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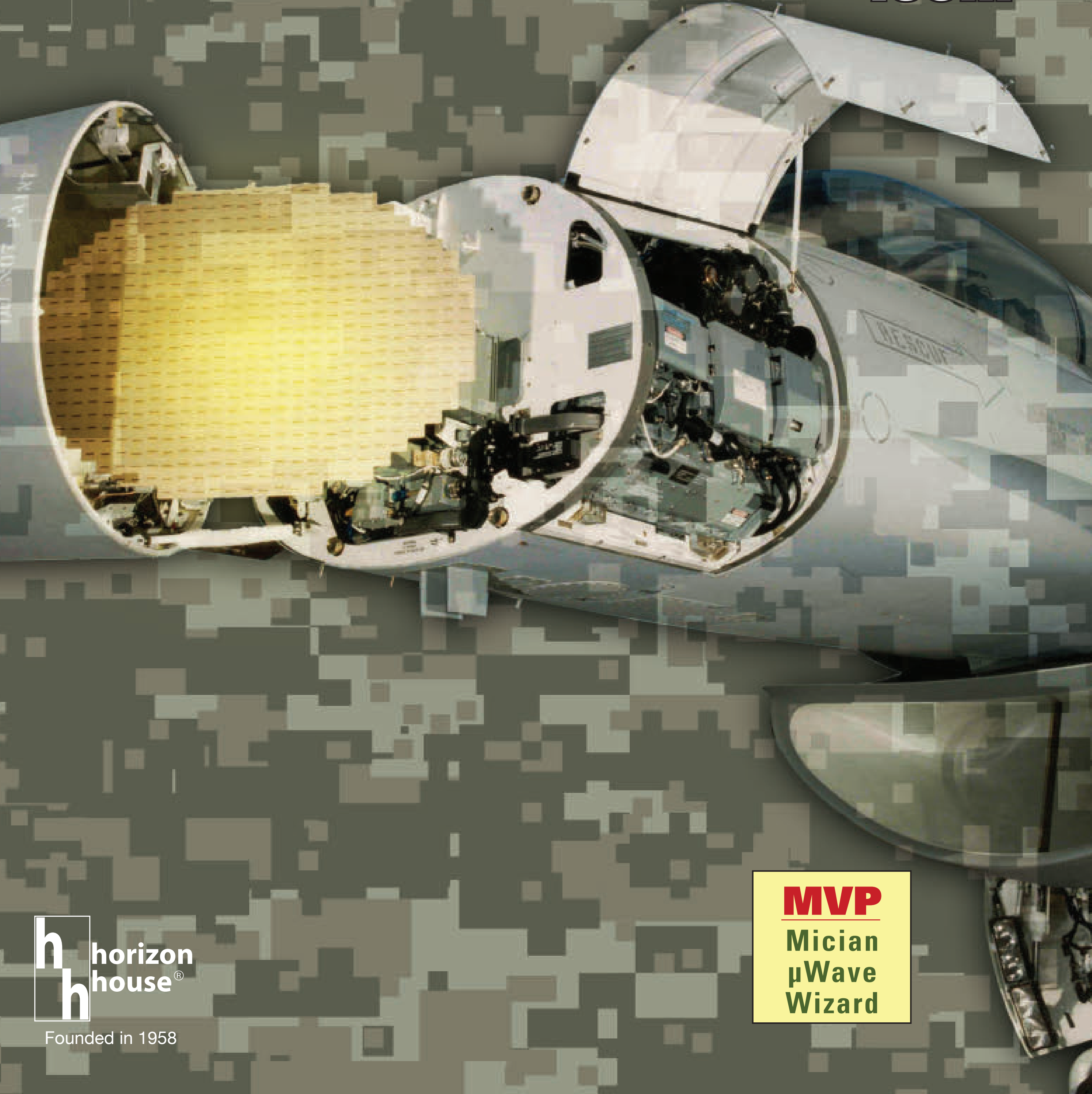

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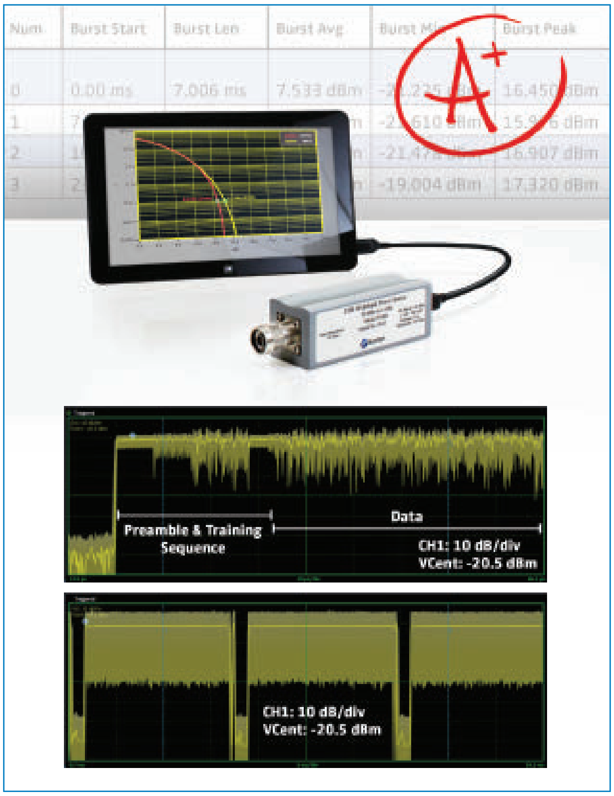

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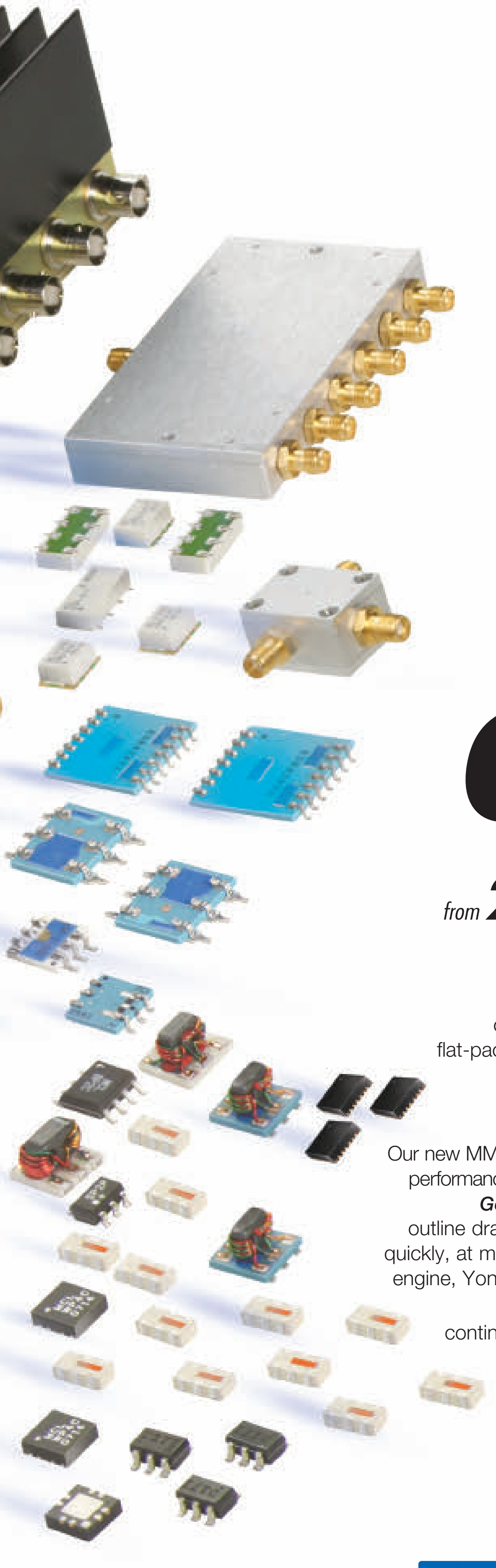

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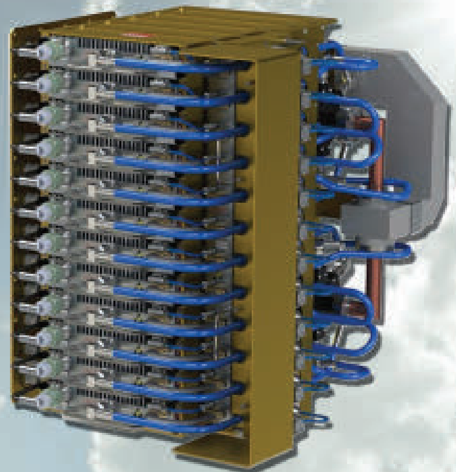

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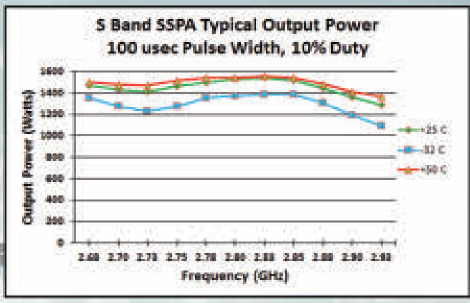

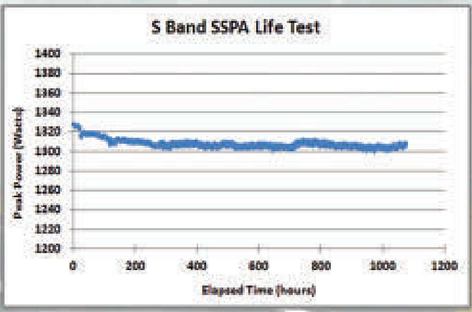

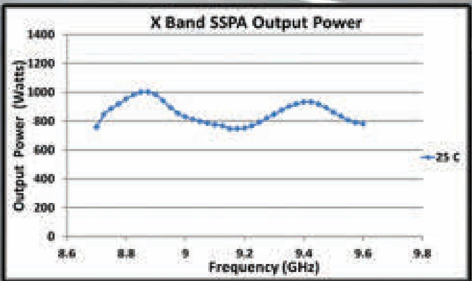

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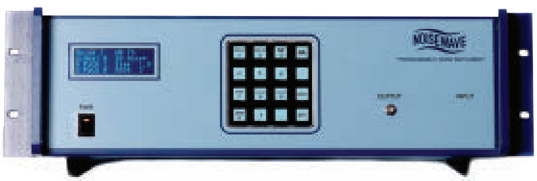

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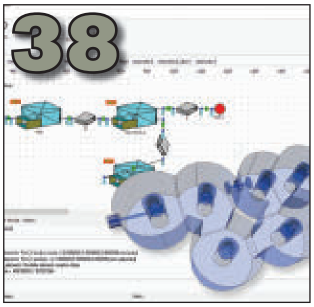

