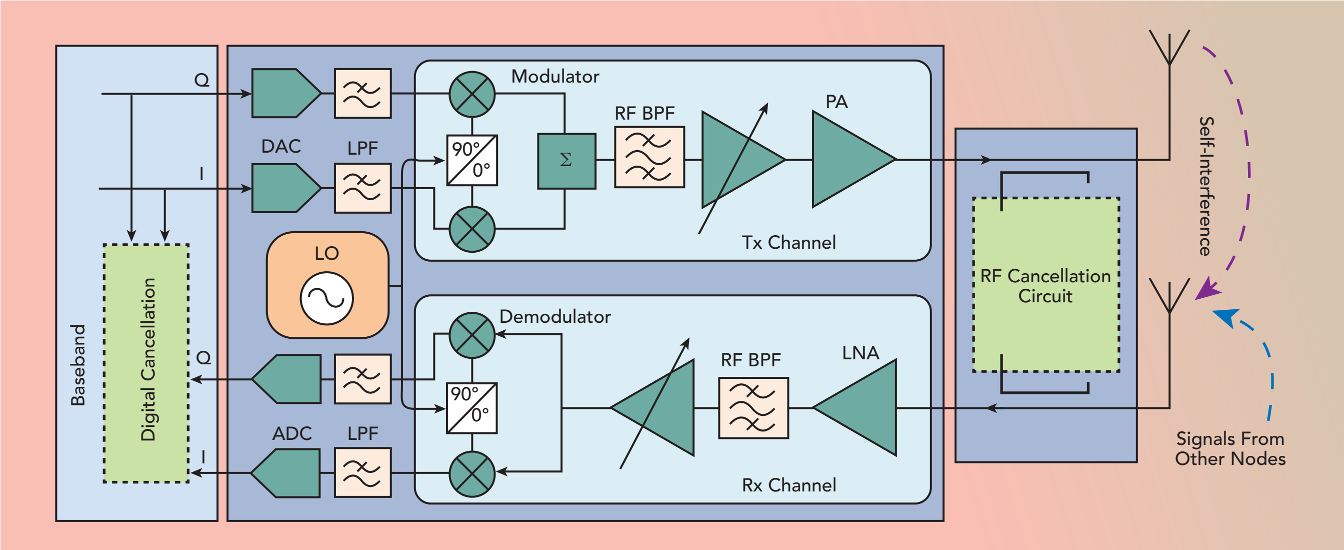

Fig. 1 Block diagram of a separated-antenna, full-duplex transceiver with an independent RF cancellation module.

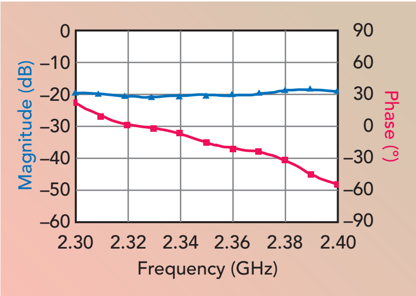

Fig. 2 Measured response from separated transmit and receive antennas in a typical laboratory environment.

al.[7] This was accomplished with an intricate 16-tap canceller composed of tunable attenuators and delay lines along with a complex cancellation control algorithm. RF cancellation can provide significant isolation to avoid receiver saturation or analog-to-digital converter overload caused by strong self-interference. Moreover, it may be augmented with digital cancellation.

This article introduces a novel RF cancellation technique with direct RF correlative detection. This is realized with an independent RF module that automatically adjusts phase and magnitude to optimize cancellation. The direct RF correlative detection method can significantly reduce hardware and adaptive algorithm complexity compared with other designs.[6,7] Correlative detection employed in this design also has several advantages as compared to the power detection method.[4] Power detection utilizes only the strength of received signals, and thus may be easily disturbed by other interference, while correlative detection will not. Correlative detection provides both the magnitude and phase information of self-interference so that an adaptive adjustment algorithm (such as the LMS algorithm) can be easily implemented. Finally, the RF cancellation module used in correlative detection can readily be cascaded to support MIMO systems.

CIRCUIT DESIGN

Frequency Response of Self-Interference Channel

In the separated-antenna based full-duplex transceiver, self-interference consists of two components: the self-interference propagating directly from the transmit to the receive antenna, and reflected components from nearby scatter. The frequency response of self-interference in a separated-antenna architecture can be written as:

$$H_a(jw) = \sum_i a_i e^{jw\phi_i} e^{-jw\tau_i} \qquad (1)$$

where i = 0 denotes the frequency response of the direct path from transmit antenna to the receive antenna, and i = 1,2,3 denotes the frequency response of multipath scattering. $a_i e^{jw\phi_i}$ represents the magnitude and phase information and τ_i is the time delay for each path. As shown in ***Figure 2***, a non-flat frequency response caused by multipath reflection is observed in a typical environment.

The self-interference signal at the receive side looks different from transmitted signal at the Tx antenna due to the non-flat frequency response, especially when a wideband modulation signal is transmitted. For this reason, it is quite difficult to obtain a perfect inverse of self-interference for RF cancellation. As a result, RF cancellation is imperfect. Despite this, RF cancellation is necessary because: 1) It provides high transmit-to-receive isolation, enough to prevent the receiver from saturating; 2) RF cancellation is unaffected by phase noise of the transceiver local oscillator; 3) RF cancellation using the transmit signal after the power amplifier as the reference can eliminate nonlinear self-interference due to power amplifier nonlinearity.

RF Cancellation Design with Correlative Detection

In this work, we consider an RF cancellation design for a separated-antenna full-duplex transceiver architecture. A simplified block diagram is shown in ***Figure 3***. The RF cancellation circuit is implemented as an independent RF module which can be divided into two parts: 1) a cancellation unit consisting of a vector modulator, a transmission delay line, several RF amplifiers a directional coupler and other supporting components, and 2) a correlative detection unit consisting of a directional coupler, an RF multiplier, a quadrature demodulator and several RF amplifiers.


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In the cancellation unit, the vector modulator is used as a programmable phase shifter and attenuator to generate a replica of the self-interference signal. It provides fine-grained control to match amplitude and phase for the inverted signal path. Cancellation that inverts a signal through phase adjustment only, however, will always have a bandwidth constraint. To obtain the inverse for wideband signals, a fixed delay transmission line is used to achieve the same group delay in the inverted and self-interference paths.

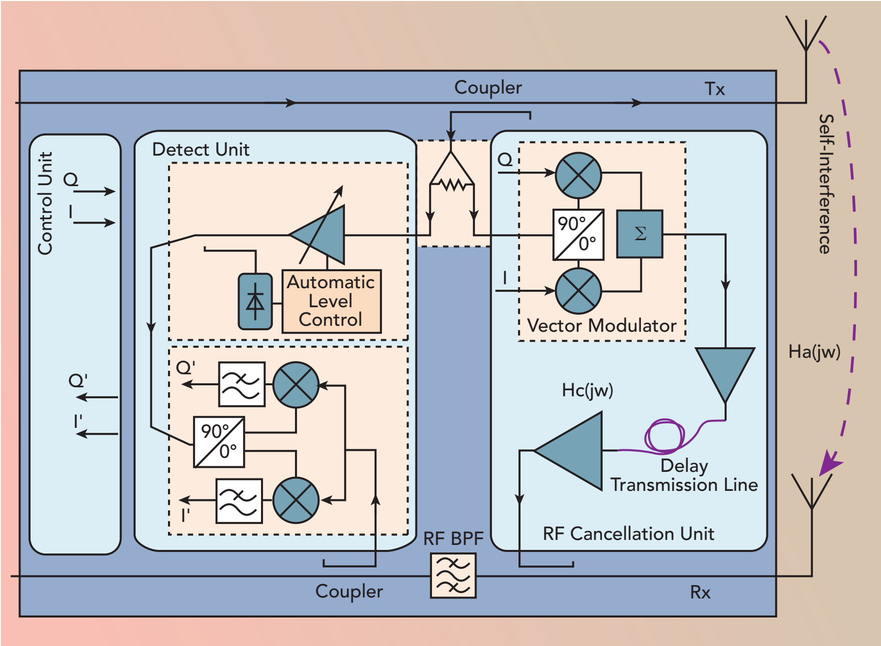


Fig. 3 Block diagram of an RF cancellation circuit with direct RF correlative detection.

Correlative detection of the self-interference signal is accomplished in the detection unit. A quadrature demodulator with low-pass filters at the baseband ports acts as a direct RF correlative detector. Considering that the power level of the reference signal at the LO port of the demodulator must be controlled within a suitable range, an automatic power level control loop is constitutive with the RF multiplier, directional coupler, log detector and operational amplifier to provide a reference signal with a constant power level.

The transmitted signal is passed through the transmit channel interface of the RF cancellation module to the transmit antenna and is also coupled and split into two parts to form reference signals for the RF cancellation and detection units. The RF cancellation unit generates an inverted replica of the self-interference signal for elimination at the receive side. Residual signal is fed to the quadrature demodulator for correlative detection. The output is sampled to obtain self-interference magnitude and phase information for cancellation adjustment. ***Figure 4*** shows the completed RF cancellation module.

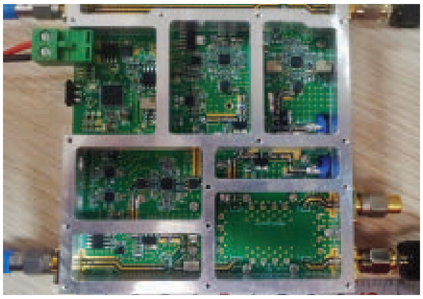


Fig. 4 RF cancellation module.

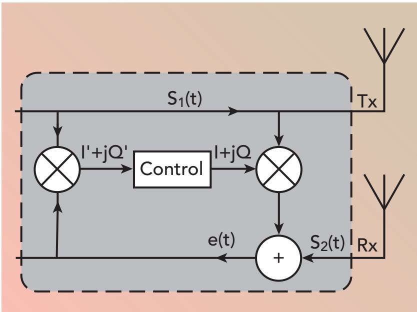


Fig. 5 RF cancellation system model.

The RF cancellation system model is shown in ***Figure 5***. The complex transmitted signal is denoted by $s_1(t)$, and $s_2(t)$ is the received signal at the receive antenna. The output of the receive channel can be written as:

$$e(t) = s_2(t) + (I + jQ)s_1(t) \qquad (2)$$

where I + jQ is the baseband input of the vector modulator for amplitude and phase adjustment of self-interference.

The complex output of the correlative detection unit is given by:

$$I' + jQ' = e(t)s_1^*(t) \qquad (3)$$

The goal of self-tuning is to set the complex amplitude I + jQ such that self-interference is minimized. The adaptive least mean square (LMS) algorithm can be easily realized in this RF cancellation implementation. The gradient vector of the LMS algorithm is:

$$\begin{bmatrix} \dfrac{\partial\left[e(t)e^*(t)\right]}{\partial I} \\ \dfrac{\partial\left[e(t)e^*(t)\right]}{\partial Q} \end{bmatrix} = \begin{bmatrix} e^*(t)s_1(t) + e(t)s_1^*(t) \\ j\left[e^*(t)s_1(t)\right] - j\left[e(t)s_1^*(t)\right] \end{bmatrix} = \begin{bmatrix} 2\mathrm{Re}\left[e(t)s_1^*(t)\right] \\ 2\mathrm{Im}\left[e(t)s_1^*(t)\right] \end{bmatrix} = 2\begin{bmatrix} I' \\ Q' \end{bmatrix} \qquad (4)$$

where Re[·] represents the real part and Im[·] represents the imaginary part.

The formula for the LMS algorithm can be written as follows:

$$\begin{bmatrix} I(k+1) \\ Q(k+1) \end{bmatrix} = \begin{bmatrix} I(k) \\ Q(k) \end{bmatrix} - \mu \begin{bmatrix} I' \\ Q' \end{bmatrix} \qquad (5)$$

where μ denotes a step size.

Note that in a practical cancellation circuit, a constant phase displacement ϕ between the reference signal of the detection unit and the signal in the cancellation unit is measured and calibrated, so the formula of the LMS algorithm is rewritten as follows:

$$\begin{bmatrix} I(k+1) \\ Q(k+1) \end{bmatrix} = \begin{bmatrix} I(k) \\ Q(k) \end{bmatrix} - \mu \begin{bmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} I' \\ Q' \end{bmatrix} \qquad (6)$$

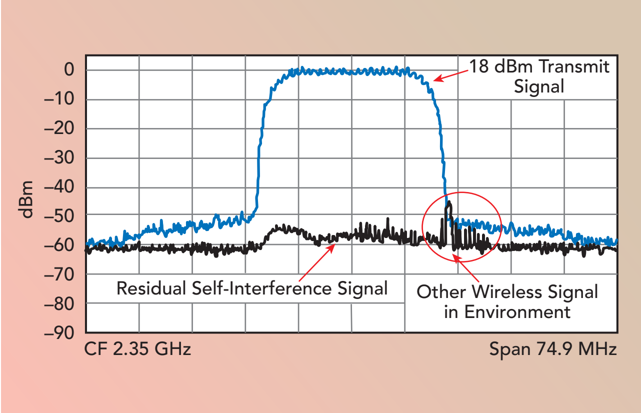
The output of correlative detection part I′ + jQ is sampled for each iteration and the complex amplitude of the cancellation unit I + jQ is calculated according to Equation 6. This RF cancellation implementation using the LMS algorithm can automatically adjust the phase and amplitude in real time to optimize self-interference cancellation.

EXPERIMENTAL RESULTS

The RF cancellation module with real-time adaptive cancellation is evaluated in a laboratory environment (see ***Figure 6***). A Rohde & Schwarz (R&S) SMBV100A vector signal generates wideband digital modulation signals at a center frequency of 2.35 GHz with an average power of 18 dBm. The output is connected directly to the Tx channel of the RF cancellation module and transmitted with an omni-directional antenna. Another omni-directional antenna is employed as the receive antenna. Signals are observed with a Rohde & Schwarz FSL6 spectrum analyzer on the Rx side. Tx-to-Rx isolation for optimal cancellation is measured using a Keysight N5230A vector network analyzer (VNA).

Adaptive RF cancellation at a 2.35 GHz center frequency with a 20 MHz bandwidth QAM-16 modulation signal is shown in ***Figure 7***. Residual self-interference is about -38 dBm at an average transmit power of 18 dBm. Thus, a total of 56 dB of self-interference suppression is achieved with the RF cancellation module. To evaluate bandwidth performance, S-parameters between the Tx and Rx ports of the module are measured in the optimum cancellation state. As is shown in ***Figure 8***, the RF cancellation module provides greater than 50 dB Tx-to-Rx isolation across a 50 MHz bandwidth. ***Table 1*** shows how this compares with other published approaches.

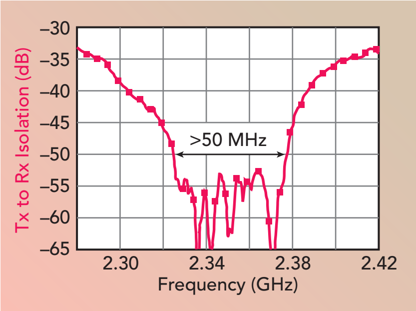
▲ **Fig. 6 Setup for measuring RF self-interference cancellation performance.**



▲ **Fig. 7 Cancellation at 2.35 GHz with a 20 MHz modulation signal.**

CONCLUSION

A practical RF cancellation circuit employs adaptive cancellation adjustment in real time using direct RF correlative detection. Experimental results show that it provides greater than 50 dB isolation over a 50 MHz bandwidth. Using correlative detection, good real-time adaptive adjustment is achieved. To build a practical full-duplex radio, however, further suppression is required through digital cancellation. With this circuit and algorithm, transmit interference can be reduced significant so that the IF circuit and the digital circuit can process the received signal with little difficulty. For MIMO, this independent RF cancellation module can be readily cascaded to cancel interference from other antennas.■



▲ **Fig. 8 Tx-Rx isolation measured at optimal cancellation.**

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Switching Speed: Measured 500 ns

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Frequency	2.0 to 18.0 GHz
Phase Range	0 - 255° Typ
Insertion Loss	18 dB Typ - Measured 12 dB
VSWR	2.5:1 Typ. - Measured 1.9:1
Amplitude Error	±3.7 dB Typ. - Measured ±3.6 dB
Phase Flatness	±37.0° Typ. - Measured ±35.7°
Control	TTL Compatible: 15 Pin Sub-D (Male)
Temperature	-40 ºC to +85 ºC Operating

Package Size: 2.0” x 2.1” x 0.5”
DC Voltage: +15 VDC @ 121 mA
Switching Speed: Measured 200 ns

Model: PS-2G18G-360-8D

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Frequency	2.0 to 18.0 GHz
Phase Range	0 - 360°
Insertion Loss	18.0 dB Typ - Measured 17.29 dB
VSWR	2.5:1 Max - Measured 1.9:1
Phase Vs Frequency	±15° Typ. - Measured ±15.39°
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TABLE 1
COMPARISON WITH REPORTED RESULTS

Reference	Tx-to-Rx Isolation (dB)	Frequency Band (GHz)	Cancellation Bandwidth (MHz)
4	45	2.43 to 2.47	40
7	63	2.41 to 2.49	80
8	40	0.902 to 0.928	26
9	50	1.885 to 1.915	30
This Work	52	2.325 to 2.375	50

ACKNOWLEDGMENT

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INVITED PAPER

Mixed-Signal Instrumentation for Design and Test of 5G Systems

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The design of radio frequency (RF) and microwave systems is usually based on the use of simplified representations of subsystems, often derived from datasheets, to predict overall system behavior. To reduce the number of design iterations, one needs a more accurate representation of "real" behavior. The common approach for RF design is to use measurement-based or electromagnetic (EM) simulated models, such as scattering parameters to represent the behavior of filters or linear amplifiers. These models capture the nonidealities more accurately. Unfortunately, when RF engineers use CAD/CAE tools for developing systems that include mixed-signal devices (where analog and digital waveforms coexist), they mainly use ideal approximations to represent the sampling circuit and the quantization subsystem or they assume them as being transparent to the RF signal, which degrades overall simulation accuracy.

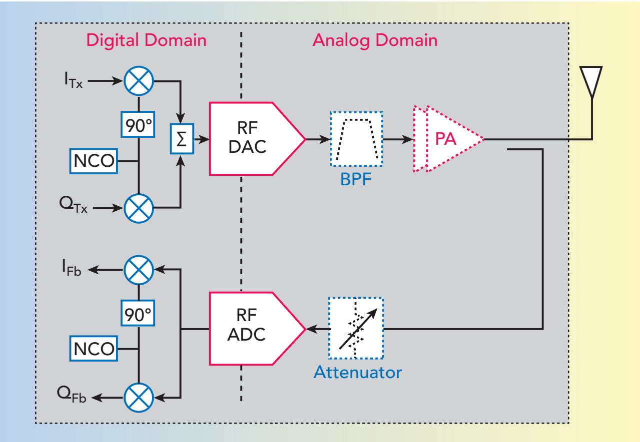
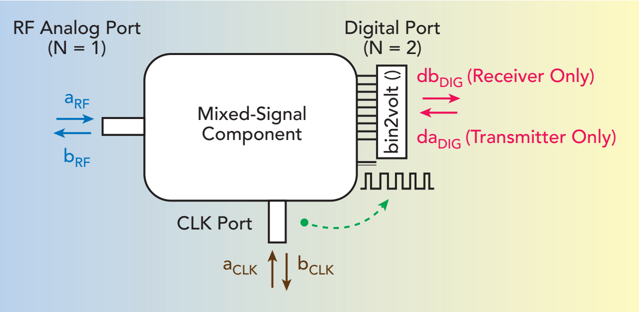
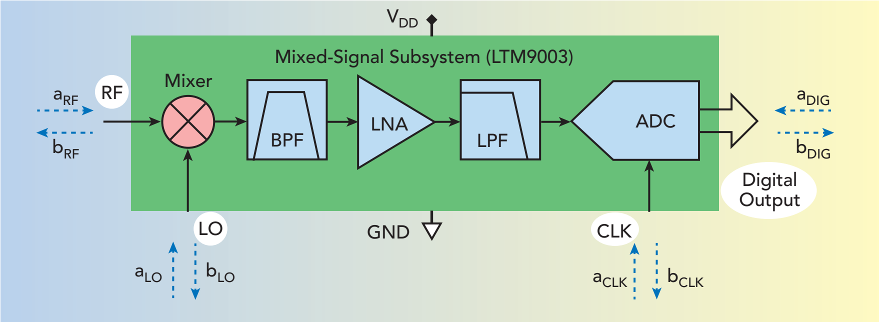


Fig. 1 SDR example with digital predistortion feedback loop.

Software-defined radio (SDR) front-ends are an example of mixed-signal system designs (see ***Figure 1***) where components such as analog-to-digital converters (ADC) and digital-to-analog converters (DAC) are key elements of the overall design. The RF characteristics, specifically the input/output impedances of these components, may vary with frequency, such that a thorough characterization of the frequency response of the mixed-signal components will significantly improve the overall SDR design. For example, the ADC/DAC subsystems can be matched to the amplifier and filters of the RF transceiver. Figure 1 shows a transmitter with a feedback loop that implements real-time digital predistortion (DPD) to correct for distortion in the transmitter. To guarantee a properly corrected transmitted signal, the feedback loop itself should introduce no distortion. Due to the need for more signal bandwidth, recent SDR solutions require sampling rates to provide more than



▲ **Fig. 2 System-level representation of a mixed-signal component.**



▲ **Fig. 3 System-level characterization approach applied to the LTM9003.**[7]

1 or 2 GHz of DPD bandwidth. To limit the complexity and the cost of corrective circuits, an alternative to increased sampling rates is using higher Nyquist zones. However, this approach requires proper correction due to increased distortion in the feedback loop. To optimize the overall system and push it to its limits, better characterization and modeling approaches are needed for mixed-signal devices.

This article describes a key tool for RF engineers designing systems where analog and digital RF waveforms coexist. This work uses a new characterization approach and subsequent extraction of a mathematical model equivalent to scattering parameters for mixed-signal devices.[1] This model is usable in system-level simulators to design 5G and other communication systems.

MIXED-SIGNAL SCATTERING PARAMETERS

In general, a mixed-signal system is considered, at least, as a three-port device, comprising the analog RF port, the digital bus and an additional port reflecting the sampling clock (local oscillator port). As it imposes a discrete time scale, the last port will determine and constrain the time sampling periods for the digital bus data. The focus of this approach is not on the individual bit-line operation,[2] rather the information that the overall bitstream comprises. Therefore, the mixed-signal system will be characterized and modeled considering the entire digital bus as a single port (in other words, the digital port), which is sampled in time.

Figure 2 shows a representation of the system-level behavioral approach for mixed-signal systems. For consistency with their analog counterparts and to unify the formalism, incident and reflected digital signals are introduced conceptually. They are noted as da_n and db_n voltage waves, respectively, where n represents the port number. The da_n wave only exists in the transmit mode and the db_n wave only exists in the receive mode, where the other respective wave is considered zero. The sampled signal at the digital port is assigned to the proper voltage wave while being expressed in a 50 Ω characteristic impedance:

$$da_n = \frac{V_{dig}}{\sqrt{Z_0}}, \text{only in transmitter mode } (db_n = 0) \quad (1)$$

$$db_n = \frac{V_{dig}}{\sqrt{Z_0}}, \text{only in receiver mode } (da_n = 0)$$

The generalization to the scattering waves formalism allows characterizing amplitude and phase over frequency for mixed-signal systems. This is similar to the well-known S-parameters for small-signal linear behavior and the polyharmonic distortion models,[3] interconnected X-parameters[4] or S-functions for large-signal operating points.[5] This generalized formalism for mixed-signal components is referred to as D-parameters™.

To simplify the model formulation, the three-port mixed-signal system is reduced to a two-port mechanism by incorporating the clock (CLK) signal into the model. This is similar to a mixer representation,[6] where the local oscillator (LO) imposes the point of operation. The D-parameter formulation for linear characteristics, as it will be employed throughout this article, is represented by:

$$\begin{bmatrix} b_{RF}(\omega) \\ db_{DIG}(\omega) \end{bmatrix} = \begin{bmatrix} D_{11}(\omega) & D_{12}(\omega) \\ D_{21}(\omega) & D_{22}(\omega) \end{bmatrix} * \begin{bmatrix} a_{RF}(\omega) \\ da_{DIG}(\omega) \end{bmatrix} \quad (2)$$

where ω represents the user-defined frequency grid, and da_{DIG} and db_{DIG} are obtained for a specific state of the CLK signal (a_{CLK}) and where the D-parameters are dependent on the LO drive.

$D_{11}(\omega)$ is equivalent to $S_{11}(\omega)$ for an analog component and represents the matching performance of the RF port. Another measure is $D_{21}(\omega)$, which is similar to the $S_{21}(\omega)$ of a two-port analog network. It represents the frequency-dependent gain from the analog RF input port to the digital output port in a mixed-signal receiver. The amplitude and phase will depend on the LO drive. More specifically, the following parameters can be devised:

$$\begin{bmatrix} D_{11}(\omega) = \frac{b_1(\omega)}{a_1(\omega)}|a_{CLK} = \beta, da_2 = 0 \\ D_{21}(\omega) = \frac{db_2(\omega)}{a_1(\omega)}|a_{CLK} = \beta, da_2 = 0 \\ D_{12}(\omega) = \frac{b_1(\omega)}{da_2(\omega)}|a_{CLK} = \beta, a_1 = 0 \\ D_{22}(\omega) = 0 \end{bmatrix} \quad (3)$$

Further details on the complete linear and nonlinear D-parameter formulation may be found in the original work.[1]

To present this approach more practically, a mixed-signal component is used to illustrate. The Linear Technology® LTM9003 wideband receiver[7] (see ***Figure 3***) is an RF-to-digital receiver subsystem that includes a 12-bit ADC, a bandpass filter (BPF), an intermediate frequency (IF) amplifier and a high linearity RF down-converting mixer.

MIXED-SIGNAL INSTRUMENTATION

For the simplest mixed-signal devices such as ADCs and DACs, the mixed-signal characterization test benches and mathematical formulations have been standardized by the IEEE for several years.[8] This standard focuses on figures of merit, calculated for either the analog or digital side. It includes almost no information on characterizing and modeling the overall behavior.

To characterize and model mixed-signal components, the instrumentation industry has used a combination of instruments. Some of the capabilities have been integrated, leading to alternative solutions such as mixed-signal oscilloscopes. They accommodate analog and digital signals in a single instrument. However, these solutions have their limitations[9] and were never capable of providing reliable RF-based characterization and modeling that enable the models to be used in the common RF/microwave simulators.