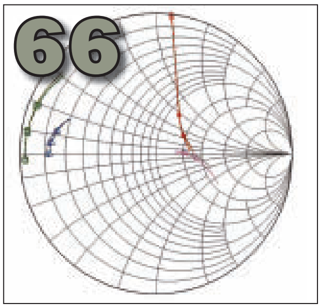

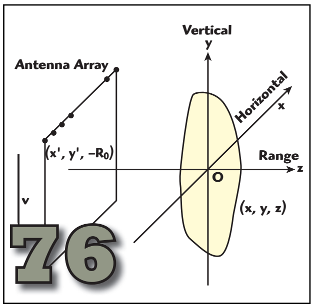

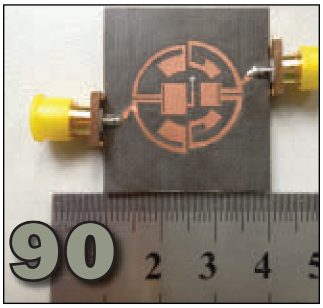

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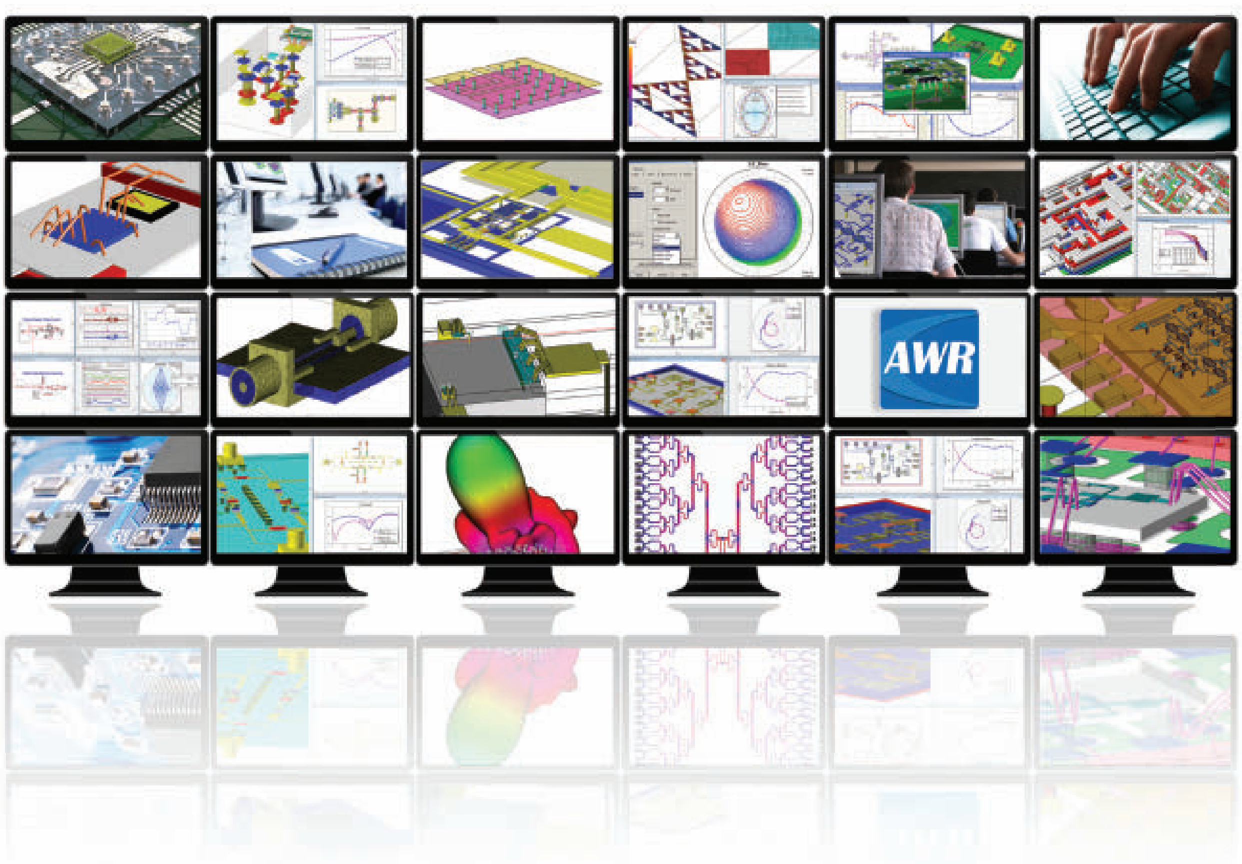

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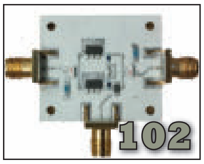

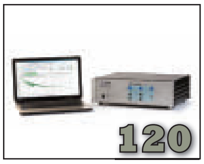

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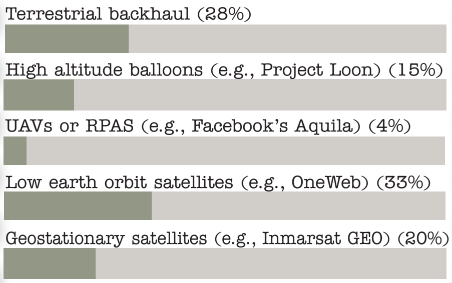

Executive Interviews

Alvin Guzon, CEO of **Cirtek Advanced Technologies and Solutions**, discusses microwave and millimeter wave market requirements for contract manufacturing and how Cirtek ATS is addressing them.

Karolina Wikander, head of the Microwave product area at **Ericsson**, shares the company's outlook for the microwave radio market, including data rate and frequency band trends.

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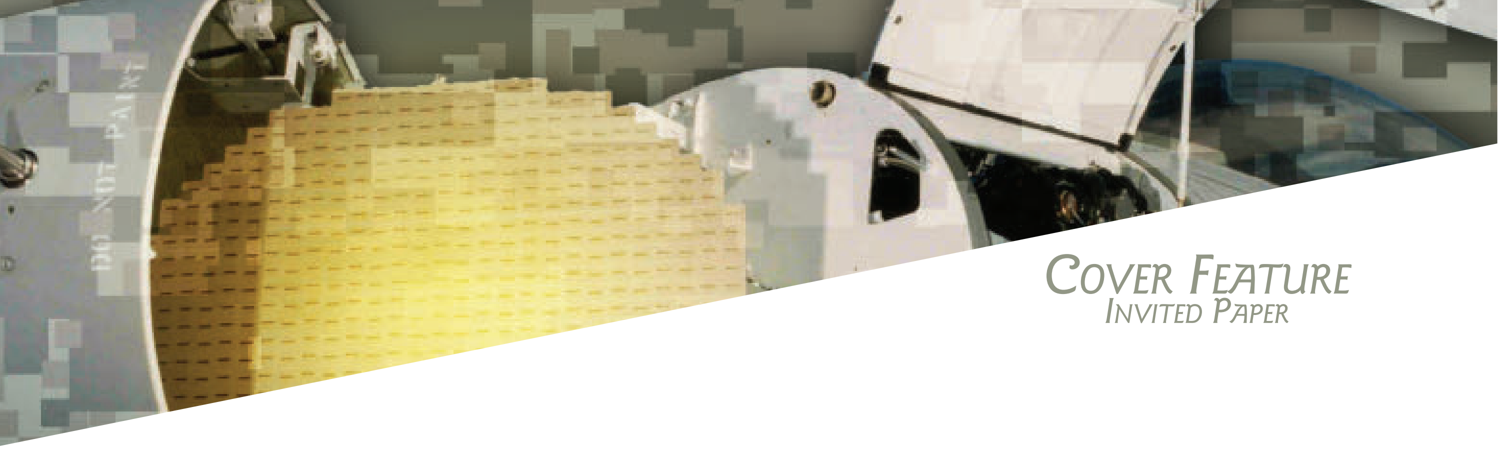


COVER FEATURE
INVITED PAPER

Radar and Phased Array Breakthroughs

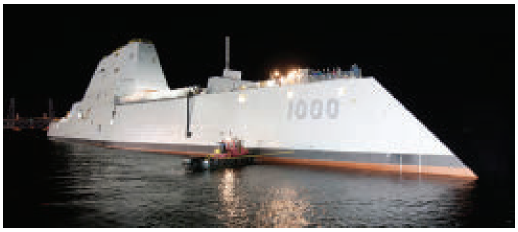
Eli Brookner

This article updates previous papers discussing significant developments, trends and breakthroughs in radar, phased arrays and the underlying technologies that enable them. [1-8]

RADAR SYSTEMS

The big news relative to system upgrades is that Patriot now has GaN active electronically scanned arrays (AESA) that provide 360 degree coverage without mechanical rotation (see ***Figure 1***). The upgrade has a main AESA array that is a bolt-on replacement antenna, approximately 9 feet wide and 13 feet tall, that is oriented toward the primary threat. It also has a new, rear, quarter-size AESA panel that gives 360 degree coverage. Another development is the launch of the first Zumwalt DDG-1000 stealth ship (see ***Figure 2***), with two more under development. It will carry the three-face X-Band SPY-3 radar. The impressive performance of the Air and Missile Defense Radar (AMDR) has recently been released (see ***Figure 3***). AMDR has an S-Band radar for air and missile defense, a three-face X-Band radar for horizon search and adaptive digital beam forming. The system handles 30 times more targets and has 30 times greater sensitivity than the SPY-1D(V). The transmitter uses GaN, which is 34 percent less expensive than GaAs and has 10^8 hour mean time between failures (MTBF). The scalable antenna is composed of 2 ft × 2 ft × 2 ft radar module assembly (RMA) building blocks, with four line-replaceable units (LRU) per RMA. Each LRU can be replaced in less than 6 minutes. The back-end radar controller is fully programmable and uses commercial off-the-shelf (COTS) ×86 processors, which allows adapting to future threats, easy upgrades with future COTS processors and no obsolescence. Lockheed Martin

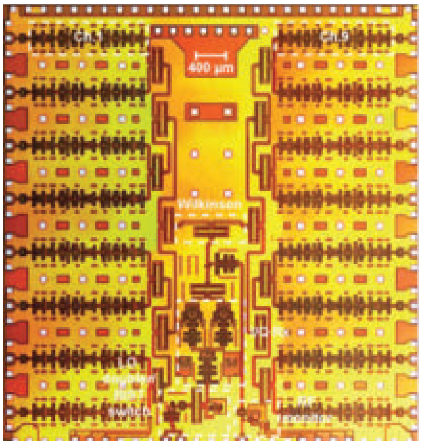
▲ *Fig. 1 New Patriot AESA radar at a test range (source: Raytheon).*



▲ *Fig. 2 Zumwalt-class guided-missile destroyer DDG 1000, which will carry the SPY-3 three-face X-Band AESA radar (source: U.S. Navy).*

▲ *Fig. 3 Rendering of the AMDR on the DDG 51 destroyer (source: Raytheon). AMDR will detect air and surface targets as well as ballistic missile threats.*

is under contract to develop the space fence radar, and the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor (JLENS) blimp system has been deployed over Washington for its defense.