During the last few years there have been several attempts to assemble a measurement test bench for specific mixed-signal cases.[10-12] More

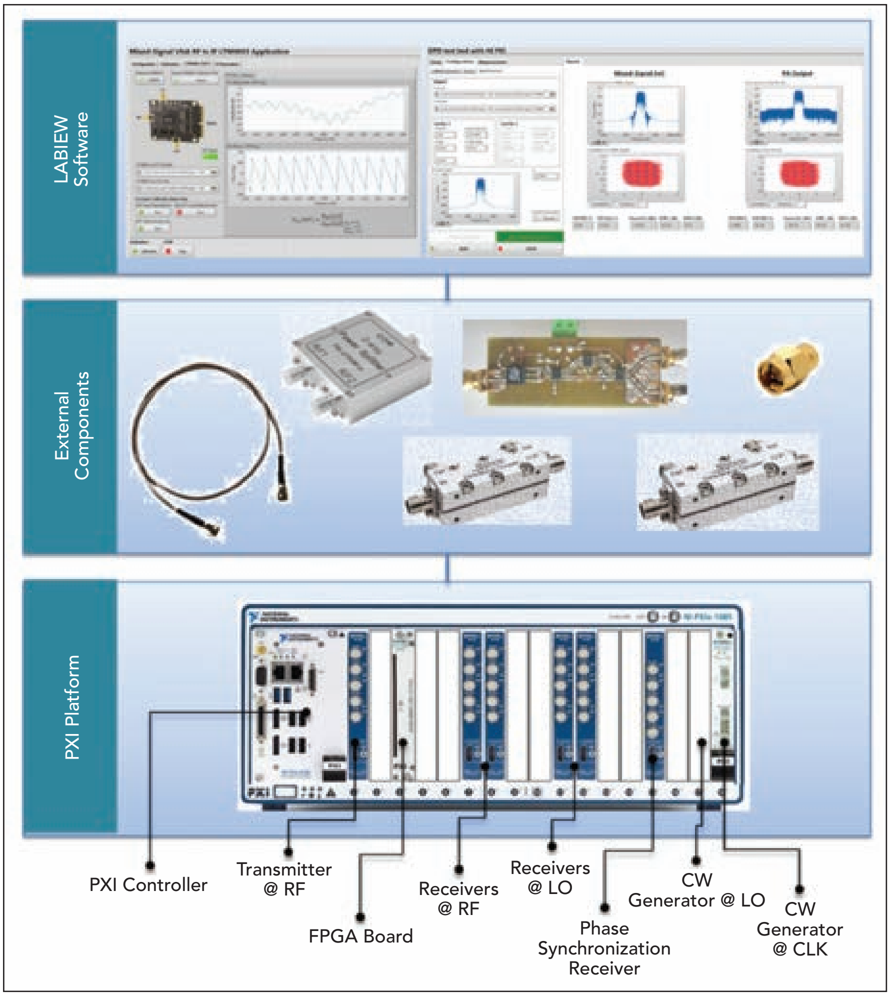


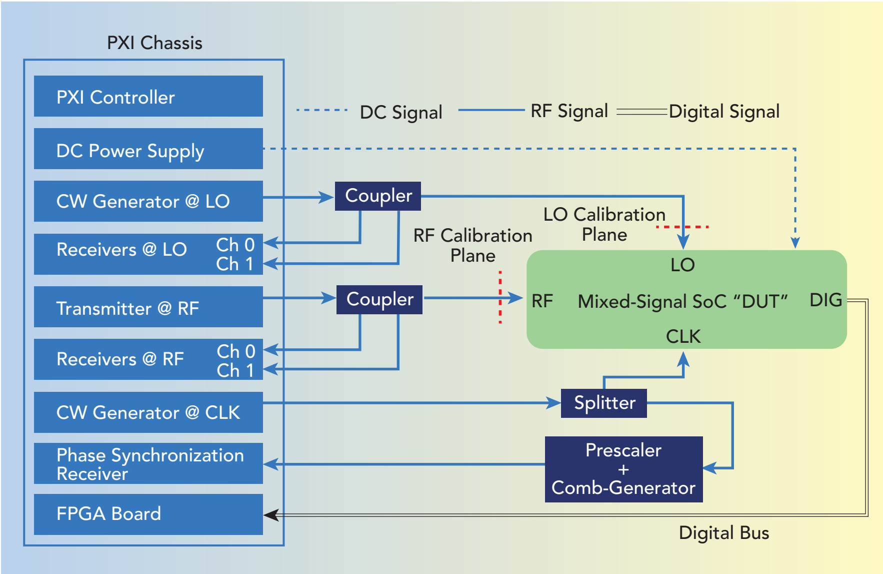
Fig. 4 Mixed-signal measurement system.

recently, a different framework for the characterization and modeling of mixed-signal systems was developed, one that includes an idealized mixed-signal instrument architecture and the D-parameters formulation.

To deal with the characterization and modeling challenge of real-world applications, test and measurement systems need to follow the evolution of the devices under test, making a switch from traditional instruments—commonly divided by the type of signal to be measured—to a software-defined architecture that integrates all relevant hardware into a single measurement system. This article illustrates one such instrument based on modular PXI hardware and LabVIEW, which makes it possible to realize a flexible, stable and practical test bench for characterizing and modeling mixed-signal systems. The full mixed-signal system comprises several layers, from PXI hardware to LabVIEW software applications and some external components, shown in ***Figure 4***. Two bidirectional couplers are employed at the RF and LO ports to allow measurement of the incident and reflected waves. This enables analog port calibration using a commercial short, open and load calibration kit. Additionally, a commercial power meter calibrates for absolute power, and an in-house developed comb generator (CG) is used to calibrate the absolute phase. This approach sets true calibration planes for the RF and LO ports (see ***Figure 5***). To enable readers to duplicate the setup, ***Table 1*** lists the instrumentation. To substitute for the "homemade" CG, any commercially available unit that accepts input frequencies from 1 to 250 MHz (the valid CLK range for the LTM9003) can be used.

MIXED-SIGNAL CHARACTERIZATION, MODELING AND SIMULATION

To demonstrate the capabilities and benefits of the measurement setup and the potential of mixed-signal scattering parameters, a practical example using the Linear Technology LTM9003 in the feedback loop of a DPD circuit is discussed. The goal of a DPD feedback loop is to generate a correction signal that eliminates the distortion generated by the power amplifier. The LTM9003 circuit sampling the output signal to generate the error information should not distort what is present at the output. Practically, however, the signal will be distorted, especially if one uses higher Nyquist zones to minimize the sample frequency and cost. Characterizing, modeling and compensating the feedback loop while linearizing is a solution to this problem. For this purpose, two LabVIEW applications were developed to obtain the RF performance and



▲ **Fig. 5 Architecture of the mixed-signal measurement system realized with the NI PXI platform.**

TABLE 1
PXI HARDWARE AND EXTERNAL COMPONENTS

PXI HARDWARE	REFERENCE	EXTERNAL COMPONENTS	REFERENCE
PXI Chassis	NI PXIe-1085	Coupler (LO Path)	Marki Microwave CBR16-0006 (2x)
PXI Controller	NI PXIe-8135	Coupler (RF Path)	Marki Microwave CBR16-0012 (2x)
DC Power Supplies	NI PXIe-4112 (Prescaler + CG NI PXIe-4138 (DUT)	Power Splitter	Mini-Circuits ZFRSC-42
CW Generator @ LO	NI PXIe-5652	Prescaler	On Semi MC12080
Receivers @ LO	NI 5792R (2x)	Comb-Generator (CG)	In-House Developed
Transmitter @ RF	NI 5793R	RF Cables	Any
Receivers @ RF	NI 5792R (2x)	Power Meter	Keysight E9301A
CW Generator @ CLK	NI PXIe-5652	Calibration Kit	Keysight 85052D
Phase Synch. Receiver	NI 5792R	Device Under Test (DUT)	Linear Technology LTM9003 EVM
FPGA Adapt. Board	NI PXIe-7962R		

▲ Fig. 6 LabVIEW application frames: configuring the system (a), calibrating the measurement test bench (b), measuring the mixed-signal LTM9003 (c) and presenting the calibrated results (d).

the RF-to-IF behavior of the LTM9003.

The first software application obtains the LTM9003 RF performance ($D_{11}(\omega)$ and $D_{21}(\omega)$), extracting the performance across the complete range of RF frequencies with a fixed IF. This IF is already in the digital domain and can be selected by the user. From the internal architecture of the mixed-signal IC, the LO signal must follow the RF sweep in either the sum (LO = RF + IF) or difference mode (LO = RF − IF). After calibrating and performing the measurement sweeps, data processing will give $D_{11}(\omega)$, which is required to understand the impact of RF input matching, and $D_{21}(\omega)$, which is the frequency-dependent gain from the RF input to a fixed digital IF. Both amplitude and phase characteristics are obtained, relating the device signals in the analog and digital domains. This information is essential to allow small-signal simulation of the mixed-signal system with the other RF components using microwave simulators. The LabVIEW frames are shown in ***Figure 6***, following the sequential steps to display the final calibrated measurements.

The RF-to-IF LabVIEW application characterizes the digital IF frequency behavior and is obtained by sweeping the RF vs. frequency while keeping the LO frequency fixed, which forces the received IF signal to vary. The RF input matching should be close to or equal in frequency to the RF performance application for the full frequency range. A transfer function between the analog input at RF port (a_{RF}) and the digital output (db_{DIG}) can be defined as the equivalent "gain" for the mixed-signal receiver, denoting the bandwidth performance of the device under test (DUT) and approximating, in this case, filter-like behavior. This measurement can be obtained for different clock (a_{CLK}) values and LO (a_{LO}) excitation frequencies and input power levels, resulting in a complete functional model. These models for mixed-signal components are important to simulate and optimize the overall performance. This LabVIEW application is similar in shape to the RF performance shown in Figure 6, so it is not included here.

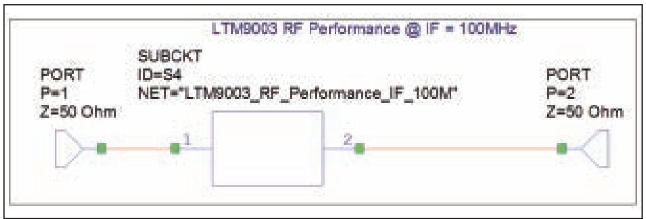


Fig. 7 Mixed-signal LTM9003 D-parameters imported into the NI AWR Design Environment.

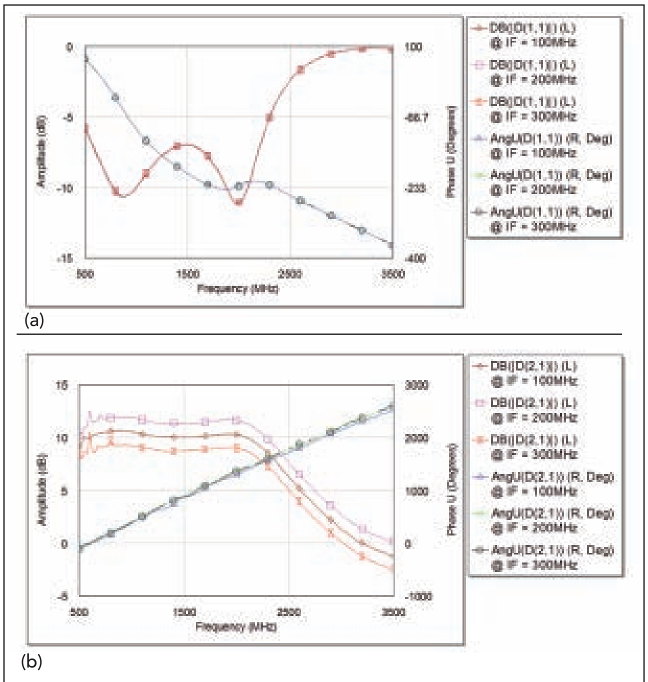


Fig. 8 D-parameters, in amplitude and phase, obtained for the RF performance application, with D_{11} (a) and D_{21} (b) imported into the simulation tool at different IF frequencies.

The next step uses the previously extracted data in RF circuit and system simulators such as Microwave Office (circuit) and Visual System Simulator™ (system). As the acquired D-parameter files (*.d2p) are compatible with the SnP Touchstone format (*.s2p) used for S-parameters, these files can be loaded directly into these simulators to obtain relevant information (see ***Figure 7***).

Figure 8 shows the D_{11} and D_{21} for the LTM9003, with a CLK frequency of 250 MHz. The curves observed in the D_{21} amplitude response show different gain values for the various IF frequencies measured. The D_{21} unwrapped phase component of the RF performance (shown in ***Figure 8b***) represents the physical delay or group delay of the DUT between the analog and digital ports for the given CLK frequency. In comparison, ***Figure 9*** shows

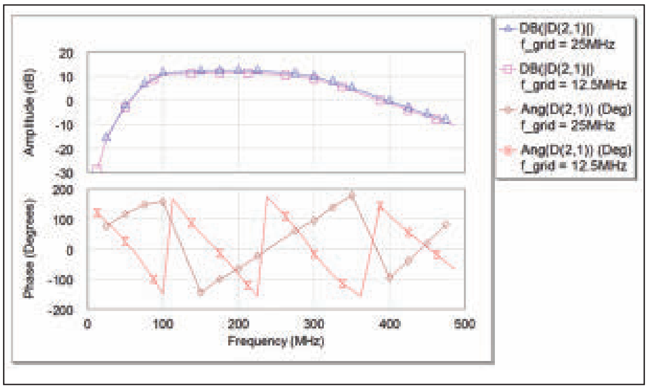


Fig. 9 RF to IF behavior, in amplitude and phase, obtained for an LO of 1 GHz when RF is swept for different frequency grid steps.