▲ *Fig. 4 16-element 77 to 84 GHz phased array with integrated receive and built-in test (reprinted with permission of UCSD).*

SEMICONDUCTOR TECHNOLOGY

MMIC technology has evolved from four X-Band T/R modules with the control circuitry on a chip,[1,2] with each T/R costing about $10, to a whole array on a chip or wafer at millimeter wave frequencies (see ***Figure 4***).[9,10] Intel built a 32-element 60 GHz Tx/Rx phased array on a chip.[9] These phased array ICs will have built-in test circuits for calibration. The cell phone and Wi-Fi markets are driving this technology, with bandwidth demand predicted to increase 1,000-fold from 2010 to 2020, and the number of mobile devices from 5 to 50 billion.[10] In the next decade, these array chips are expected to find wide use in garage door openers, video players and computers.[10] They will talk to each other via high bandwidth Wi-Fi. In the future, compact, ultra-low cost multiple-input-multiple-output (MIMO) millimeter wave multi-beam AESAs will be in everyday devices.[10] We also see car radar benefiting from these highly integrated MMICs.[11,12] ***Figure 5*** shows the functional block diagram of a single-chip 77 GHz transceiver, and ***Figure 6*** illustrates how the transceiver will be assembled with the signal processor and antenna on a PCB to minimize cost. Some forecast that future car radars will cost only a few dollars. A 24 GHz single-chip car radar developed by Autoliv[13] fits on a 3.5" × 2.25" board, including the radar chip and a Texas Instruments signal processor that performs Kalman filter tracking.[14] Over 2 million radar systems have been manufactured, with the cost of the board less than $100.[14] Valeo Raytheon has developed a 25 GHz blind-spot, seven beam, phased array radar, costing only hundreds of dollars as an option from the car dealer.[1,15,16] Who said phased arrays are expensive? Over 2 million of these have been produced.[16] The car radar market is huge: over 70 million cars were built in 2014; assuming four radars per car, the market potential is over 280 million per year.

Gordon Moore predicted the application of MMICs to radar and phased arrays. The last sentence in his now famous paper[17] states, “The successful realization of such items as phased array antennas, for example, using a

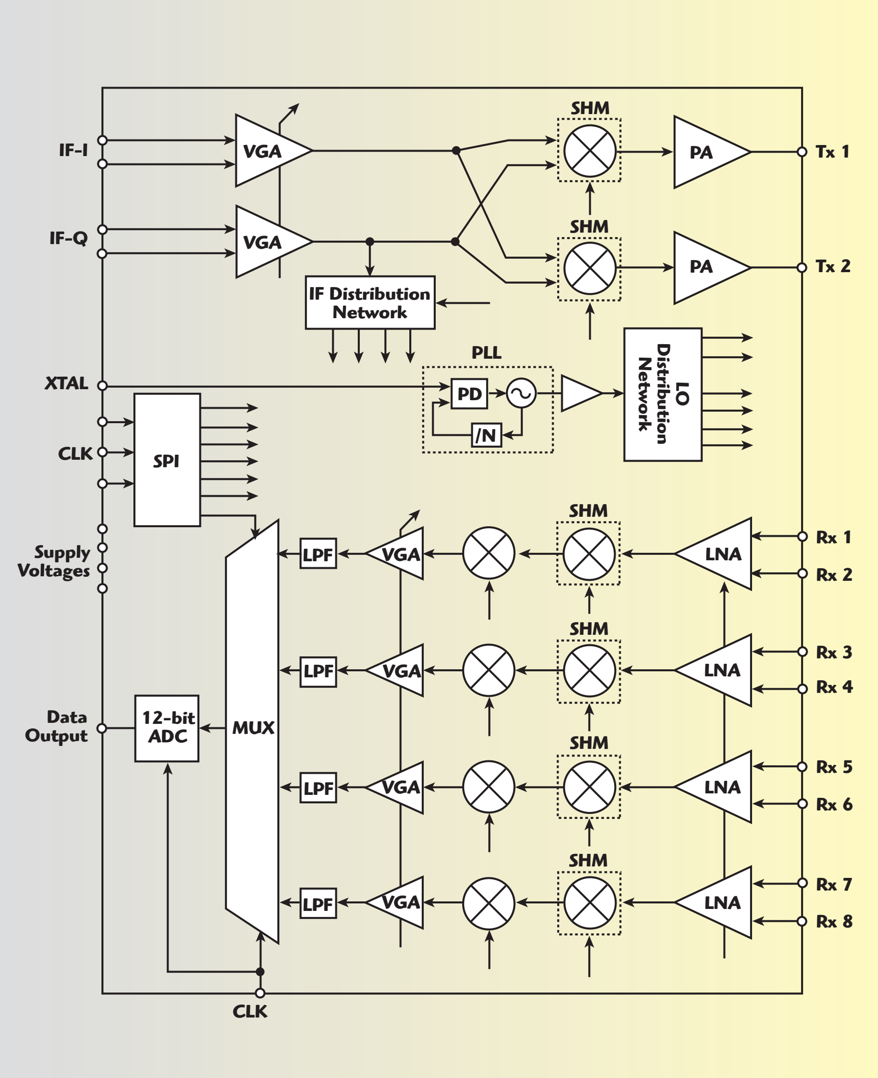


Fig. 5 Functional block diagram of a single-chip 77 GHz automotive radar transceiver (source: University of Melbourne).

multiplicity of integrated microwave power sources, could completely revolutionize radar." ***Table 1*** indicates the amazing advance made by Moore's Law, showing a 350,000 improvement in the performance of FPGAs over 36 years. DARPA is funding the development of commercial FPGAs at microwave frequencies.[1] Moore's Law predicted that the number of transistors on a chip will increase by a factor of two every two years. Many think that will continue for a while, although it is getting more difficult.[18] One extreme prediction is 600 years; more conservative ones are 10 to 20 years.[18] Intel expects to go from a production line width of 14 nm in 2014 to 10 nm in 2017, a doubling in density in three years.[52] Robert Colwell, formerly with the DARPA Microsystem Technology Office and, before that, Intel's chief architect, predicts we will see an increase in the number of transistors by about a factor of 50 in the next 30 years, which averages to a doubling about every five years over the next 30 years.[19] DARPA has a program to lower the power consumption of processors by a factor of about 75.[19] Quantum computing offers the potential of orders-of-magnitude increases in computing power every generation, instead of the factor of two that Moore's law provided.[53] In 2014, 2.5 × 10^{20} transistors were manufactured – 250 billion billion. Imagine what it would take to do this with 1" × 1" × 2" vacuum tubes? They would cover the

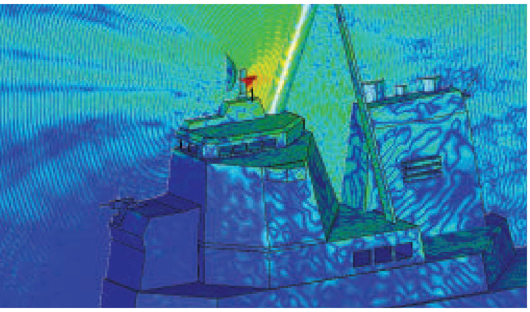


TABLE 1

FPGA IMPROVEMENT AS AN EXAMPLE OF MOORE'S LAW

Year	Multiplier Type	Multipliers per Chip	Clock Rate (MHz)	Power (W)
1977	16 × 16	1	4.3	5
2013	18 × 18	4,000	600	8

surface of the earth and stand eight miles high.

Helping further semiconductor technology is DARPA's Compound Semiconductor Materials on Silicon (COSMOS) program[1,20] and the follow-on Diverse Accessible Heterogeneous Integration (DAHI) program.[21] The COSMOS program demonstrated, for the first time, the integration of GaN and CMOS on the same silicon substrate without wirebonds.[20,21] Potentially helping to advance signal processing capabilities are nanotechnology, spintronics,[54] graphene and carbon nanotubes[1,22] (see ***Figure 7***), memristors,[2] synaptic transistors[23] (see ***Figure 8***) and the future possibility to transmit data optically on the chip. Transmitting electrical and optical signals over the same wire has been demonstrated.[24] An alternative possibility is using IR beams in a Si IC (Si is transparent to IR) for transmitting signals at the speed of light and without ohmic losses.[25] Graphene and carbon nanotubes (CNT) have the potential for terahertz transistor clock speeds, instead of gigahertz, which is nearly three orders of magnitude faster. The manufacture of graphene transistors on CMOS has been demonstrated. This could allow Moore's law to march forward using present day manufacturing techniques. Spintronics could revolutionize the computer architecture away from the 1945 John von Neumann model of separate logic and memory units. Instead, the two functions would be the same for some products, with logic being low cost, non-volatile memory. Spintronics has the potential to replace hard drives with low cost, low power and more reliable memory, with no moving parts and faster access time for the data. There is also the potential for computing the way the brain does – efficiently and amazingly – going analog by using synaptic transistors and/or memristors. Realizing that the brain only weighs about two to three pounds and consumes only 20 W, we have a long way to go. It has been predicted that by using memristors, one could do what the brain does in a shoebox rather than a computer the size of a whole city and requiring a nuclear plant.[2,55]

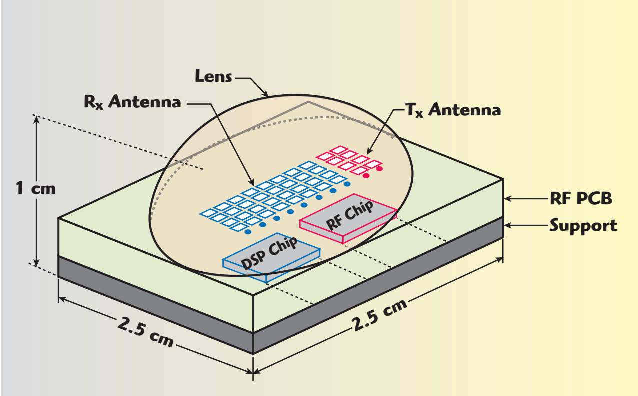


Fig. 6 To minimize the cost of the 77 GHz radar, the single-chip RF transceiver, DSP, patch antenna array and lens will be assembled on a single PCB (source: University of Melbourne).

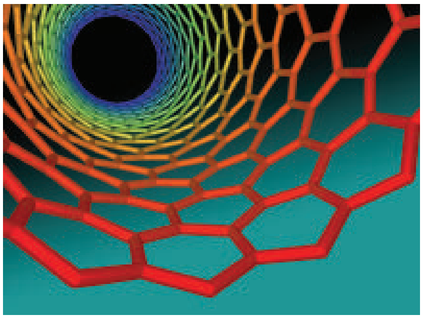
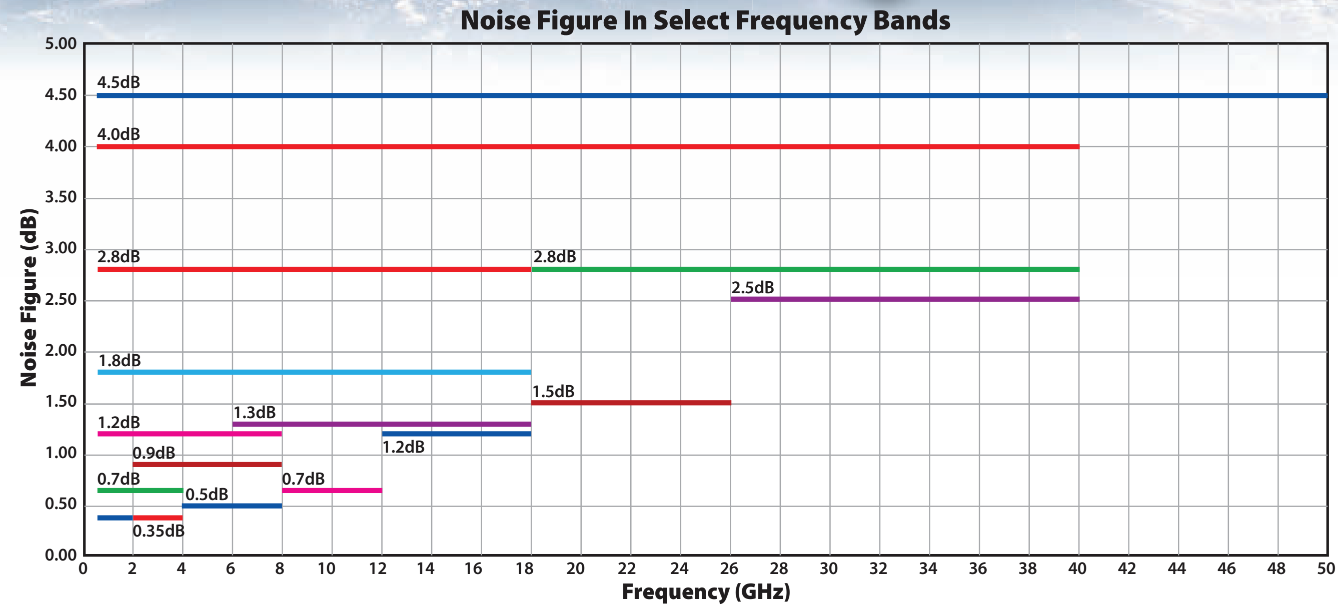


Fig. 7 Carbon nanotubes may enable transistors to reach terahertz clock speeds (source: Geoff Hutchison, flickr.com, CC BY 2.0).

METAMATERIALS

Metamaterials are man-made materials that consist of repeated structures having a size less than a wavelength. These materials have properties not found in nature, like a negative index of refraction. Metamaterials

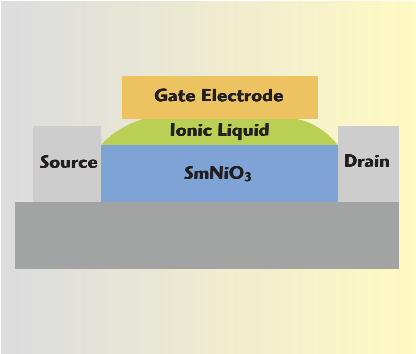
Has Amplifier Performance or Delivery Stalled Your Program?



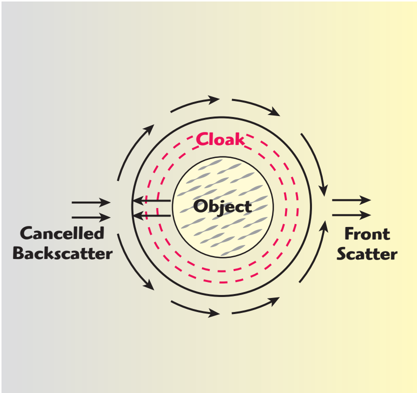
are being used by Kymeta to develop communication antennas at 20 and 30 GHz, which could cost only $1,000.[26-29] Kymeta is supplying these antennas for the Ob3 satellite system, which has 12 satellites in equatorial orbit at a medium earth orbit (MEO) altitude of 8,063 km. The antennas use slotted waveguides, with resonators placed along the waveguide to control whether the signal at the resonator is radiated. The resonators contain liquid crystals whose dielectric constant is controlled by a bias voltage; this shifts the resonator frequency which allows the signal to radiate or not radiate. The antennas are only the size of a laptop computer. The key question is whether they can achieve their production cost goal. A second company, Echodyne (which has ties to Kymeta), is developing metamaterial antennas for radar.[30]

Target cloaking has been demonstrated using fractal metamaterials. With cloaking, the electromagnetic wave signal transmitted by a radar goes around the target, making it invisible (see ***Figure 9***). Another way to hide a target is to have the target absorb the incident radar signal. Such "stealthing" has been simulated using a fractal metamaterial coating that is less than 1 mm thick.[33] 90 percent absorption was achieved from 2 to 20 GHz and around 99 percent from 10 to 15 GHz. Good absorption was achieved for a very large range of incident angles and polarizations.

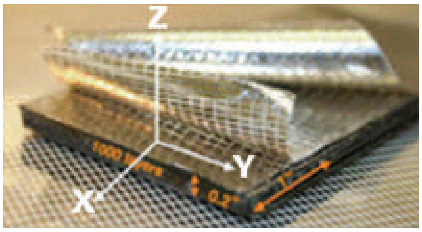
With metamaterials it is now possible to replace the tall, highly visible Army jeep whip antennas with a flush mounted λ/20 thick antenna[34] (see ***Figure***



▲ *Fig. 8 Structure of synaptic transistor (source: Harvard University).*



▲ *Fig. 9 Wave propagation around an invisibility cloak.*



▲ *Fig. 10 Low profile magnetic metamaterial antenna, designed for 250 to 505 MHz coverage (source ARL).*

qorvo
TGA2578-CP

10). Other capabilities of metamaterials include the ability to focus beyond the λ/2 diffraction limit, provide higher isolation and increase the scan angle for arrays.[1,2]

MIMO

A MIMO full/thin array radar system (consisting of a full transmit linear array of N elements having λ/2 spacing and a collocated, parallel, receive thinned linear array having Nλ/2 spacing) is equivalent to a full array of N2 elements having λ/2 spacing. It achieves N times the accuracy and resolution of a conventional full array of N elements: 10, 100 or 1000 times better than a conventional array, depending on N.[35,36] It has since been shown[37,38] that a conventional array radar can do as well as a MIMO full/thin array radar. Specifically, a conventional full/thin array provides the same resolution and accuracy as the MIMO array. The conventional full/thin array had some disadvantages, such as grating lobes, but in some situations it provides better energy search efficiency than its MIMO equivalent.[38] More recently, a new conventional array was presented which has the same resolution and about the same angle accuracy as the MIMO full/thin array radar and with no grating lobes.[39,40] It uses the same search time and about the same power-aperture product for volume search as the MIMO radar. The new conventional array consists of the same full and thin arrays, but with their roles reversed: the thin array transmitting and the full array receiving. The new conventional array is called a thin/full array to distinguish it from the former full/thin array. The matched filter processing load for MIMO full/thin and thin/full arrays depend on whether the transmit or receive beam forming is done first.[40] MIMO radar systems do not have any advantages relative to barrage jammer, hot clutter jammer or repeater jammer suppression.[38-40] Most recently, it was shown how the conventional thin/full array can be used for ground moving target indication (GMTI), so it should provide the same minimum detectable velocity as the MIMO thin/full array.[40]

DIGITAL BEAM FORMING

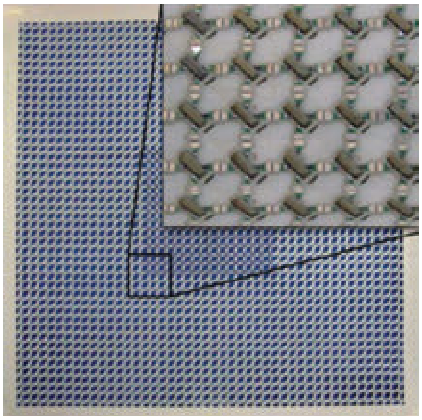
In addition to the S-Band shipboard AESAs developed by Elta in Israel and CEA Technologies in Australia that utilize digital beam forming at every element,[2] add Thales with a 1000 element, S-Band radar.[41] Raytheon is developing a mixer-less system with direct RF analog-to-digital conversion that has greater than 400 MHz instantaneous bandwidth and is reconfigurable, able to switch between S- and X-Band.[42] Instead of using down-converters followed by a low frequency ADC, the design uses a sample-and-hold chip followed by a low frequency ADC. For the SANTANA Internet on-the-move system, IMST has developed AESAs for 30 MHz uplink and 20 MHz downlink between satellites and airplanes, railroad trains and cars. These AESAs utilize an ADC and digital-to-analog converter (DAC) for every element channel.[43] Instead of PCBs, they use LTCC stacks.

ADDITIONAL ADVANCES

The high power microwave tubes used for active denial systems may soon be replaced by solid-state power devices. The magnetrons in microwave ovens are being replaced by transistors. Raytheon and MIT Lincoln Laboratory are using commercial technology to achieve low cost AESAs for ground radar.[1] Rockwell Collins is continuing this trend with the development of an X-Band airborne AESA using low cost SiGe ICs and PCBs for the array.[46] MIT Lincoln Laboratory increased receiver SFDR, limited by intermodulation from receiver and ADC nonlinearities, by 40 dB. This represents a 40 year advance, given the historic progression of one bit every six years for ADCs.[47]

Printable electronics is making great strides and should soon yield major advances because of the large market for wearable, flexible electronics. Several approaches are being investigated, including the use of metal-insulator-metal (MIM) diodes,[48] 2D MoS_2 ink[49] and Si and $NbSi_2$ particles, which have produced diodes at 1.6 GHz and have the goal of operating at the 2.4 GHz Wi-Fi band.[50] It was recently shown that a low thickness (λ/40), wideband (20:1 bandwidth), dual polarized antenna can be built using tightly coupled dipole antennas (TCDA)[44,45] (see ***Figure 11***). And quantum radar, based on microwave-optical entanglement, is claimed to provide better false alarm rate and signal-to-noise ratio than a conventional radar.[51]

We live in exciting times. ■



▲ *Fig. 11 Wideband antenna based on tightly-coupled dipole antennas (source: Raytheon).*

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Eli Brookner *is well known for his contributions to radar technology. He retired from Raytheon as Principal Engineering Fellow in 2014 after a long and distinguished career. He has contributed to radars for air traffic control, defense, space and navigation – virtually every major defense radar program. Brookner has been recognized with numerous awards and honors, including Fellow of the IEEE, AIAA, and MSS and the 2006 Dennis J. Picard Medal for Radar Technology and Application. He has written numerous papers and articles and four books on radar systems and signal processing. Brookner received his bachelor's degree in electrical engineering from the City College of New York and his master's and Dr.Sc. from Columbia University.*


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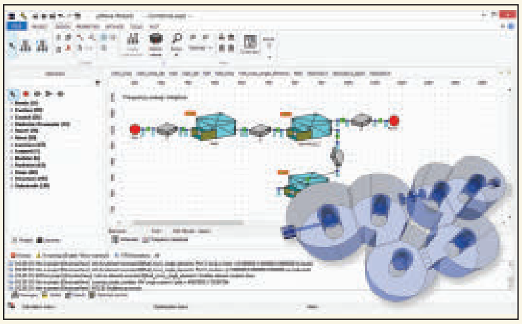
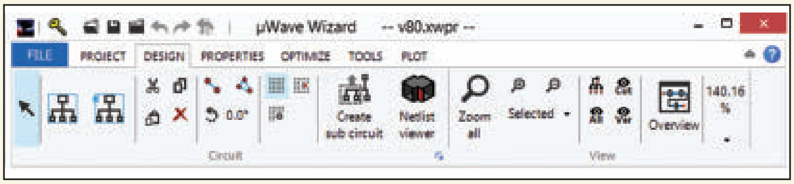


µWave Wizard Version 8 Adds Features and Speed

Mician
Bremen, Germany

Version 8 of Mician's µWave Wizard software combines the flexibility of the 2D/3D finite element method (FEM) with the speed and accuracy of traditional mode matching techniques. The benefit of mode matching lies in its ability to perform and combine sub-circuit type full-wave simulation with full parameterization of structural geometries using µWave Wizard's built-in optimizers.