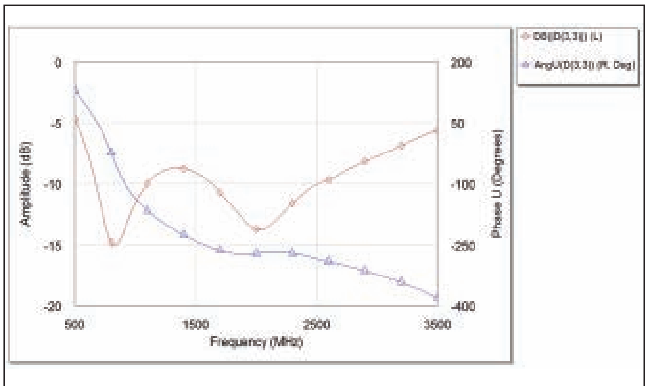
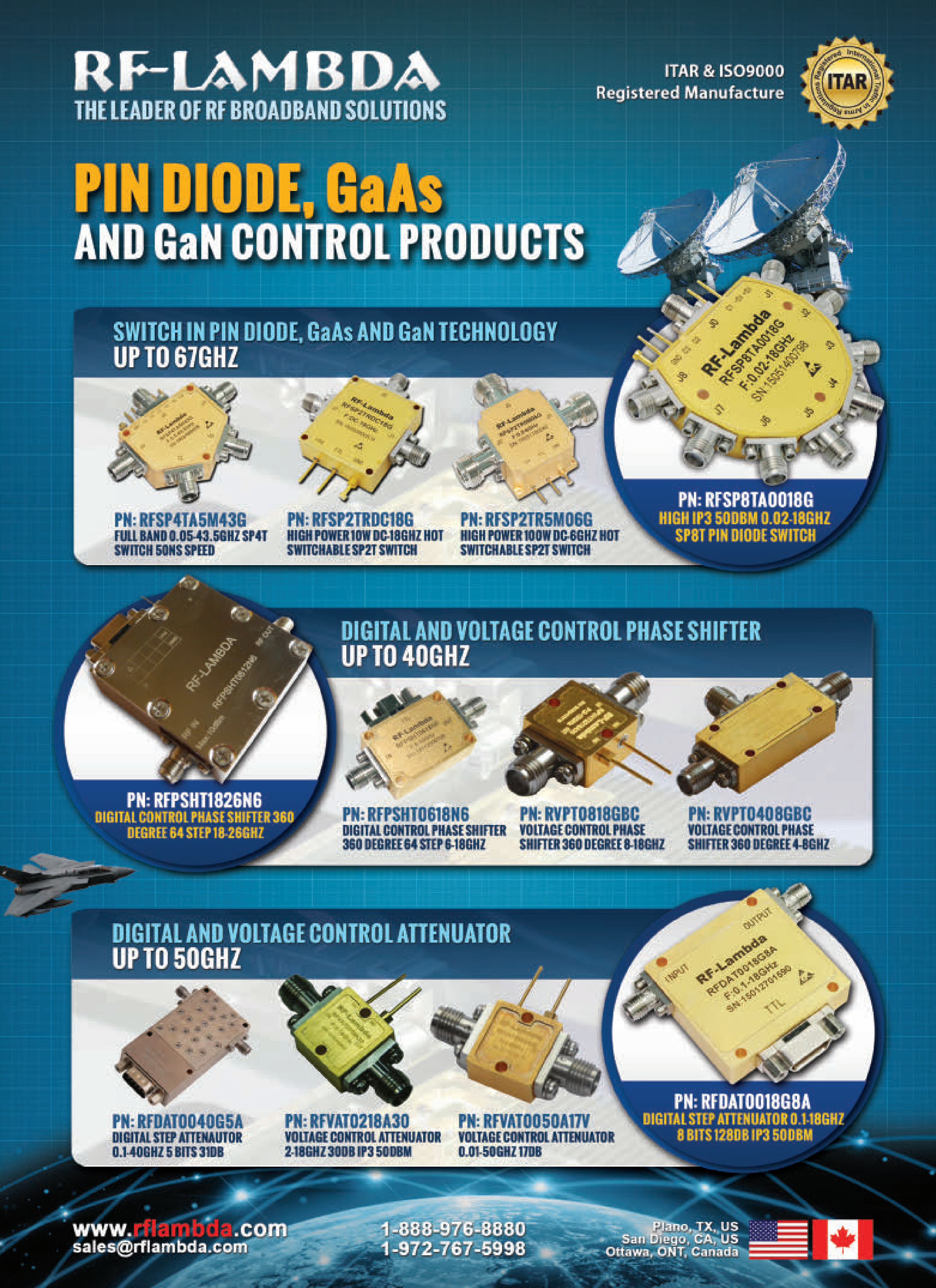


Fig. 10 LTM9003 LO port wideband matching performance.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the D_{21} phase component for the RF-to-IF performance normalized to 2π when using different frequency grids, which indicates a dependency between the CG grid and the CLK frequency. Also, it is easy to see the different Nyquist zones (multiples of CLK frequency) for the different grids. The D_{21} amplitude component depicts the expected BPF behavior. ***Figure 10*** shows the LO port performance as a function of frequency.

The LabVIEW applications offer diverse possibilities to further integrate this data into more complex configurations. With this new approach it is now possible to integrate mixed-signal analysis into the NI AWR Design Environment and optimize subsequent analog components inserted in the system, such as filters, matching networks and amplifiers.

CONCLUSION

This article addressed the D-parameter framework, practical implementation of a PXI-based characterization system for D-parameter extraction and examples of integrating the information into RF/microwave simulators. This approach provides a complete framework for characterizing mixed-signal devices, whether systems on chip or full discrete systems. This type of characterization is important for SDR system designers and DPD-PA optimization. Characterizing mixed-signal components is an important step in the optimization of these circuits, particularly when considering impairments or limitations in the feedback loop chain.[13-14] ■

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Full Function Oscilloscopes for ATE Systems

Keysight Technologies Inc.
Santa Rosa, Calif.

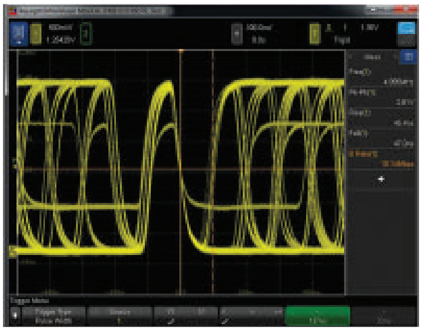
When testing electronics, it's hard to beat the general purpose oscilloscope. To validate electronic circuits, engineers depend on the ability to see and measure the signals in their designs. Automated test equipment (ATE) does not typically help with visual troubleshooting, which is challenging for users that have to install, calibrate and troubleshoot the system. These operations require the visualization tools that an oscilloscope delivers, and nothing beats the variety of measurements an oscilloscope provides. To achieve oscilloscope functionality in an ATE environment, users often use soft front panel oscilloscope software with a digitizer. While the software looks like an oscilloscope, it does not have the performance tools traditional oscilloscopes have that are required for troubleshooting.

OSCILLOSCOPE IN A SINGLE PXI SLOT

Keysight's new InfiniiVision PXIe modular oscilloscopes are designed to provide the usability and performance of a traditional benchtop oscilloscope in a PXIe modular system. Three models allow the choice of bandwidth to fit measurement requirements: the M9241A provides 200 MHz bandwidth; the M9242A, 500 MHz and the M9243A, 1 GHz.

Keysight has been manufacturing high performance oscilloscopes for more than 60 years and leveraged this knowledge to create PXIe oscilloscopes that go beyond merging a digitizer with scope software. The M924XA modular oscilloscopes have the same high performance MegaZoom technology that is used in the popular InfiniiVision 3000T X-Series benchtop scopes. They also share the same optimized user interface, so operating the M924XA oscilloscopes on a PC will look and feel similar to using a familiar oscilloscope.

Oscilloscopes acquire, process and plot data on the screen for user troubleshooting and signal analysis. The display shows multiple waveforms on the screen at the same time. The use of waveform intensity allows quick identification of signal errors that are key to viewing the signal. However, this is more difficult for people who try to use a digitizer with oscilloscope software, and



▲ Fig. 1 With a high update rate, the Keysight modular oscilloscopes can capture infrequent pulses.

▲ Fig. 2 Zone triggering enables isolating a signal with a non-monotonic edge.

▲ Fig. 3 Serial communications can be decoded and analyzed with protocol analysis tools.

they are frequently frustrated by the signal display limitations. The Keysight modular oscilloscopes address these limitations by providing an industry-leading waveform update rate—up to 1 million waveforms per second—that enables capturing more signal detail. When a runt pulse occurs just a few times per second on a high frequency signal, it takes a high waveform update rate to capture and display the signal (see ***Figure 1***). Using zone triggering, these scopes allow the user to create a trigger based on signal information that is displayed on the screen. With zone triggering, if you can see the event on the display, you can easily trigger on it by simply drawing a box on the screen with a mouse or finger (on a touch-enabled screen) and selecting the desired trigger action (see ***Figure 2***).

Acquiring massive amounts of data from digitizers running oscilloscope software is often required, because they do not have the ability to properly isolate the desired signal in real-time. So large data captures are transferred to the controller for software analysis, hoping that the signal of interest was captured. Oscilloscopes approach this problem by providing tools that enable selective data to be captured, concentrating data acquisition and analysis on advanced parametric information such as runt pulse, rise/fall time, setup and hold. Users can isolate the signal of interest and then use the measurement and analysis tools to determine the signal parameters of interest. Sometimes it is not the data—but simply identifying and counting these events—that proves to be the required information.

ADDED CAPABILITIES

While the oscilloscope capability is the primary benefit of Keysight's M924XA series modular oscilloscopes, it is not the only analysis tool included. The integrated 20 MHz arbitrary waveform generator provides stimulus to activate the circuits and operations of the system being tested, allowing users to capture, edit and replay signals. The waveform generator also provides a quick and easy way to integrate a function generator for more standard signals.

Protocol analysis is often a difficult tool to find integrated into the modular environment; however, the M924xA series has this capability. It includes many advanced protocol tools for triggering and decoding serial communications signals. Whether chip-to-chip communication or military communications, its full-featured protocol analysis capability allows users to define packets of interest for triggering and decoding the communications protocol.

As an example, ***Figure 3*** shows counting CRC errors on an automotive CAN communications link. Sometimes simply counting signal events is all that is required, and all of the oscilloscope trigger events can be converted into an event counter or totalizer. The general purpose counter can be used as an 8-digit frequency counter or an event, providing triggering capabilities that are faster than the display's 25 million events per second.

Whether performing pass/fail tests to specifications in manufacturing or testing for infrequent signal anomalies, mask/limit testing can be a valuable productivity tool. In the past, ATE systems often required a custom FPGA to provide real-time analysis. Keysight's new modular oscilloscopes feature powerful hardware-based mask testing that can perform up to 270,000 tests per second. Users can easily create a mask based on a previously captured "ideal" signal and then report the test results as simple counts or as a six-sigma performance benchmark.

Signal analysis is only as good as the probes used to capture the signal. Keysight has a wide range of probing solutions for the modular environment, enabling a variety of different applications to be supported. In addition to the standard range of passive voltage probes, Keysight offers high temperature environmental probes, high sensitivity current probes, high current probes, high voltage probes and power rail probes. Notably, the power rail probe provides a large offset, low noise and 1:1 attenuation with very low loading for making critical power integrity measurements.

ATE operation often places a heavy burden on the software—and the programmer—to perform a correct analysis when characteristics are still under development or the operational performance of the system is being profiled. An oscilloscope is the general purpose "go to" tool for validating the system test configuration, and the integration of an oscilloscope into an ATE system can improve the test operation. It can be a powerful tool to improve system availability through improved calibration and troubleshooting for interactive operation.

VENDORVIEW

Keysight Technologies Inc.
Santa Rosa, Calif.
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Entry-Level Oscilloscope Offers Power, Performance and Flexibility

Rohde & Schwarz
Munich, Germany

Claimed to be the first low cost oscilloscope to offer touch screen operation as well as a 10-bit vertical resolution, the entry-level R&S RTB2000 is designed for education, R&D and manufacturing applications. The series comes in two and four channel models and offers bandwidths of 70, 100, 200 and 300 MHz. The instrument offers the "power of 10" by providing a 10-bit analog-to-digital converter (ADC), 10 Msample memory and 10.1" capacitive touch screen.

10-BIT VERTICAL RESOLUTION

Oscilloscopes measure voltage versus time. The ADC (shown in ***Figure 1***) determines how well the oscilloscope can resolve the amplitude of measured signals. In the past oscilloscopes have predominantly offered eight bits of vertical resolution, which allows a signal to be mapped to one of 256 vertical positions. The R&S RTB2000 includes a proprietary 10-bit ADC with 1024 vertical positions—a four-fold improvement compared to a conventional 8 bit ADC.

The increased resolution enables users to make more precise measurements and can be particularly useful for detecting small signals in the presence of large-amplitude signals. One example is the characterization of switched-mode power supplies. The voltages across the switching device must be determined precisely throughout the switching process within the same acquisition.

The R&S RTB2000 oscilloscope offers sensitivity down to 1 mV/div. Traditional oscilloscopes reach this level of input sensitivity only by employing software based magnification or by limiting the bandwidth. In contrast, the R&S RTB2000 oscilloscope retains the full measurement bandwidth—even at 1 mV/div—ensuring high measurement accuracy.

The accuracy of measurements on a signal also depends on the oscilloscope's inherent noise. The R&S RTB2000 precisely measures even at the smallest vertical resolution by using low-noise front-ends and state-of-the-art ADC.

▲ **Fig. 1 The 10-bit analog-to-digital converter ensures highest signal fidelity at highest resolution.**

10 MSAMPLE MEMORY

After bandwidth and sample rate, memory depth is the most important attribute that determines an oscilloscope's ability to handle a large range of troubleshooting tasks. The R&S RTB2000 oscilloscopes feature a 10 Msample acquisition memory on each oscilloscope channel, and 20 Msample per channel in interleaved mode. Users benefit from high sampling rates for longer time captures for testing and troubleshooting, which provides additional insight into electronic devices.

This large standard memory also has the option to further extend to 160 Msample of segmented memory. The R&S RTB-K15 option with deep, segmented memory analyzes signal sequences over a long observation period. For example, protocol-based signals with communications gaps such as I²C or SPI can be captured over several seconds or minutes. Thanks to the variable segment size from 10 ksample to 10 Msample, the 160 Msample memory is optimally utilized; more than 13,000 cohesive individual recordings are possible.

10.1" TOUCH SCREEN

Today, touch operation has become commonplace in work and personal environments. Consequently, capacitive touch is also becoming more important for oscilloscope users as it allows them to operate the instrument more quickly and efficiently. With the R&S RTB2000, for the first time, users with lower budgets have access to not only touch screen but capacitive touch screen operation with a large display. The oscilloscope delivers a 1280 × 800 pixel 10.1" capacitive touch screen to quickly navigate in pop-up menus and a touch function to easily adjust scaling, to zoom in or to move a waveform – just like on a smartphone.