The fast and easy composition of complex RF structures using basic building blocks eliminates the need to create a full 3D model of the entire structure and speeds the development process. In addition to its fast and powerful numerical methods, µWave Wizard offers flexibility and openness, including a COM API interface and CAD export formats that interface with most mechanical design tools.



▲ *Fig. 1 User-friendly ribbon-based GUI.*

RIBBON GUI

Version 8 offers a ribbon graphical user interface (GUI) that makes a convenient, user-friendly environment, even for a beginner. The attractive icon-based shortcuts and controllers distributed across the ribbon (see ***Figure 1***) help the user to understand each task quickly and easily. The project tree view provides all information about the current project, such as frequency settings, variables by type (real, optimization, tune and equation with complex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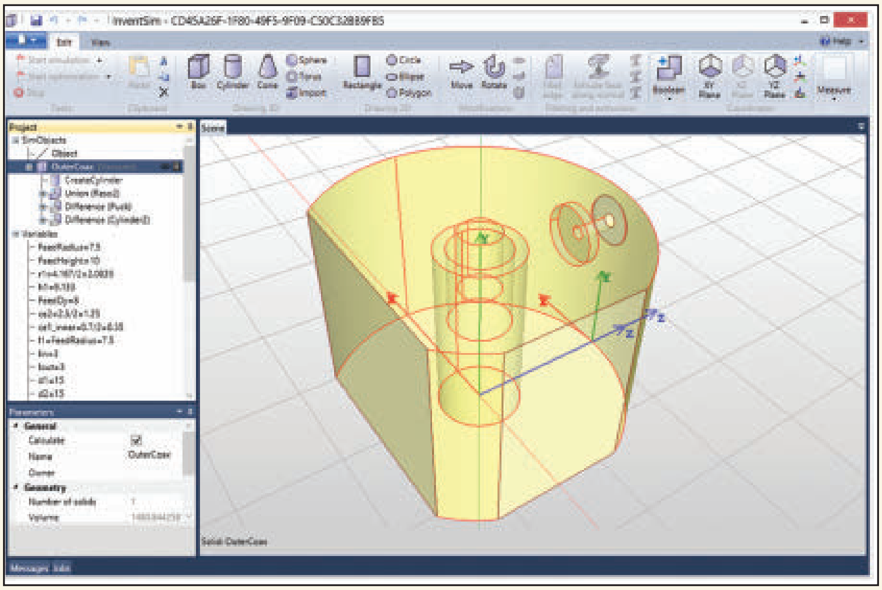
mathematical expressions), circuits and sub-circuits and default settings like units, accuracy, symmetries and material properties. The new GUI separately identifies the variables that correspond to the circuit currently selected. µWave Wizard's schematic editor supports zooming, drag and drop, cut and paste and undo/redo functionality for the elements and circuits and contains many useful macros. All of these editing options are easily found under ribbons. Another new feature enables changes at both the project and circuit levels, as desired.

The OpenGL based 3D viewer provides visualization of circuit geometries, mesh files and field patterns and enables the graphic to be exported to common CAD formats like STL, DXF, VRML and STEP. With Version 8, real-time 3D visualization of all library elements is introduced. When both the element editor and the 3D viewer are open at the same time, a change of a geometric parameter in the element editor will be immediately visible in the viewer.

One of the main assets of µWave Wizard is the library module, which has over 450 key building elements, such as steps, irises, cavities, bends, junctions, coaxial probes, entire structures (e.g., tapers, OMTs) and radiation. Searching for an element is possible by using the new filtering option, filtering the component by name – even by a part of the name of the desired element – or by using port properties.

MODELER

Although µWave Wizard's elements offer high flexibility,

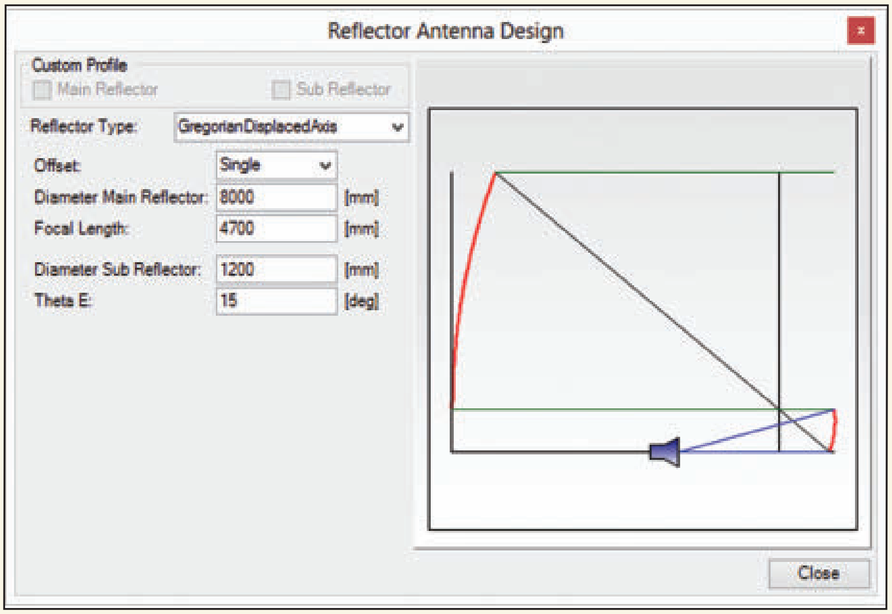


▲ *Fig. 2 The modeler is a 3D editor for creating and modifying geometric models of 3D and planar structures.*

some designs may require the creation of user-defined elements. μWave Wizard Version 8 now includes a modeler which is directly accessible through the new μWave Wizard modeler library. The modeler (see ***Figure 2***) is a versatile 3D editor enabling the creation and modification of geometric models of 3D and planar structures. Modeling is based on a constructive solid geometry (CSG) technique, where complex geometries are created from simple objects called primitives (e.g., boxes, cylinders, rectangles) and then modified and/or subjected to Boolean operations (e.g., union, subtraction, intersection). For example, a partial height post in a cavity is created by first creating a box, then a cylinder and subtracting it from the box. Each time an object is created or modified, the action is added to the object's operation list, which acts as a blueprint. This makes the design and further modification of structures simple and fast.

A different approach to the design comprises building the structure in two steps. First, a two-dimensional cross-sectional profile is created using 2D primitives. Second, the profile is extruded along a line to get a 3D structure. Other features of the construction include arrays of objects using the cloning tool, fillets to create accurate models of devices built by machining and structures with ruled surfaces and surfaces of revolutions.

This new feature not only facilitates easy building of structures, it also provides a simple and powerful way to change structures once built. Thanks to parameterization



▲ *Fig. 3 Synthesizing a Gregorian DAX antenna with the reflector synthesis tool.*

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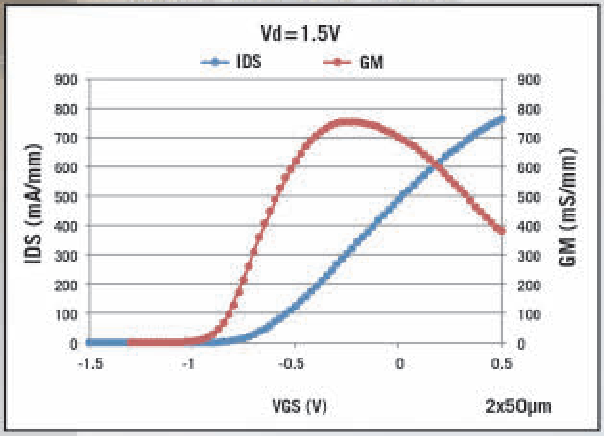
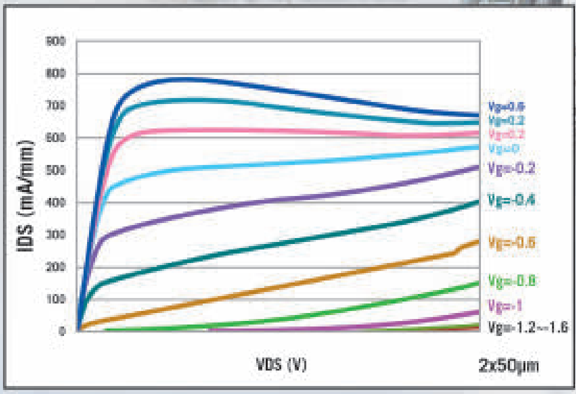
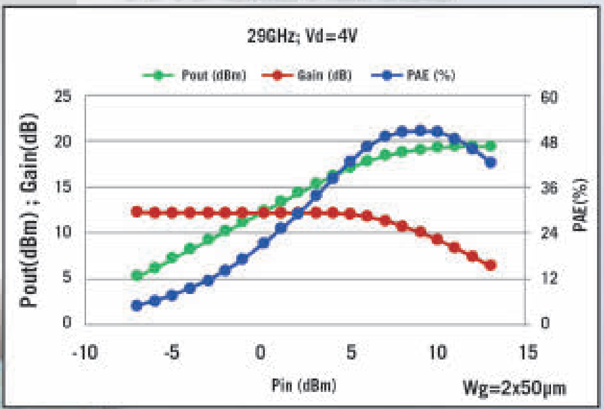


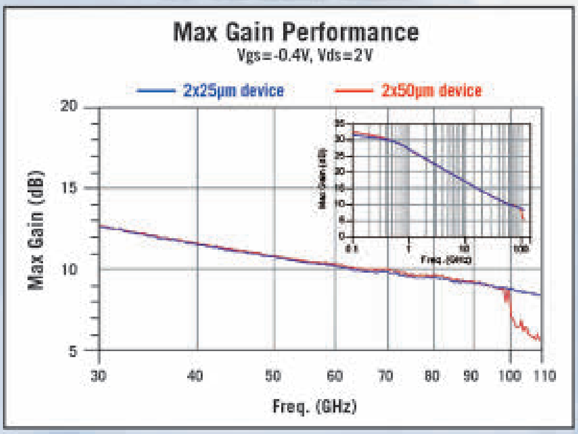
PP10 I-V Curves



PP10 Load Pull Data



PP10 Max Gain



of all operations on geometries, the dimensions and other parameters of a structure can be quickly changed without building the structure again. The user simply selects the desired operation on the screen and types a new parameter value; the structure is automatically rebuilt according to the new parameters.

The modeler incorporates a flexible variable mechanism that not only enables the introduction of simple numerical values but also complex equations, utilizing a range of built-in predefined functions. Further design flexibility is achieved by utilizing multiple nested coordinate systems. All variables are synchronized between the modeler and µWave Wizard's GUI. The connection between modeler elements (even complex structures) is supported by the multimodal scattering matrix. No normalization or manual sorting of modes is necessary. The user simply connects the corresponding waveguide ports between the elements.

Version 8 includes several additional features and enhancements:

Direct and Iterative Solver: µWave Wizard uses 3D FEM as an additional method to solve Maxwell's equations, offering high flexibility in modeling capabilities (i.e., geometry, material fillings, field and loss calculations). Now with µWave Wizard Version 8, two new 3D FEM solvers – one direct and one iterative – have been introduced. They use a set of hierarchical basis functions, up to third order, and curvilinear tetrahedral elements to solve the wave equation. The use of higher order basis functions leads to more accurate approximations of the electromagnetic fields, where curvilinear tetrahedral elements result in accurate shape modeling of curved and complex geometries. The field calculation and mode matching interface have been extended for full compatibility with existing modules. The iterative solver uses a multilevel preconditioner for greater efficiency.

Reflector Synthesis Tool: The reflector computation, which was extended by a reflector synthesis tool since the previous version (7.11) of µWave Wizard, has been further modified in Version 8. This tool is now capable of designing several reflector and sub-reflector types, ranging from very basic structures like parabolic and hyperbolic to more complex structures such as displaced axis (DAX) Cassegrain or Gregorian reflectors (see ***Figure 3***). This tool also offers the user the facility to create any user-defined reflector or sub-reflector.

Parallelization: µWave Wizard offers different levels of parallelism for efficient use of multi-core CPU architectures. The parallelization of all 3D FEM solvers and many of the mode matching and 2D FEM modules significantly speeds up the simulation of a single project.

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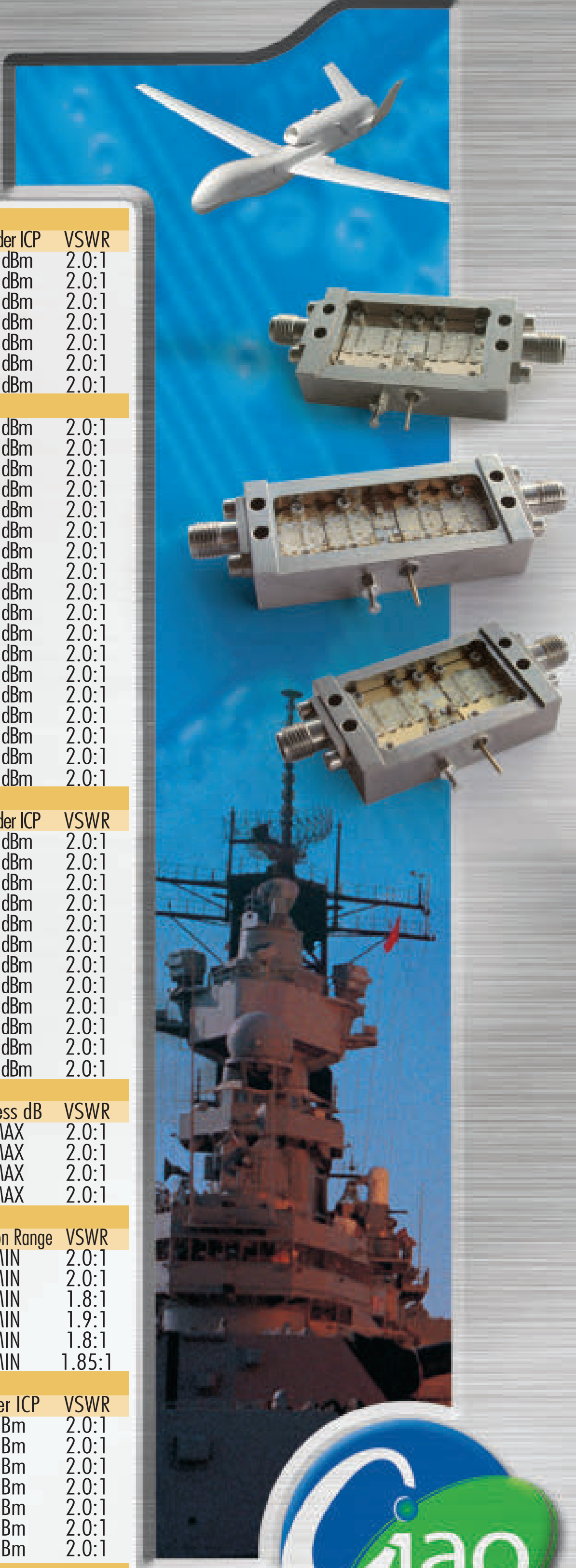

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
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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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Thales Alenia Space's Poseidon-3C Radar Altimeter Chosen for SWOT Satellite

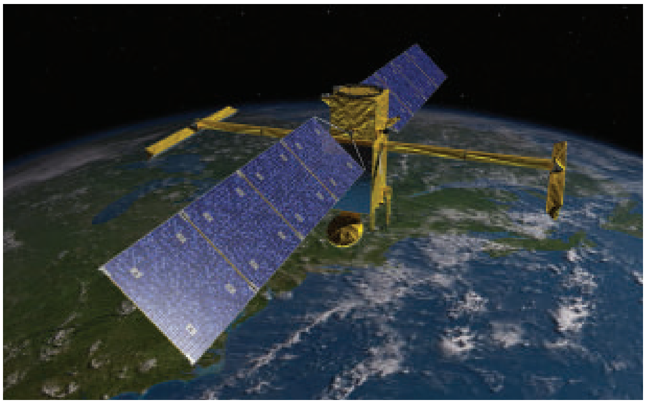
Thales Alenia Space recently signed a contract with the French space agency CNES (Centre National d'Etudes Spatiales) covering the design and development phase for the Poseidon-3C radar altimeter on the SWOT (Surface Water and Ocean Topography) satellite, new altimetry program that will demonstrate new applications.

The contract covers the supply of a nadir altimeter (for vertical measurement), along with the brand new main instrument, the KaRIn (Ka-Band Radar Interferometer) wide-swath altimeter. The Poseidon-3C instrument will integrate the latest improvements from the Poseidon 3B instrument, already mounted in the Jason-3 satellite, to be launched shortly by a Falcon rocket.

Thales Alenia Space's Poseidon family of altimeters are dual-frequency radars operating at 13.6 GHz and 5.3 GHz. They provide precise measurements of ocean surface height, a critical parameter to monitor climate change and the rise in sea levels, along with ocean dynamics and currents, wave height and surface wind force. More recently, and especially since the advent of Jason 2, these instruments have added the measurement of river and lake heights, and we are now seeing a boom in "space hydrology", which will be the stake of the SWOT mission.

Hervé Hamy, vice president, Observation and Science at Thales Alenia Space France, said, "The aim of SWOT is to measure the topography of seas and oceans, as well as lakes and large rivers. Winning the contract for this new instrument confirms the excellence of our product family, and also the continued trust expressed by CNES and NASA in our altimetry expertise. This mission will offer a never-seen level of precision, resolution and data refresh rate, further bolstering Thales Alenia Space's contribution to environmental and climate change monitoring."

The SWOT satellite will be built in collaboration with U.S. JPL (Jet Propulsion Laboratory) on behalf of the French (CNES) and American (NASA) space agencies, with contributions from the Canadian (CSA) and British (UKSA) agencies. Visit https://swot.jpl.nasa.gov/ for more information on SWOT.



Source: NASA

BAE Increases Effectiveness and Survivability of USAF F-15 Fleet with EW Upgrades

BAE Systems has been selected by Boeing to develop and manufacture a new, all-digital electronic warfare system for the U.S. Air Force's (USAF) fleet of F-15 fighter aircraft. The new electronic warfare system is part of a multi-billion dollar program to develop the Eagle Passive Active Warning Survivability System (EPAWSS), an integrated system that will provide advanced aircraft protection, significantly improved situational awareness, and support future USAF F-15 mission requirements.

"This selection builds on our extensive electronic warfare legacy, a history we were able to leverage to develop an executable, affordable and low-risk solution for the F-15 fleet," said Brian Walters, vice president and general manager of Electronic Combat Solutions at BAE Systems. "By upgrading to an enhanced all-digital system, the Air Force, in conjunction with the platform prime, Boeing, will provide next-generation electronic warfare capability to F-15C and F-15E aircraft to help keep the platform capable and mission-ready against current and future threats."

> EPAWSS, an integrated all-digital system, provides advanced electronic warfare capabilities and a significant growth path for the F-15 Eagle.

The F-15 EPAWSS system will replace the current F-15 Tactical Electronic Warfare Suite (TEWS), which has been in use since the 1980s. Updating the electronic warfare system is critical to the F-15, which is scheduled to be in service through 2040.

EPAWSS, an integrated all-digital system, requires a smaller footprint than TEWS and provides advanced electronic warfare capabilities and a significant growth path for the F-15 Eagle. The system will improve aircraft protection with advanced electronic countermeasures, radar warning, and increased chaff and flare capability. EPAWSS is designed to meet future F-15 requirements, including the capability to detect and defeat threats in contested and highly contested environments.

Source: USAF

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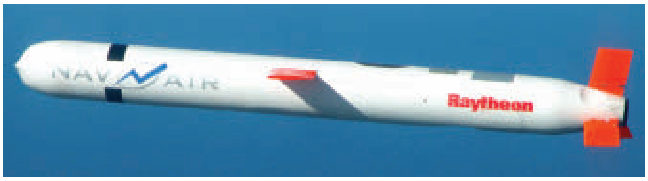
US Navy, Raytheon Demo Network-Enabled Tomahawk Cruise Missiles in Flight

A Tomahawk Block IV cruise missile successfully showed it can take a reconnaissance photo and follow orders to re-target in mid-flight during a test conducted by the U.S. Navy and Raytheon Co.

During the test, a missile launched from the guided missile destroyer USS Gridley (DDG 101) used its onboard camera to capture battle damage indication imagery and then transmitted the image to fleet headquarters via its two-way UHF SATCOM datalink. The missile then entered a loiter pattern to await further instructions.

Meanwhile, strike controllers at the U.S. Fifth Fleet headquarters in Bahrain retargeted the missile to a new aim point on the Navy's range at San Nicolas Island, off the coast of southern California. The missile performed a vertical dive and struck the designated target.

The test was designed to show that the missile's strike controllers, located at multiple fleet headquarters, can control and redirect multiple missiles simultaneously. To reduce testing costs, only one of the large salvo of missiles was a live launch. The rest were flown via computer simulation through various missions directed by forward deployed strike controllers.



Source: U.S. Navy

NGC Selected by US Army to Develop New ARL-E Long-Range Radar

Northrop Grumman Corp. has been selected by the U.S. Army to develop the Airborne Reconnaissance Low-Enhanced (ARL-E) long-range radar.

Under terms of the indefinite delivery indefinite quantity contract, the company will develop a synthetic aperture radar (SAR)/ground moving target indicator (GMTI) system for the ARL-E DHC-8.

"The Long Range Radar (LRR) is a natural fit into the Northrop Grumman family of intelligence, surveillance and reconnaissance (ISR) systems and mission solutions," said Steve McCoy, vice president of tactical sensor solutions, Northrop Grumman Electronic Systems. "Our low-risk, affordable solution combines mature Active Electronically Scanned Array (AESA) technology with operationally proven hardware and software to meet all-weather and long-range ISR requirements."