X-IN-1 OSCILLOSCOPE

The R&S RTB2000 gives users more than just an oscilloscope. It also includes a logic analyzer, protocol analyzer, waveform and pattern generator and digital voltmeter.

Dedicated operating modes for frequency analysis, mask tests and long data acquisitions are also integrated. Debugging all kinds of electronic systems is easy and efficient and satisfies the all-important rule of investment protection. The following outlines these features.

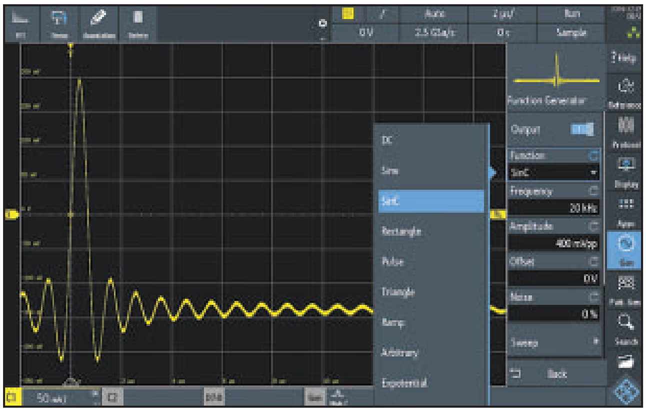
Oscilloscope — A waveform update rate of more than 50,000 waveforms/s ensures a responsive instrument that reliably catches signal faults. Included standard tools provide quick results, e.g., QuickMeas, mask tests, fast Fourier transform (FFT), math, cursors and automatic measurements, including statistics.

Logic Analyzer — The R&S RTB-B1 option turns every R&S RTB2000 into an intuitive-to-use MSO with 16 additional digital channels. The oscilloscope captures and analyzes signals from analog and digital components of an embedded design—synchronously and time correlated to each other. For example, the delay between input and output of an ADC can conveniently be determined using the cursor measurements.

Protocol Analyzer — Protocols such as I²C, SPI and CAN/LIN are among the most commonly used to transfer control messages between integrated circuits. The R&S RTB2000 has versatile options for protocol-specific triggering and decoding of serial interfaces. Selective acquisition and analysis of relevant events and data is possible. With the hardware-based implementation, smooth operation and a high update rate is ensured even for long acquisitions. This is advantageous, for example, to capture multiple packetized serial bus signals.

Waveform and Pattern Generator — The integrated R&S RTB-B6 waveform and pattern generator up to 50 Mbit/s is useful for educational purposes and for implementing prototype hardware. Apart from the common sine, square/pulse, ramp and noise waveforms, it outputs arbitrary waveforms and 4-bit signal patterns. Waveforms and patterns can be imported as CSV files or copied from oscilloscope waveforms. Before playing signals back, the user can preview them to quickly check signal correctness. Predefined patterns for e.g., I²C, SPI, UART and CAN/LIN can be used (shown in **Figure 2**).

Digital Voltmeter — The oscilloscopes feature a three-digit voltmeter (DVM) and six-digit frequency counter on each channel for simultaneous measurements. Measure-



▲ **Fig. 2** The built-in generator offers many commonly used functions, as well as the possibility to reproduce arbitrary waveforms.

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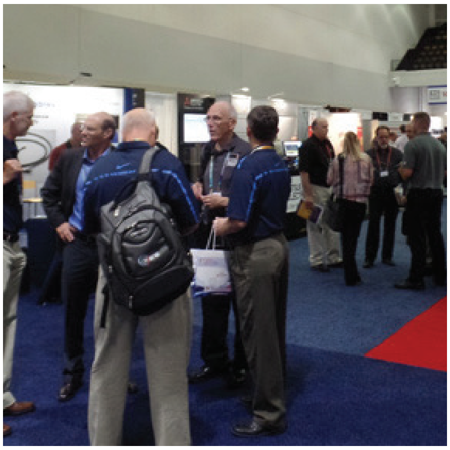

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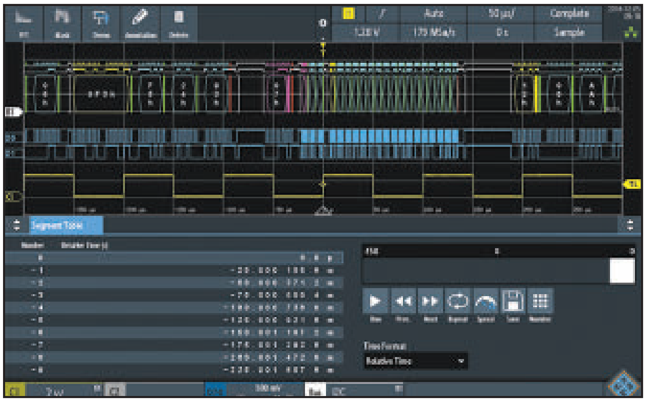


Fig. 3 The deep segmented memory enables recording serial protocol packets.

ment functions include DC, AC+DCRMS and ACRMS—included in scope of delivery.

Frequency Analysis Mode — Difficult-to-find faults often result from the interaction between time and frequency signals. The FFT function is activated with the push of a button and by just entering center frequency and span. Due to this high-performance FFT signals can be analyzed with up to 128 kpoints. Other practical tools include cursor measurements and autoset in the frequency domain.

Mask Test Mode — Mask tests quickly reveal whether a specific signal lies within defined tolerance limits. By using statistical pass/fail evaluation, they assess quality and stability of a device under test. Signal anomalies and unexpected results are quickly identified. When the mask is violated, the measurement stops. Each violation can generate a pulse output at the AUX-OUT connector and this pulse output can be used to trigger actions in the measurement setup.

History and Segmented Memory Mode — The R&S RTB-K15 history function option increases the memory from 10 Msample to 160 Msample. Users scroll through past acquisitions and analyze the data using all of the oscilloscope tools, e.g., protocol decode and logic channels. Serial protocol and pulse sequences are recorded practically without interruptions (shown in ***Figure 3***).

FUTUREPROOF

The R&S RTB2000 oscilloscopes flexibly adapt to needed project updates by installing software licenses. This applies, for example, to triggering and decoding of serial protocols and the history and segmented memory mode. The waveform and pattern generator and the MSO capabilities are built-in and just need to be activated. Also, via keycode, the bandwidth can be upgraded up to 300 MHz, which makes retrofitting easy.

To facilitate global use the oscilloscope's user interface and online help support 13 languages—English, German, French, Spanish, Italian, Portuguese, Czech, Polish, Russian, simplified and traditional Chinese, Korean and Japanese. Users can change the language in just a few seconds while the instrument is running.

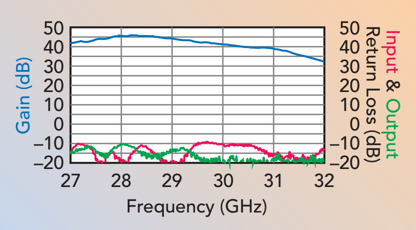
VENDOR**VIEW**

Rohde & Schwarz
Munich, Germany
+49 89 4129 12345
www.rohde-schwarz.com

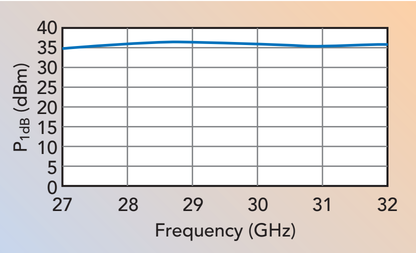
27 to 32 GHz, 4 W Linear Power Amplifier for 5G

SAGE Millimeter Inc.
Torrance, Calif.

SAGE Millimeter's engineers have developed a 4 W linear, Ka-Band power amplifier to help its clients reach 5G. Developed for laboratory prototyping and rapid concept demonstration, the SBP-2733233836-KFKF-S1 will help users develop and test components in one of the main frequency bands used for 5G. Customers can save time and resources using an off-the-shelf amplifier with high performance, rather than investing in a custom component that requires a non-recurring engineering budget and a longer R&D timeline.



▲ **Fig. 1 Small-signal gain and input/output return loss, with V_d = +6 V, I_d = 4.2 A, V_g = −2 V.**



▲ **Fig. 2 Output power at 1 dB compression, with V_d = +6 V, I_d = 7 A, V_g = −2 V.**

The small-signal gain, return loss and output power at 1 dB compression across 27 to 32 GHz are shown in ***Figures 1*** and ***2***. The typical P_{1dB} is +36 dBm, the small-signal gain is 38 dB, and the input and output return losses are -10 dB or better. The amplifier is biased with a nominal drain voltage of +6 V_{DC}, drawing 4.2 A quiescent and 7 A under RF drive. It also requires a gate bias of -2 V_{DC} and draws less than 1 mA for gate control. The amplifier is housed in an aluminum case, measuring 1.2" (W) × 1.2" (L) × 0.5" (H), and typically weighs 1.3 oz. The amplifier has a compact profile, which makes it suitable for system integrators and feasible for volume manufacturing. The SBP-2733233836-KFKF-S1 has female K connectors at the input and output, although the design is offered with other configurations, such as right angle or end-launch WR-28 waveguide interfaces. Due to the high DC power consumption, the amplifier requires a proper heat sink for continuous wave operation, to prevent the case temperature from exceeding +50°C.

The laws of physics continue to challenge the implementation of millimeter wave technology. Due to the atmospheric attenuation in free space at Ka-Band, system engineers must balance power requirements and linearity for communications and instrumentation systems. Higher frequencies have shorter wavelengths, limiting the range for a given power. The solution to this limitation is to transmit higher power with higher antenna gain, but this adversely affects noise and can exponentially increase cost. SAGE Millimeter's SBP-2733233836-KFKF-S1 serves as a middle ground for the market, offering a higher output power at a price point accessible to cost-conscious programs. The high- power Ka-Band amplifier can be used for any variety of applications in the frequency range. The higher gain allows the amplifier chain to achieve the desired output power with a single unit, versus cascading multiple components to achieve the same gain and output power. This makes the SBP-2733233836-KFKF-S1 ideal for linear, high-power applications such as Ka-Band VSAT, high capacity point-to-point and point-to-multipoint radios and radar systems that demand +37 dBm of saturated output power.

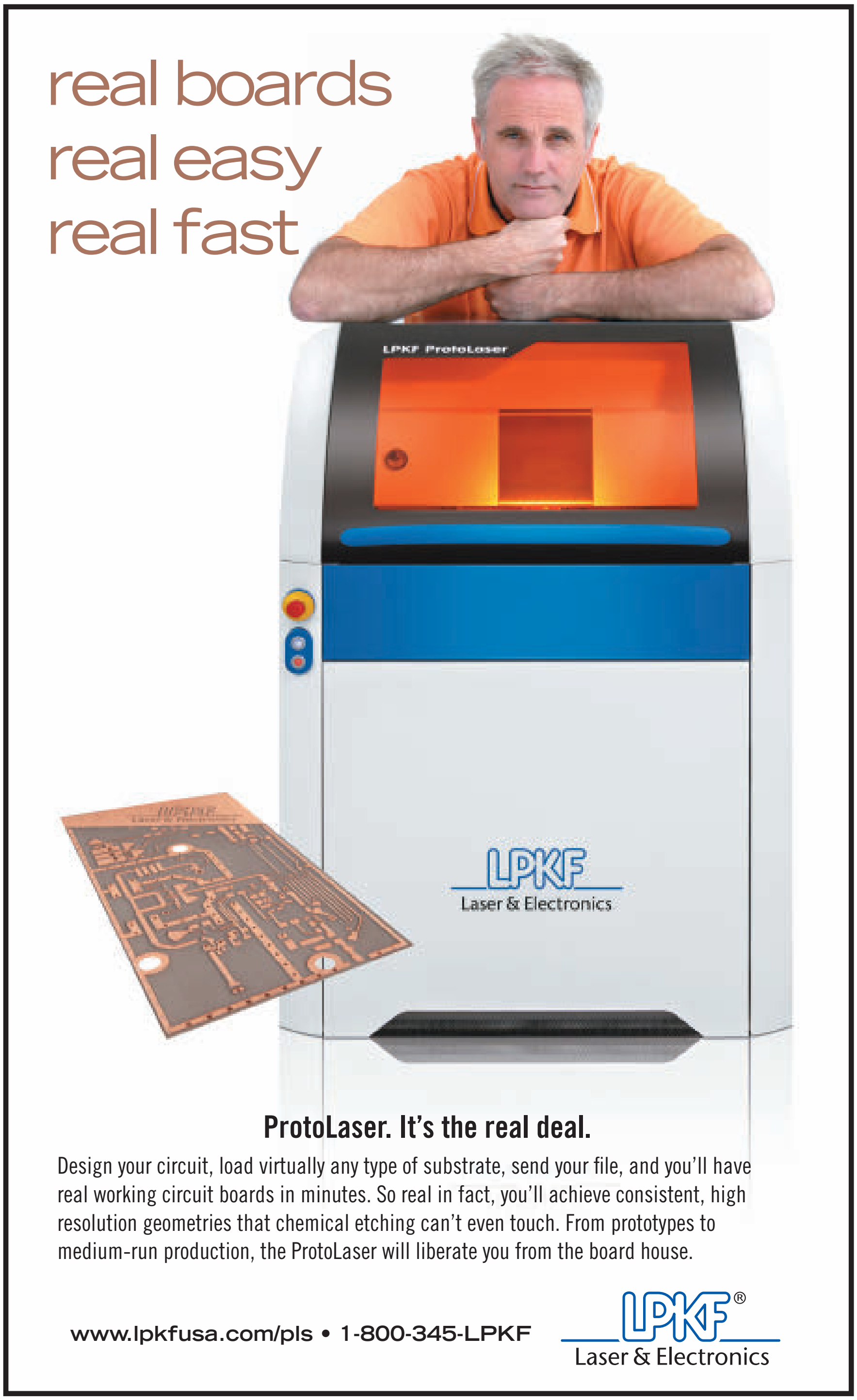
With experience designing and manufacturing millimeter wave components and sub-assemblies, SAGE Millimeter works closely with its customers to meet extremely high frequency requirements across multiple industries. A recurring conversation SAGE engineers have with customers is how to balance the often competing interests of lead-time, performance and cost. Moving from microwave to millimeter wave frequencies can be an expensive process, with lab and test equipment upgrades and a formidable knowledge and experience gap. Responding to these challenges, SAGE began developing and manufacturing an extensive portfolio of demonstrated, ready-to-use components for the marketplace. The SBP-2733233836-KFKF-S1 power amplifier was inspired by an actual customer requirement for a ground-based SATCOM application and is one of many products to come from this ready-to-use initiative.