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InternationalReport

Richard Mumford, International Editor

Ericsson Report Identifies E-Band as Key to Boosting Microwave Capacity

VIEW VIDEO

Ericsson's latest edition of "Microwave Towards 2020," an ongoing series on the state of the microwave business, predicts several major developments by 2020. Firstly, microwave technology will support multi-gigabit capacities in traditional frequency bands and beyond 10 Gb in the millimetre wave (E and V-Bands).

In the coming years, the choice between fibre and microwave in backhaul networks will not be about capacity, but fibre presence and TCO. Ericsson foresees that microwave will continue to be the dominant backhaul technology. In 2020, 65 percent of all cell sites will be connected by microwave solutions; markets such as China, Japan, South Korea and Taiwan that have existing deep fibre investments will be the exception.

E-Band spectrum will prove key in catering for capacity increases in both fronthaul and backhaul. The E-Band (70/80 GHz) will experience major growth and will represent up to 20 percent of new deployments in 2020. Traditional bands will represent 70 percent of new deployments in 2020.

Ericsson foresees a paradigm shift in microwave planning, with the introduction of multiband use. A seven-time capacity increase can be achieved using a wide, low-availability link in the E-Band to boost a high-availability link in traditional bands.

Karolina Wikander, head of Microwave, Ericsson, said, "Microwave networks are a vital ingredient for operators to provide the best possible performance and quality of experience in the most cost-efficient way, and will continue to be the dominant backhaul technology in the future. Capacity needs will continue to increase on the road to 5G, and keeping up requires continued technology evolution and re-imagining network efficiency."

Karolina Wikander will explain the findings of the "Microwave Towards 2020" report in greater detail and Ericsson's activity in the microwave market in an Executive Interview that appears on microwavejournal.com.

Xhaul Consortium to Develop Integrated Solution for 5G Networks

The Xhaul Project, part of the European H2020 5G Public-Private Partnership (5G PPP) Infrastructure, will define and develop the next generation of integrated fronthaul and backhaul networks that will respond to the needs of the future 5G communications system.

The Xhaul Consortium comprises 21 partners including leading telecom industry vendors, operators, IT companies, small and medium-sized enterprises and academic institutions.

The term Xhaul refers to the integrated combination of fronthaul and backhaul and is defined as the common flexible transport solution for future 5G networks, aims at integrating the fronthaul and backhaul networks with all their wire and wireless technologies in a common packet based transport network under a Software Defined Networks (SDN) based and Network Functions Virtualization (NFV) enabled common control.

The consortium's envisioned novel Xhaul architecture will enable an unprecedented level of flexibility and dynamicity at a reduced cost, allowing operators to reconfigure and share the network in a cost-effective and time-efficient manner. It will consider a mix of different heterogeneous (both wire and wireless, existing legacy and novel) physical and link technologies to implement a unified fronthaul and backhaul networking infrastructure.

The technical approach is based on two novel building blocks: a control infrastructure using a unified, abstract network model for control plane integration – Xhaul Control Infrastructure (XCI) and a unified data plane encompassing innovative high-capacity transmission technologies and novel deterministic-latency switch architectures – based on the Xhaul Packet Forwarding Element (XFE) – seamlessly interconnecting different heterogeneous transport technologies, and employing a single, versatile frame format.

High-Tech Electronics Helps the Search for Space Life

The EU-funded TeraComp Project has developed a new 'terahertz receiver' that could help detect traces of life in space – especially if used for the first European Space Agency (ESA) mission to Jupiter's moons, planned for launch in 2022.

"If Europe is going to send instruments into space, we need to be able to produce some of the key technologies in Europe," said Jan Stake, project leader at the Chalmers University of Technology, Gothenburg, Sweden. "Building the capacity to make these instruments benefits European industry," he explained, reducing reliance on U.S. suppliers.

The project team focused on developing Schottky di-

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For More Information — Visit mwjournal.com for more international news odes – devices to detect and receive high-frequency signals. The team also worked to integrate complementary circuits such as a local oscillator within the same receiver. This enabled them to push the frequency response as high as possible and optimise the components so that they work well together. "We start with microwave circuits and then multiply up the frequency until we generate a signal for the receiver and signal processing," explained Stake. The end result is a compact, lightweight receiver that could make the grade for ESA's upcoming JUICE mission to Jupiter's moons.

"With EU funding, we were able to bring seven partners into the project, enough to push development in different parts of a complex receiver so the components are optimised to work together," said Stake. EU support is boosting Europe's position in the space race. Thanks to the outcome of TeraComp, participating SMEs such as Omnisys Instruments AB have already received commercial contracts for further instrument development.

Thales and CNRS Extend Strategic Partnership

Building on proven credentials in leading-edge research, Thales and French scientific research agency CNRS have extended their long-standing framework agreement for a further five years. The two partners have been working together under this strategic arrangement since 1985.

> ...technology leadership in the face of tough competition...

In each of its five key markets, Thales needs to consolidate its technology leadership in the face of tough competition. Pursuing advanced research in physics, algorithms, modelling and software, the Thales and CNRS teams have highly complementary expertise and a shared ambition to develop value-adding innovations for customers and users of Thales solutions.

Joint laboratories and integrated research teams set up under this type of agreement are a constant source of inspiration and motivation for both partners. Working with innovative industry players helps CNRS to extend the worldwide influence of the French research community, while French industry benefits from the agency's world-class scientific and technological excellence.

Alain Fuchs, president of CNRS said, "The renewal of this contract will further consolidate such a long-standing partnership. Thales and the CNRS involves more than 100 scientific collaborations, a joint physics unit, a joint international research unit in Singapore, a shared laboratory and hundreds of mutually-owned patents."

Cliff Drubin, Associate Technical Editor

Key Players in Global Civilian Drones Market 2015-2019

VIEW VIDEO

According to a New Study by ASDReports, the following companies are key players in the global civilian drones market: 3d robotics, Aeryon, Aibotix, Dji, Parrot and Walkera. Other prominent vendors are: Aeronautics, Aerovironment, Airware, Aurora Flight Sciences, Cybaero, Drone Deploy, Ehang, Precision Hawk, Thales, Trimble Navigation and Xaircraft.

Commenting on the report, an analyst said, "The use of and demand for civilian drones in film and media applications increased after the FAA approved its use in the industry in September 2014. Drones are used for filming aerial photos and videos on sets. They can also be used in indoor sets that are restricted to the public; however, the operator requires prior permission and pilot certification for entry."

> Drones are increasingly being used to detect and avoid hazardous environments and natural disasters.

According to the report, drones are increasingly being used to detect and avoid hazardous environments and natural disasters. They can be used for search and rescue operations, crisis mapping, and the provision of relief packages and cargo.

Further, the report states that civilian drones pose serious threats to commercial airplanes and helicopters. Many incidents have been reported by pilots wherein the drones came in close vicinity to the aircraft, risking the lives of the passengers aboard.

The study was conducted using an objective combination of primary and secondary information including inputs from key participants in the industry. The report contains a comprehensive market and vendor landscape in addition to a SWOT analysis of the key vendors.

The Microwave Tube Market Still Strong at Over $1B for 2015

While microwave and millimeter wave high-power vacuum electron devices (VED) remain "below the radar" of many industry observers, the total available market (TAM) for this segment is over $1 billion. Despite its size, and although these tubes remain essential elements in specialized military, scientific/medical and space communications applications, this market is generally under-reported and poorly understood by those not directly involved in it.

After several rounds of consolidation in recent years, this is essentially now a stable industry. ABI Research director Lance Wilson believes there is potential for further consolidation, but there are no signs of that happening yet. However one new RF semiconductor technology – gallium nitride (GaN) – will change the landscape, but has not yet done so to any large scale. While it is not yet near monopolizing the RF/microwave power industry, GaN is advancing steadily and is a technology that should be closely watched, as it will be a threat to some aspects of the microwave and millimeter wave VED marketplace.

> One new RF semiconductor technology – gallium nitride (GaN) – will change the landscape, but has not yet done so to any large scale.

Wilson states, "The size of this historic market continues to surprise everyone, and its longevity and firm resistance to RF power semiconductor encroachment is as surprising; however, that will be changing as GaN devices move up in frequency and power. These specialized vacuum electron devices may at first seem anachronistic, but in some cases there is no other way to generate such high levels of RF power within an acceptably small space. Certain microwave and millimeter wave VEDs can generate megawatts, and it would take tens of thousands of transistors to do that."

These findings are part of ABI Research's recent study, "Microwave and Millimeter Wave High-Power Vacuum Electron Devices: One of Electronics' Original Technologies is Going Strong," which examines the microwave and millimeter wave high power vacuum electron device market and assesses how GaN devices could affect that business.

Wi-Fi Calling a Must Have Service from Mobile Operators

With at least 10 wireless operators already offering native Wi-Fi Calling, the market is set to grow rapidly in Q4 2015, according to the Strategy Analytics Wireless Operator Strategies (WOS) service report, "Wi-Fi Calling Momentum Builds as Carriers Plan Voice Future."

Unlike earlier versions of calling on Wi-Fi, native Wi-Fi Calling lets users make and receive calls and texts on their smartphones just as if they were on the cellular network, using the phone's dialer and contact lists. Calls can hand over between Wi-Fi and voice over LTE (VoLTE) during the call for a seamless customer experience. Apple's support for Wi-Fi Calling in last year's iPhone 6 encouraged more operators to add the service capabilities to their networks and offer software upgrades for capable phones – certain models from Apple, Samsung, Microsoft and others. With 13 million new Wi-Fi Calling capable iPhones 6s and 6s+ sold the first weekend they were on sale, the number of wireless customers that can take advantage of Wi-Fi Calling is expanding rapidly.

Key findings:

- T-Mobile US has been the leading global operator championing Wi-Fi Calling, taking advantage of Wi-Fi to im-

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prove customer experience for in-building calling and international roaming, enhancing its competitive position.

- Around the globe, at least 10 mobile operators have commercially launched native Wi-Fi Calling, including T-Mobile US and Sprint, EE and Vodafone in the UK, SmarTone and 3 in Hong Kong and Vodacom in South Africa.
- The number one driver for Wi-Fi Calling is to enable customers to make and receive mobile calls in are as with poor cellular signal but good Wi-Fi coverage.
- Wi-Fi Calling enables both improved customer experience and new service offerings that can attract new customers, reduce churn and compete with over-the-top (OTT) services.

According to Susan Welsh de Grimaldo, director, Wireless Operator Strategies, "Coverage and voice quality are still critical factors in selecting a wireless service provider. Because it offers better voice in more places, Wi-Fi Calling will move quickly from being a first mover differentiator to standard table stakes – a service that subscribers come to expect from their mobile service provider."

Hotspot 2.0 Becomes Mainstream as Deployments Exceed 6 Million by 2020

Mobile operators are increasingly relying on Wi-Fi networks, both directly and indirectly, to support their businesses. Out of the massive global Wi-Fi coverage in 2020, at least 6 million public locations will support Hotspot 2.0 features.

Although a number of operators have already upgraded or committed to upgrade their networks to support Hotspot 2.0, the adoption remains slow. Initially, Hotspot 2.0 offered seamless discovery and access, which can potentially enhance the user experience and attract more engagement. Operators, however, still lack the tools to generate revenue streams from this technology. "Hotspot 2.0 will evolve to allow operators higher flexibility for supporting different policies, which in turn, will encourage implementation of innovative business models, and ultimately wider market adoption," says Ahmed Ali, research analyst at ABI Research.