This Ka-Band power amplifier holds true to the SAGE Millimeter design philosophy of creating elegant, easy-to-use components. The universal design makes for multi-system compatibility, enabling it to fit into most industry-standard systems and test setups. The amplifier can also be used with components from other manufacturers, but the best integration and performance is achieved when it is paired with other SAGE-designed components, such as mixers, oscillators, antennas and multipliers.

The SBP-2733233836-KFKF-S1 has received interest from many industry sectors working at Ka-Band, especially after the FCC's July 2016 action that allocated 10.85 GHz of spectrum above 24 GHz, of which 3.85 GHz is within Ka-Band. While additional spectrum was allocated at higher frequencies, telecommunications and wireless leaders have been working aggressively at 28, 37 and 39 GHz. The FCC's announcement unleashed waves of new innovation, with a wide economic impact in other industries, including radar systems, test equipment, VSAT/SATCOM, military and space. These diverse customers can take advantage of the SBP-2733233836-KFKF-S1 amplifier's performance, lead-time and cost.

VENDORVIEW

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



SP4T MEMS 0 Hz (DC) to 13 GHz Switch Has 5 kV ESD Rating

Analog Devices Inc.
Norwood, Mass.

Groundbreaking technology is needed to solve big problems: microelectromechanical system (MEMS) switches can deliver the innovation needed to overtake relays and let the industry achieve the next level of performance. Relays date to the earliest days of the electric telegraph, and, until now, no alternative switching technology has been developed that can meet all the evolving market needs in test and measurement (T&M), communications, defense, healthcare and consumer. As one example, T&M users are demanding multi-standard test solutions in the smallest form factor, with maximum parallelism and DC to 10s of GHz coverage. Mapped against this requirement, electromechanical relays have narrow bandwidths, a limited number of channels and large package sizes — plus limited actuation lifetimes.

With an internal state-of-the-art MEMS fabrication facility, Analog Devices (ADI) is now mass producing MEMS switches that are high performance, small, fast, low power, mechanically durable and electrostatic discharge (ESD) protected. Initially, two catalog products are available: the ADGM1004 is a SP4T switch covering 0 Hz (DC) to 13 GHz with enhanced ESD protection: 5 kV human body model (HBM) on the RF ports — a MEMS switch industry first. The ADGM1004 integrates solid-state ESD protection technology to increase the ESD rating. The second switch, the ADGM1304, offers similar RF performance; however, it does not include the added solid-state ESD protection technology and is rated at 100 V HBM.

MEMS SWITCH TECHNOLOGY

Central to the ADI MEMS switch technology is an electrostatically-actuated micromachined gold cantilever beam switching element. The switch can be thought of as a micrometer-scale mechanical relay, with

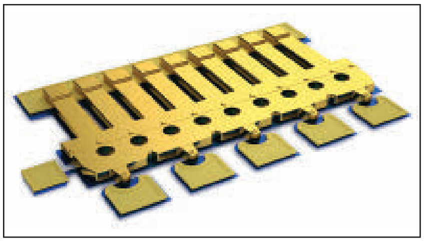


Fig. 1 Single MEMS cantilever switch beam.

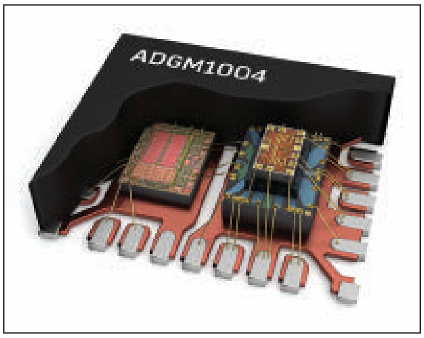


Fig. 2 MEMS switch with ESD protection (right) and driver IC (left) assembled in QFN package.

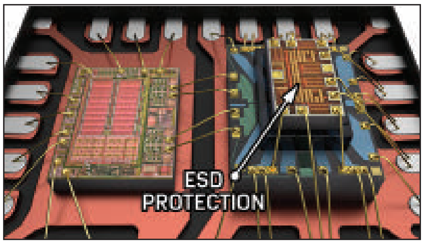


Fig. 3 Solid-state ESD protection die mounted on the MEMS switch.

metal-to-metal contacts that are actuated through high DC voltage electrostatics. ***Figure 1*** is a graphic of a single MEMS switch cantilever, showing the five parallel contacts in the front and the hinge structure with air gaps in the rear.

A companion driver IC, designed by ADI, makes the MEMS switch easy to use. It generates the high DC voltage required to actuate the switch, ensuring fast and reliable actuation and long switching lifetime. The driver typically consumes only 10 mW, which is 10× lower than typical drivers used for RF relays. The MEMS die and driver IC are assembled in an ultra-small SMD QFN package.

The ADGM1004 version of the MEMS switch also integrates solid-state ESD protection technology (see ***Figure 2***), which increases the RF port ESD rating to 5 kV (HBM). The non-RF ports are rated at 2.5 kV (HBM). The integrated solid-state

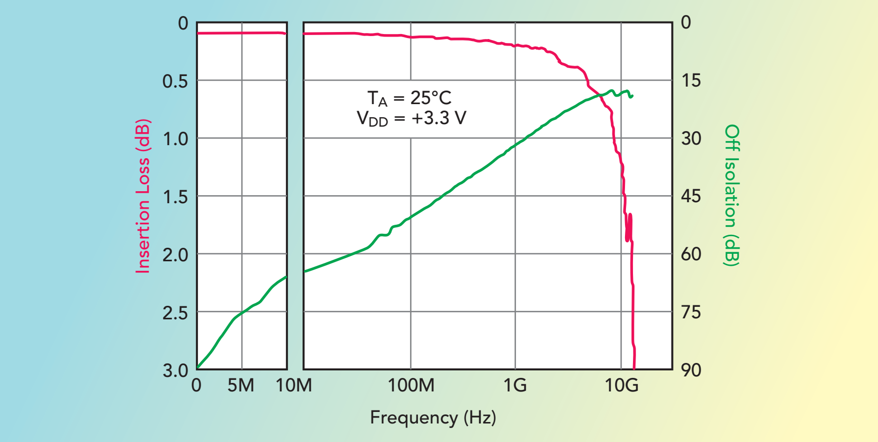


Fig. 4 Insertion loss and isolation of the MEMS switch.

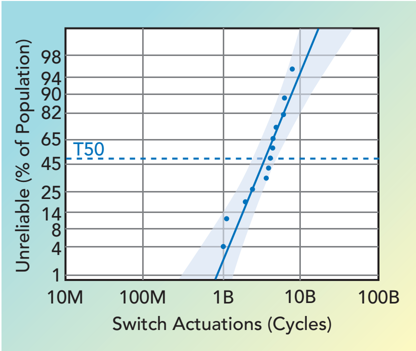


Fig. 5 10 dBm hot switch mean lifetime is approximately 3.4 billion cycles.

ESD protection circuitry is a proprietary ADI technology that provides protection with minimal effect on RF performance. ***Figure 3*** shows the ESD protection die, which is mounted on the MEMS die in the package. The wire bonds to the RF pins of the package are optimized for both RF and ESD performance. To develop the ADGM1004, ADI combined three proprietary lithographic technologies with assembly and a MEMS capping technology to achieve this breakthrough HBM ESD rating.

0 HZ TO 13 GHz PERFORMANCE

The strength of the MEMS switch is that it combines DC precision and wideband RF performance in a 5 mm × 4 mm × 1.45 mm, surface-mountable form factor. ***Figure 4*** shows the measured insertion loss and off isolation for the ADGM1004 SP4T switch. Insertion loss is only 0.45 dB at 2.5 GHz, and the 3 dB bandwidth reaches 13 GHz. RF power handling is rated at 32 dBm without compression, and the third-order intercept point (IP3) is typically a constant 67 dBm vs. frequency, with no degradation at very low frequencies. Switching speed is 30 μs. On resistance is typically 1.8 Ω, off leakage current is a maximum of 0.5 nA, and the switch will pass ±6 V and 220 mA. The switch requires a supply voltage between 3.1 and 3.3 V and consumes 10 mW typical.

The actuation lifetime of the ADGM1004 switch has also been characterized by toggling the switch with RF power passing through it (i.e., hot switching). ***Figure 5*** shows the projected lifetime probability distribution when hot switching a 2 GHz, 10 dBm RF signal. From this test, the mean number of cycles before failure (designated T50) is approximately 3.4 billion cycles. The ADGM1004 data sheet provides data for higher power levels. ADI specifies a cold switch lifetime of 1 billion cycles minimum.

CONCLUSION

ADI's groundbreaking MEMS switches are easy to use and provide excellent switch performance in RF and 0 Hz applications. With footprint an increasingly critical requirement across all markets, a MEMS switch occupies up to 95 percent less volume than a typical DPDT electromechanical relay. ADI's MEMS technology consumes 10× less power, is 10× more reliable and 30× faster than relays. The ADGM1004 provides enhanced ESD protection, with a rating of 5 kV HBM on all RF ports.

VENDORVIEW

Analog Devices Inc.
Norwood, Mass.
www.analog.com

DC to 26.5 GHz SP6T and SPDT Switches

Dow-Key® Microwave has released SP6T and SPDT switches to the Reliant Switch™ family, giving the automated test equipment (ATE) industry the flexibility to choose between lifetime and cost without sacrificing performance.

The SP6T switch has an operating frequency range of DC to 26.5 GHz, guaranteed insertion loss repeatability of 0.03 dB across the full band and 100 dB isolation up to 12.4 GHz. The switch has 50 Ω, 2 W terminated ports and is offered with latching actuators, SMA connectors, optical position indicators and the option of a TTL interface. The SP6T switch is designed for an operating life of 5 million cycles.

Dow-Key's SPDT and SPDT terminated coaxial switches also cover DC to 26.5 GHz and achieve the same insertion loss repeatability of 0.03 dB across the entire frequency range. They also have latching actuators, optical position indicators, SMA connectors and an optional TTL interface. However, these SPDT switches have an extended operating life of 10 million cycles.

Engineers performing component manufacturing and system integration face the challenges of reducing the cost of test while ensuring reliability over the life expectancy of the test system. Test reliability requires maintaining insertion loss repeatability between ports, to increase measurement accuracy and reduce the source of errors. A longer life expectancy keeps the cost of replacing RF switches to a minimum and reduces system downtime. Dow-Key Microwave's Reliant Switch product line is economically priced to minimize budgetary concerns, while delivering excellent electrical and mechanical performance over a broad frequency range.

Dow-Key Microwave
Ventura, Calif.
www.dowkey.com/solutions/reliant-switch/

10 W, 32 to 40 GHz, GaAs FET Power Amplifier

Exodus Advanced Communications has introduced its latest solid-state high power module, the AMP3060. This linear, GaAs FET hybrid, Class AB design provides 10 W output across 32 to 40 GHz, with a minimum power gain of 40 dB and 4 dB peak-to-peak maximum flatness when driven with a constant maximum input power of 0 dBm. The AMP3060 is suitable for EMI/EMC susceptibility, millimeter wave component testing, electronic warfare, Ka-Band satellite and general communications applications.

The high power module, which measures 5.51" × 6.89" × 0.98", requires a nominal +9 VDC bias and draws 37 A maximum current. The amplifier is also available in a standard 19" rack-mounted chassis configuration with self-contained air cooling and AC operation. An optional controller with a front panel touch screen LCD supports Ethernet TCP/IP, RS422 or RS485 and, upon request, remote Bluetooth connectivity.

Exodus Advanced Communications develops and manufactures solid-state RF power amplifiers (PA) covering various frequency bands from 100 kHz to 47 GHz, with module output power greater than 1 kW and complete systems exceeding 10 kW. Other standard products include a family of 10, 20 and 40 W PAs over 6 to 18 GHz and PAs up to 250 W over 2 to 6 GHz. Exodus PAs integrate discrete LDMOS, GaAs and GaN devices with ceramic substrates using hybrid chip-and-wire assembly processes. In-house capabilities include RF circuit design; system mechanical, electrical and digital circuit design; control software development and prototype verification.

VENDORVIEW

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

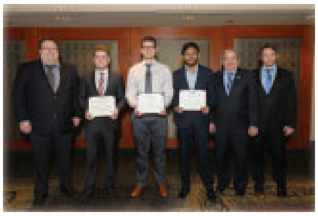
Radio Wireless Week

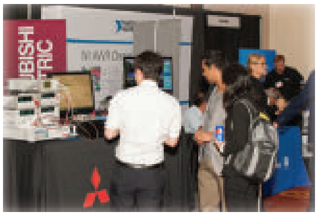
14-17 January 2018, Hyatt Regency Orange County, Anaheim, CA

IEEE MTT-S

Paper Deadline 25 July 2017

http://www.radiowirelessweek.org





Call For Papers

The 2018 IEEE Radio and Wireless Symposium (RWS2018) will be held during the week of 14 January 2018 in Anaheim, CA, USA.

RWS2018 and the 18th IEEE Topical Meeting on Silicon Monolithic Integrated Circuits SiRF2018 are co-located and will continue to hold joint sessions. Topical conferences held in parallel provide more focused sessions in the areas of RF Power Amplifiers (PAWR), Topical Workshop on The Internet of Space (TWIOS), and Wireless Sensors and Sensor Networks (WiSNet). Additional events include an RWS Demonstration Track and the 2nd Annual Young Professionals Workshop!

1. High-speed and Broadband Wireless Technologies
- Broadband Fixed Wireless and Last-Mile Access
- Ultra-High Data Rate Communications Links - Powerline Communication Technologies
- 3G/4G Wireless Communication Services
- Ultra-Wideband (UWB) Systems
- Optical Networks and Systems

2. Emerging Wireless Technologies and Applications
- M2M & V2V Technologies & Applications
- Resource Management, Security
- Femtocell and Heterogeneous Networks
- Satellite Network Systems
- Green, Sustainable Wireless Tech. & Networks - Advances in LANs, PANs, BANs, MANs, RANs

3. Wireless System Architecture and Modeling
- Ad Hoc Network Techniques for Internetworking
- Distributed Network Architectures
- Cellular Architectures and Systems
- Wireless Mesh and Broadband Local/Personal/ Body Area Networks
- Wireless Security and RFID Technologies

4. Propagation/Channel Modeling and Utilization
- Propagation/Channel Characterization & Modeling - Fading Countermeasures
- Spectrum Sensing Technologies
- Frequency and Channel Allocation Algorithms

5. Digital Signal Processing, SDR, & Cognitive Radio
- Digital/Analog Adaptive/Collaborative Signal Processing
- Methods for Maintaining Signal Integrity and Signal Conditioning
- Interference mitigation and Cancellation Techniques
- Software/Hardware architectures, Algorithms
- MAC, Networking protocols, Regulatory Policies, Standardization
- Dynamic Spectrum Sharing, Coexistence, Interoperability

6. Applications to Bio-medical, Environmental, and Internet of Things
- Miniaturization and integration of wireless technologies and micro sensors
- Personal area networks and body area sensor networks
- Wireless positioning technologies & remote sensing

7. MIMO and Multi-Antenna Communications
- MIMO, MU-MIMO, Space-Time Processing - Relaying Technologies
- Cooperative/Collaborative Technology
- Multi-Beam Smart Antennas

8. Antenna Technologies
- Passive & Active Antennas from RF to THz Frequencies
- Miniaturized, Multi-frequency and Broadband Antennas
- Wireless Platform Integrated Antennas - Vehicular and Satellite Antennas

9. Transceiver & Front-end Technologies, SOC & SiP
- Receiver, Transmitter and Transceiver Components - Active Circuits and Sub-systems
- Multi-Standard Circuits and Sub-systems
- Low-Power/Low Noise RF/Analog IC and System-On-Chip
- Highly Integrated Transceivers for Sensing and Imaging

10. Passive Components & Packaging
- Discrete, Embedded and Distributed Passive components
- Filters, Couplers and Signal Separation Devices
- Discrete and Highly Integrated Packaging
- 3D-packaging, Interconnects, TSV Technologies and Applications
- Packaging of MEMs, Biosensors, Organic ICs, THz Electronics, Optoelectronics - Reliability Issues

11. MM-Wave to THz Technology & Applications
- Device and circuit concept & demonstration
- Unique receivers and transmitters - Integrated circuits
- Wireless links, Arrays & Applications

12. 3D & Novel Engineered Materials
- Additive 3D manufacturing for wireless components and systems
- Novel engineered materials for antenna, packaging, passive devices and flexible electronic integration

Paper submission instructions will be found at http://www.radiowirelessweek.org/. Submissions should be formatted according to the submission review. Authors should indicate their preference for oral or poster presentation. All submissions must be received by 25 July 2017.
All accepted papers will be published in a digest and and be included in IEEE Digital Library Xplore. Submission will be evaluated based on novelty, significance of the work, technical content, interest to the audience, and presentation.

CatalogUpdate

Test Solutions Product Guide

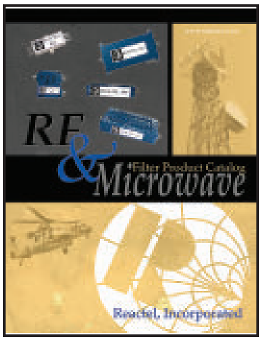
VENDORVIEW

Mini-Circuits' line of custom test solutions has expanded with an even wider lineup of capabilities to meet your needs. The third edition of their Test Solutions Product Guide is a 52-page complement to the second edition, featuring a selection of the new models developed in 2016 with additional details on applications, companion products and more. Highlights include a new series of compact modular test systems, N-port mesh network modules and 2 x N port switch matrices.

Mini-Circuits
www.minicircuits.com

Filters, Multiplexers and Multi-Function Assemblies

VENDORVIEW

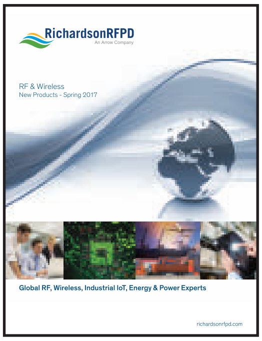


When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. You can count on Reactel to satisfy the most demanding requirements for units used in extremely harsh environments. The full-line catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy visit the company's website or e-mail reactel@reactel.com.

Reactel Inc.
www.reactel.com

New RF & Wireless Products

VENDORVIEW

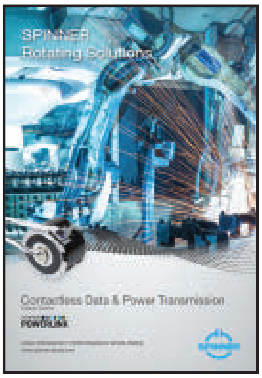


The latest version of Richardson RFPD's New Products' Spring 2017 reference guide provides a snapshot of the most exciting new devices from their roster of leading global manufacturers. From the most recent additions to their line card, to the newest innovations in M2M/IoT solutions, SDI video and optoelectronics products, and a new PEMCO feature, this guide will help you stay up-to-date with what's new in RF & Wireless at Richardson RFPD.

Richardson RFPD
www.richardsonrfpd.com

Contactless Data & Power Transmission

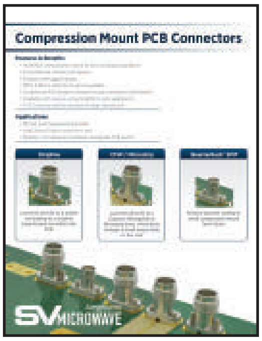
VENDORVIEW



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

SPINNER GmbH
www.spinner-group.com

Compression Mount App Note

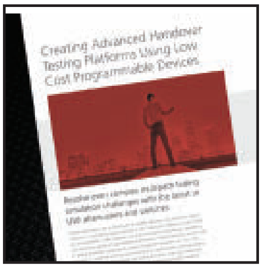


SV Microwave announced the release of their Compression Mount Application Note. The Application Note details the benefits, features and applications of the company's hot-selling, solderless precision RF compression mount connectors. These connectors are available in high frequency bands, including mmWave frequencies. SV Microwave's solderless application makes assembly fast, easy and does not damage the PCB board. Additionally, COTS versions are readily available through distribution. Visit www.svmicrowave.com/resources/application-notes to download a copy today.

SV Microwave
www.svmicrowave.com

Handover/Handoff Testing Brief

VENDORVIEW



Vaunix Technology Corp. recently produced an insightful technical brief discussing handover/handoff testing using USB-based digital attenuators for complex and scalable fading simulations. The tech brief details the critical aspects of handover/handoff testing, and how recent technological advances have dramatically increased the complexity of such testing. The new height of handover/handoff testing also includes mixed wireless standards, such as cellular-to-Wi-Fi and vice versa, as well as an expanded need for more fading channels. Visit www.vaunix.com to download a copy today.

Vaunix Technology Corp.
www.vaunix.com

NEW PRODUCTS

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COMPONENTS

High Power SPDT RF Switch

CEL introduced the new CG2409X3 high power single-pole, double-throw (SPDT) GaAs MMIC RF switch that is intended for various wireless systems where a switch of high-power capability is required. It is specified for the frequency range of 0.05 to 6 GHz, and can operate at a control voltage from 1.8 V to 5 V. The CG2409X3 is manufactured using state-of-the-art pHEMT technology and is packaged and tested in Japan with high quality and reliability. It is a drop-in replacement for Renesas' uPG2409T6X switch.

CEL
www.cel.com

HCC-62 Cross Converter

Link Electronics introduced the HCC-62 cross converter, a stand-alone unit that converts Serial Digital Interface (SDI) to High Definition Multimedia Interface (HDMI) and simultaneously converts HDMI to SDI. In addition to cross converting in a single piece of equipment, thus decluttering the studio, this new technology is also more economical. Three additional modes of operation allow the user to monitor the video from a SDI stream without using expensive SDI monitors.

Link Electronics
www.linkelectronics.com

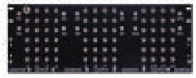
Low PIM 40 dB Coupler

VENDORVIEW

MECA's low PIM high power (300 W) couplers meet and exceed the industry standard of -161 dBc typical for all your DAS application needs. Available in 3, 6, 10, 20 and now 40 dB models and weatherproof IP 67 standard and IP 68 available Type N. Made in the U.S. and 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

Rack-Mounted Power Divider Matrix



MegaPhase custom rack-mounted components make it easy to split one power signal in however many ways you need. Ideal for multiple uses, including telecom testing, the dividers operate over an extended frequency range. Each divider includes a monitor port for quick signal checks. MegaPhase can design a custom rack to meet your precise specifications.

MegaPhase
www.megaphase.com

YIG-Tuned Bandreject Filters

Micro Lambda Wireless announced the production release of YIG-tuned bandreject filters with 50 dB notch depths at 500 MHz and 60 dB notch depths starting at 2 GHz. Standard models cover the 500 MHz to 2 GHz, 2 to 6 GHz, 6 to 18 GHz and 2 to 18 GHz. Customer specified tuning ranges can be supplied on special order. Applications include test Instruments, wide band receivers, telecom, satcom and a variety of military applications.

Micro Lambda Wireless
www.microlambdawireless.com

Dual/Differential Lowpass Filter

VENDORVIEW

Mini-Circuits' DLFCV-1000+ is a dual lowpass filter with a passband from DC to 1000 MHz designed into a single 1210 ceramic package. The dual filter can also be used as a differential filter in differential circuits where interference and noise must be minimized.

This model provides 1.2 dB passband insertion loss, 27 dB stopband rejection with steep roll off, and RF input power handling up to 8.5 W (each filter). It supports a wide range of applications and is ideal for minimizing interference at amplifier inputs and ADC outputs.

Mini-Circuits
www.minicircuits.com

Revolutionary Reflectionless Filter

VENDORVIEW

Mini-Circuits' new XHF2-153+ reflectionless highpass filter has a passband from 15.3 to 30 GHz with a 3 dB frequency cutoff at 14.2 GHz, supporting a wide range of applications including WiMAX, military, space and more. It provides 1.8 dB passband insertion loss, 2.1:1 passband VSWR, 13.7 dB stopband rejection, 2.2:1 stopband VSWR and 1.26 W RF input power handling in the passband (0.16 W in the stopband). It comes housed in a tiny 2 x 2 mm QFN package, allowing designers to use it almost anywhere on their PCB.

Mini-Circuits
www.minicircuits.com

Transformer

VENDORVIEW

The MRFXF5732-1 transformer is designed for applications that require very small, low cost, and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. These units are built lead-free and RoHS compliant and feature welded wire construction for increased reliability. S-parameters are available on request.

MiniRF
www.MiniRF.com

Capacitor Custom Kits

Passive Plus Inc. (PPI) can now develop custom sample kits based specifically on an engineers' needs. Custom kits offer a variety of capacitors based on case size, temperature coefficient, value ranges, tolerances, voltages and quantities per value. All kits are RoHS compliant. With over 30 years in the RF/microwave industry, PPI manufactures high quality, high-power passive components using state-of-the-art manufacturing techniques. Specializing in magnetic and non-magnetic HI-Q/low ESR capacitors, PPI supplies reliable quality components to the military, medical, semiconductor, broadcast and telecommunications industries.

Passive Plus Inc.
www.passiveplus.com

Direct Read Attenuators

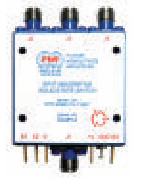
VENDORVIEW

Pasternack, a provider of RF, microwave and millimeter wave products, has released a new line of waveguide direct read attenuators for instrumentation, test benches, high efficiency RF/microwave transmissions, SATCOM, MILCOM, radar and telecom applications. Pasternack's direct read attenuators are available in WR-42 to WR-10 waveguide standards operating in seven waveguide bands within the 18 to 110 GHz frequency range. They boast ± 2 percent typical attenuation accuracy and feature an easy-to-read drum scale and military standard UG-style flanges.

Pasternack
www.pasternack.com

Absorptive, High Speed, Single Pole Three Throw Switch

VENDORVIEW



PMI Model No. P3T-4G8G-75-T-SFF is an absorptive, high speed, single pole three throw switch capable of switching within 100 ns maximum. The frequency range is 4 to 8 GHz. This switch has > 75 dB isolation, and is outfitted with SMA female connectors. Unit size is 1.5" × 1.5" × 0.4" with painted blue finish.

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

Dual SiC MOSFET Driver

VENDORVIEW

Richardson RFPD Inc. announced the availability and full design support capabilities for a new SiC MOSFET driver reference design from Microsemi Corp. The MSCSICMDD/REF1 is designed to provide a reliable reference driver solution, a means of evaluating silicon carbide MOSFETs in a number of different topologies, as well as a means to assess device performance for parametric test purposes. The new evaluation board requires only a +24 V power input and is optimized to drive SiC devices at a high speed with desaturation protection.

Richardson RFPD
www.richardsonrfpd.com

High-Power Lowpass Filters

RLC Electronics' high-power lowpass filters are designed for high-power systems in the frequency range of 100 to 8000 MHz. These filters are designed to handle 2500 W average under extreme temperature and altitude conditions, while offering low loss (0.2 dB typical) and 1.5:1 VSWR (max). RLC filters offer you the flexibility of choosing your cutoff frequency, number of sections and connector type (N, SC, HN, 7/16) for a truly custom high power low pass product.

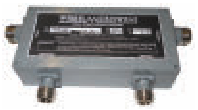
RLC Electronics Inc.
www.rlcelectronics.com

Wide Band Coaxial Circulator

Model F2700-1300-A0 is a wide band SMA connectorized circulator operating over 6 to 18 GHz. It features 1.5 dB maximum insertion loss, 10 dB minimum reverse isolation and 1.9:1 maximum VSWR. This circulator can handle 10 W of forward CW power. The package size of the circulator is 0.748" × 0.787" × 0.512" and it weighs only 1 oz.

Wenteq Microwave
www.wenteq.com

Dual Directional Coupler



Model 2CNK125 from Werbel Microwave is a dual directional coupler that operates from 100 kHz to 250 MHz at 40 dB coupling. Nominal power rating is 100 W, designed for 250 W max. Typical directionality is 25 dB. Main line VSWR is 1.1:1 and typical insertion loss is 0.3 dB. Housing measures 5" × 2.5" × 1.5". All products are made in-house at their N.J.-based location and sourced from as many U.S.-based suppliers as possible.

Werbel Microwave LLC
www.WerbelMicrowave.com

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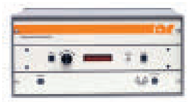
High Speed Interconnects' 086, RF/microwave assemblies are designed to be cut to any length, terminated to 2.92 connectors, and shipped within one week. HSI's 48" assemblies deliver ± 2.5° phase and ±0.03 IL stability (180° flexure), IL 6.1 dB, VSWR 1.15:1 through 40 GHz.

High Speed Interconnects
www.highspeedint.com

AMPLIFIERS

Single Band Amplifiers

VENDORVIEW



AR's new 20S6G18A and 40S6G18B are self-contained, air-cooled, broadband, class A solid-state amplifiers designed for applications where instantaneous bandwidth, high gain and linearity are required. Model 20S6G18A, when used with a sweep generator, provides a minimum of 20 W of RF output power instantaneously from 6 to 18 GHz, while the 40S version delivers 40 W. These instruments are suitable for radiated immunity testing, TWTA replacements and EW applications.

AR RF/Microwave Instrumentation
www.arworld.us

SSPA Module

VENDORVIEW

Exodus Advanced Communications announced the release of a new state-of-the-art ruggedized power amplifier. AMP3095 is a 31 to 40 GHz, 5 W min broadband module, featuring a class AB linear GaAs FET hybrid design. It operates from a 9 VDC supply at 16A with gain flatness of 8 dB max peak-to-peak. With instantaneous wide bandwidth, built-in protection circuits and high reliability, the AMP3095 is suitable for all single channel modulation standards and applications such as EMI/RFI, EW, communications, SATCOM and general testing for mmWave products.

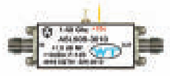
Exodus Advanced Communications
www.exoduscomm.com

New**Products**

5 W Broadband SSPA

The TA1049 is a broadband SSPA for applications such as EMC testing, EW/jamming, and general purpose lab use. It utilizes internal DC to DC conversion, so it can operate from a +9 to +33 V supply voltage without any effect on RF performance. The TA1049 can be shipped with an integral heatsink and heatsink/fan assembly if required.
Triad RF Systems
www.triadrf.com

1 to 50 GHz Series Amplifiers

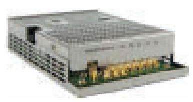


The newly released ASL50B series amplifiers feature extended frequency operation. The ASL50B series products consist of gain blocks with +25, +30 and +35 dB. The noise figure levels are +6 dB typical and +7 dB max at 50 GHz. The output P1 dB is +13 dBm typical and +10 dBm min. at 50 GHz. Like all WT products these ASL50B series amplifiers are battle tested, and backed with the 4-year warranty program. This type of service can give customers the support they need for long term uses reducing costly replacements. All WT products are RoHS compliant, and burn in tested for 48 hours at +50°C.
Wright Technologies
www.wrighttec.com

SOURCES

OEM Pulse/Delay Generator

VENDOR**VIEW**

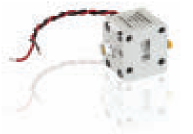


The unique high performance model 745-OEM pulse/delay generator is engineered for direct system integration. Offering a package designed to be embedded easily, it provides system architects an excellent resource for all triggering, synchronizing and timing needs. With industry-leading specifications such as 250 fs timing resolution, 5 ps jitter, synchronized outputs and much more, the 745-OEM is ideal for laser timing systems or other precision applications.
Berkeley Nucleonics
www.berkeleynucleonics.com

Dual-Channel RF Signal Generator

DS Instruments introduced the SG6000LX, a compact and economical dual channel RF signal generator covering 25 MHz to 6 GHz. Output power is independently adjustable on each channel in 0.5 dB steps and with a vernier setting. The USB port is configured as power source and industry standard COM port requiring no special drivers for remote operation.
DS Instruments
www.dsinstruments.com

Gunn Diode Oscillator



Fairview Microwave Inc., a supplier of on-demand microwave and RF components, has released a waveguide Gunn oscillator that provides a cost effective source for microwave power with excellent frequency and power stability while generating low phase noise. Typical applications include transmit and receive oscillators for radio communications, local oscillator source that can be multiplied for higher mmWave frequency test and measurement, military and commercial radar sources, police radar, Doppler sensors and security screening.
Fairview Microwave Inc.
www.fairviewmicrowave.com

Wideband High Performance VCO

The DCMO3288-5 has greater than an octave tuning of bandwidth covering 320 to 880 MHz with a planar resonator construction. This wideband model has exceptional phase noise performance of -109 dBc/Hz (typ.) at 10 kHz offset and -129 dBc/Hz (typ.) at 100 kHz offset. Other features include an output power of 3 dBm (min.), a harmonic suppression of 10 dB (typ.), a tuning sensitivity of less than 3:1 (typ.) and a bias voltage of +5 V and +24 V of tuning.
Synergy Microwave Corp.
www.synergymwave.com

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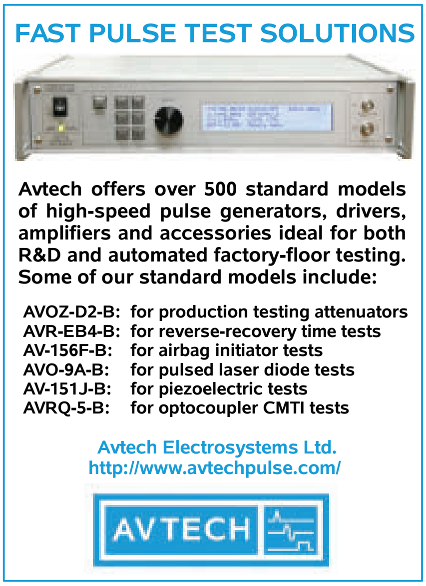
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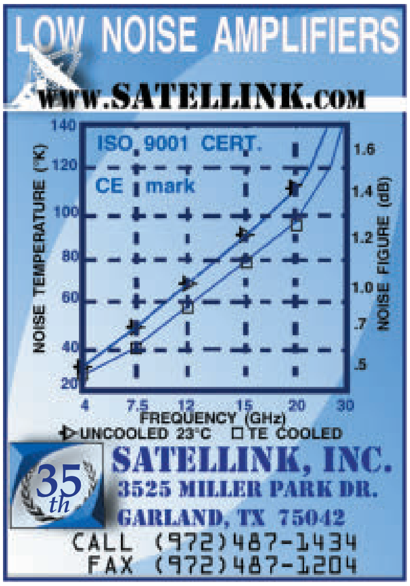
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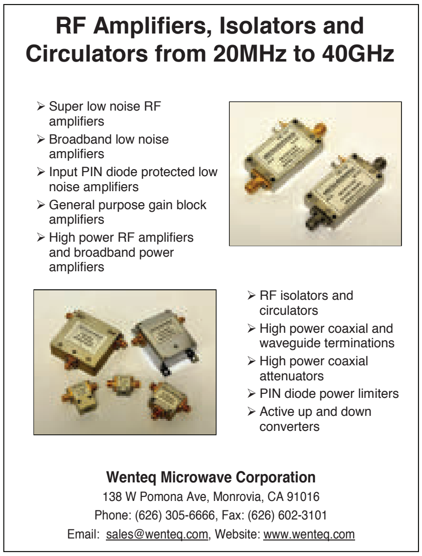
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Communications Receivers Principles and Design

Ulrich L. Rohde, Jerry C. Whitaker, Hans Zahnd

This new edition of the classic, "Communications Receivers," was prompted by the maturation of software-defined radio (SDR) technology over the past decade. Enabled by improvements in component technology and software — the increasing sampling rates of analog-to-digital and digital-to-analog converters and the processing power of field programmable gate arrays — SDRs are no longer just an academic subject. SDR systems are now widely fielded, the mobile phone perhaps the most topical example.

This fourth edition of "Communications Receivers" reflects this transition, enhancing the treatment of direct digital conversion and systems on a chip (SoC) and removing analog topics that are no longer relevant to a nearly all-digital world. Nonetheless, the fundamental analog principles and technologies are thoroughly addressed. In 11 chapters spanning almost 700 pages, the authors discuss basic radio considerations, radio receiver characteristics, receiver system planning, receiver implementation, SDR principles and technologies, SDR transceivers, antennas, mixers, frequency sources, ancillary receiver circuits and performance measurements. The chapter on SDR principles and technologies describes various architectures: classic heterodyne, direct-conversion, digital IF, direct-sampling, broadband and multicarrier receivers and discusses the associated RF front-end design considerations. A commercially available wideband monitoring receiver is presented in the appendix to illustrate the implementation of a SDR.

Ulrich Rohde and Jerry Whitaker wrote the prior three editions, beginning in the 1980s. To best address the technology shift to SDR, they recruited Hans Zahnd to join them and contribute his extensive experience with SDR receiver and transmitter systems. This latest edition continues the excellent technical discussion of communications receivers and will be a worthy reference for the next decade.

To order the book:

Published by McGraw-Hill Education
www.mheducation.com
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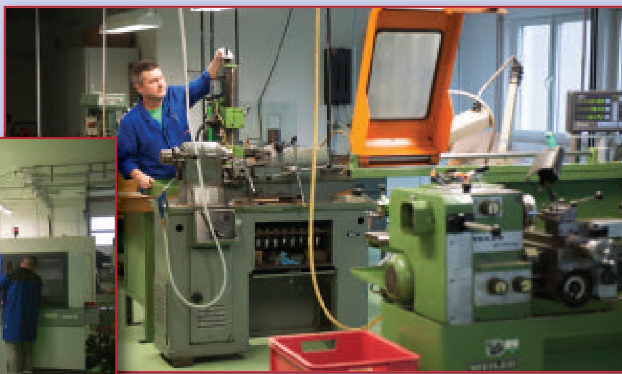
Spectrum – One Man's Vision Sees the Light



At its Munich site, where the facility has recently quadrupled in size from the original building on the plot, the sign at the entrance may read Spectrum Elektrotechnik GmbH, but the company is essentially Peter von Nordheim, a man who has dedicated his working life and financial security on developing the company from humble beginnings to a global engineering enterprise.

von Nordheim started the business in 1981, together with a technician and a bookkeeper, four kilometers from the current site in a two-room office with a total space of 60 m^2. One room was the office and the other was for manufacturing, which housed his first small turning machine that his father bought him for about DM10,000.

It was a tough time with no interest from banks, with the only offer being: "If your company exists in two years time come back then!" Undeterred, von Nordheim asked local companies if they had any engineering problems and from there he picked up orders for work that no one else wanted. As a result he rented a 400 m^2 room for manufacturing in another building 200 m away.

In the mid 1980s von Nordheim heard that the city of Munich would sell land to companies who wanted to own their own facility. He says that he applied 'just for fun,' never expecting that such a small start-up company would be successful but he was offered a 1,960 m^2 plot.

Originally he had difficulty finding financing, with the bank charging high interest and demanding a minimum of 10 percent of his own money for the necessary investment, which he did not have. He eventually found a bank that would provide the full amount through state loans, provided that von Nordheim take out life insurance for DM 300,000, which he happily accepted. The company moved to the site in 1988, with a staff of about 10 people.

The original building on the site was roughly 1,300 m^2. It was extended with a further 1,300 m^2 in 2004 and doubled in size again in 2014 after acquiring an adjacent 2,000 m^2 plot when a second building, linked to the first, was added, with a capacity of 2,600 m^2. The transition into the new building was completed in 2016.

The original building is now dedicated to office space and shipping/receiving. The machine shop that was housed in the basement so cramped that staff had to 'walk like penguins' to pass between the machines, has now moved to a 800 m^2 floor in the new building, which for the first time offers room for expansion.

Similarly, assembly occupies 800 m^2, engineering occupies another 800 m^2 and there has been significant investment in new machinery/equipment. These include analog network analyzers to 71 GHz, including two in-house designed cable cutting and stripping machines, along with sophisticated brazing equipment, a heat treatment oven, a vacuum leak tester, highly sophisticated laser equipment, and many CNC turning and milling machines. Add to that ultrasonic cleaners, vacuum ovens and inspection microscopes for every assembler, with a clean room in the pipeline. With the exception of surface treatment the company does everything in-house from design, manufacturing every single part, assembly and testing.

The extension provides the opportunity to capitalize on the prospect of big orders. For example, the company builds duplexers, which are used in long range radar applications, but such expensive items are usually part of a long term plan that requires Ministry of Defense (MoD) funding. However, when those funds are available Spectrum is in a position to fulfill the orders.

Once a three-man operation, the company—fueled by von Nordheim's conviction and hard work— now employs 65 onsite and is geared up, ready for the future.

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

Directional Couplers

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

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