The rise of IMS-enabled Wi-Fi calling has boosted the confidence in Wi-Fi voice capability and is suggesting an even larger role for Wi-Fi technologies in 4G and 5G networks. Many operators that have tapped the technology in countries such as the United States, the United Kingdom, Australia, South Africa and Hong Kong, have launched the service with VoLTE side by side, aiming for a complete seamless voice experience and driving the usage to five-fold by next year.

Migrating to 802.11ac is another top priority for operators in order to release or avoid congestion problems within public spaces. Following the residential and enterprise pattern, metro dual-mode access point shipments rapidly grow to dominate the carriers' equipment shipment.


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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Raytheon Co. announced it has acquired Herndon, Virginia-based **Foreground Security**, a provider of security operations centers (SOC), managed security service solutions and cybersecurity professional services. The acquired company, which will be called Raytheon Foreground Security (RFS), accelerates Raytheon's expansion into managed security services across federal, international and commercial markets. RFS has approximately 165 employees, 85 percent who are trained cybersecurity experts. Foreground Security's Virtual Security Operations Center (V-SOC) and Automated Threat Intelligence Platform (ATIP) offer unique advanced cyber monitoring, threat hunting and professional services capabilities.

Skyworks Solutions Inc. and **PMC-Sierra Inc.** announced a definitive agreement under which Skyworks will acquire PMC for $10.50 per share in an all-cash transaction valued at approximately $2 billion. Upon completion of the acquisition, Skyworks expects annual revenues of more than $4 billion with gross margin in the 55 percent range and operating margin exceeding 40 percent.

GigOptix announced signing a definitive agreement to acquire **Terasquare Co. Ltd.**, a Seoul, Korea-based, fabless semiconductor company and provider of low power, CMOS high speed communication interface semiconductors for 100 Gbps Ethernet, Fiber Channel and EDR Infiniband applications. GigOptix is executing this acquisition as a cash deal, paying about $4 million in cash to Terasquare's investors and paying an additional $1.15 million of Terasquare's debt and other liabilities. The amounts to be paid are subject to customary adjustments. Based on the current Korean Government subsidies provided to Terasquare, the acquisition is neutral to accretive immediately upon closing.

CommScope, a global provider of connectivity and essential infrastructure solutions for communications networks, has completed its acquisition of **Airvana LP**, a privately-held leader in small cell solutions for wireless networks. Airvana provides award-winning 4G LTE and 3G small cell solutions that enable people to access communications, information and entertainment in the most challenging and high-value environments – offices, public venues and homes. This acquisition will expand CommScope's leadership and capabilities in providing indoor wireless capacity and coverage, an increasingly important market opportunity that is growing due to consumers' and businesses' insatiable demand for wireless data.

Communications & Power Industries LLC (CPI) acquired **ASC Signal Corp.**, which designs and builds advanced satellite communications, radar and high-frequency antennas and controllers. ASC Signal's high-performance antennas are used in commercial and government satellite communications, terrestrial communications, imagery and data transmission, and radar and intelligence applications. Under the acquisition agreement, CPI acquired ASC Signal from Resilience Capital Partners. CPI expects to realize approximately $50 million in annual sales, as well as positive contributions to its earnings in the first year following the acquisition.

COLLABORATIONS

As the passenger demand for quick and easy access to inflight entertainment and connectivity (IFEC) increases, aircraft IFEC systems need to provide faster data transmission over longer distances. **W. L. Gore & Associates** and **Kontron** – a global manufacturer of embedded computer modules, boards and systems – are working together to successfully meet these growing demands. GORE® Ethernet Cables are engineered for the increasing data demands of modern airborne digital networks. These cables coupled with Kontron's embedded computing avionic systems deliver reliable signal integrity for high-speed data transmission up to 10 gigabits over longer distances.

Modelithics Inc., an RF/microwave simulation model provider, announced a new partnership with **Vishay**, a manufacturer of discrete semiconductors and passive electronic components. As part of a Strategic Modelithics Vendor Partner (MVP) project, Modelithics and Vishay are collaborating to develop two new Microwave Global Models™ for the Vishay VJ HIFREQ 0402 and 0603 surface-mount RF and microwave capacitor families. Modelithics Microwave Global Models are high accuracy equivalent circuit models that cover an entire component series within one model. These powerful models, unique to Modelithics, feature substrate, part value and pad scalability, and accurately predict parasitic effects based on the model parameter settings.

Nokia's president and chief executive officer Rajeev Suri met with Emmanuel Macron, France's Minister of Economy, Industry and Digital Affairs, to formally affirm Nokia's commitment to driving innovation in France and globally, from France, that will result from Nokia's proposed combination with Alcatel-Lucent. The announcement follows an open and fruitful dialogue between Nokia and the French Government since the proposed combination was announced in April 2015. In its discussions with the French Government, Nokia has confirmed that France will play a leading role in the combined entity's Research and Development operations.

Tronics, a designer and manufacturer of innovative nano and microsystems, and **Airbus Group**, a global leader in aeronautics, space and related services, announced their partnership for the development of capacitive MEMS-based RF switches and circuits. Under this agreement, Tronics accesses Airbus Group's patent portfolio through an exclusive license for the development of a breakthrough technology platform for RF MEMS switches. This plat-

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form will serve Airbus Group business units, as well as any other company wishing to manufacture nPnT switches or custom circuits, such as tunable filters, switch matrices and switched delay lines.

NEW STARTS

JitterLabs announced the launch of an independent test lab to characterize frequency sources, and a software-as-a-service application for vendors of timing devices to manage their test data. For companies with limited characterization capabilities, JitterLabs provides an independent test lab to characterize clock signals between 10 MHz and 7+ GHz, such as output by frequency-control devices, PLLs, PHYs, ASIC and test equipment. Available measurements include phase noise, jitter, Allan deviation, VCO modulation bandwidth, power supply noise rejection and PLL jitter transfer. Testing is billed at an affordable hourly rate. For companies who characterize their devices in-house, JitterLabs offers a software-as-a-service application to organize their test data, and make it accessible and useful to others.

ACHIEVEMENTS

Anritsu Co. announced that its ME7873LA LTE-Advanced RF Conformance Test System has obtained the world's first LTE 3CA PTCRB certification. By obtaining PTCRB certification for 3CA, the ME7873LA supports deployment of LTE 3CA downlink, expected to be available in North America by the end of the year. The certification is part of Anritsu's ongoing commitment to be a leading developer of LTE-Advanced conformance test, and builds on previously announced 3CA capability for Carrier Acceptance Test in the ME7834LA Mobile Device Test System. A scalable GCF, PTCRB, and carrier-validated test system, the ME7873LA enables certification of 3G and LTE devices to industry and carrier standards.

ViaSat Inc., a global broadband services and technology company, has received its first Supplemental Type Certificate (STC) from the FAA for its in-cabin distribution system. This is the first of two significant STCs ViaSat expects to obtain with respect to in-flight entertainment and connectivity, with the second STC anticipated in Q1 2016 for its hybrid Ku/Ka-Band antenna system.

CONTRACTS

Harris Corp. has received a $21 million order from a Latin American nation for Falcon III® tactical radios that will be used to establish high data rate networks as part of a military communications modernization program. The order includes manpack, vehicular and base configurations of the Harris RF-7800H wideband tactical radio, which delivers expanded data capabilities in long-range, beyond-line-of-sight environments. The radio transmits voice, images and other larger data files over thousands of kilometers. The nation is also acquiring handheld and vehicular configurations of the Harris RF-7850M multiband networking radio – the first international radio to simultaneously support wideband communications, mobile ad-hoc networking and legacy narrowband waveforms.

MVG (Microwave Vision Group) announced a significant contract (approximately €9 million) from **PIT-RADWAR S.A.** for the purchase of a turnkey, state-of-the-art, antenna test facility in Poland. This new operation will include two large anechoic chambers, one with a Planar Near field scanner and the other with a compact antenna test range reflector and a highly accurate radar antenna positioner. Both chambers will be delivered as turnkey installations including RF instrumentation, computers and control software. The project, secured in cooperation with ORBIT/FR Europe GmbH and MVG's Polish partner Tespol, is expected to span 18 months and will improve PIT-RADWAR's capability to measure the next generation of radar antennas at their test and measurement facility in Kobyłka, Poland.

Mercury Systems Inc. announced it received a $2 million follow-on order from a leading defense prime contractor for high performance digital signal processing modules for a manned airborne synthetic aperture radar (SAR) application. The order was booked in the company's fiscal 2016 first quarter and is expected to be shipped by its fiscal 2016 second quarter.

Mitek announced that it has received reorders from two Mobile Deposit® partners, one in the U.S. and one in Canada, totaling $1.7 million. These agreements closed in Mitek's fiscal 2015 fourth quarter and consisted of $1.4 million in software license revenue and $0.3 million in annual maintenance revenue.

U.S. Navy researchers needed ferrite phase shifter modules for advanced radar development work. They found their solution from **Microwave Applications Group Inc.** in Santa Maria, Calif. Officials of the Naval Air Warfare Center Aircraft Division in Lakehurst, N.J., announced a $10.2 million contract to Microwave Applications for 1,800 ferrite phase shifter RF and microwave modules, which researchers will use to develop a closed-loop passive electronically scanned array radar system. The ferrite phase shifter modules from Microwave Applications, as well as the closed-loop passive electronically scanned array radar system under development, are for the Naval Air Systems Command's Test Readiness Management Center's Closed Loop Passive Electronically Scanned Array Project Office.

Thales Alenia Space signed a contract with French space agency **CNES (Centre National d'Etudes Spatiales)** covering the design and development phase for the Poseidon-3C radar altimeter on the SWOT (Surface Water and Ocean Topography) satellite, new altimetry program that will demonstrate new applications. The contract signed today covers the supply of a nadir altimeter (for vertical measurement), along with the brand-new main instrument, the KaRIn (Ka-Band Radar Interferometer) wide-swath altimeter. The Poseidon-3C instrument will integrate the latest improvements from the Poseidon 3B instrument, already mounted in the Jason-3 satellite, to be launched shortly by a Falcon rocket.

Around the **Circuit**

PEOPLE

▲ *Masud Al Aziz*

▲ *Rick Hollowell*

Copper Mountain Technologies (CMT) has hired two new employees to support the company's growth. **Masud Al Aziz** and **Rick Hollowell** will both play strong roles when it comes to helping customers improve their radio frequency and microwave testing processes via the company's affordable, lab-grade equipment. As the new senior applications engineer and RF specialist for CMT, Al Aziz brings extensive experience in microwave engineering, RF circuit design, antenna design and digital signal processing to the company. Hollowell is the new national business development manager for CMT and will focus on expanding the company's market position by implementing new strategic goals, enhancing key customer relationships and identifying new business opportunities.

REP APPOINTMENTS

BJG Electronics Inc. and **Maury Microwave** announced a North America and Europe distribution agreement whereby BJG will add Maury Microwave's test cable and adapter portfolio to their line card. BJG will stock Maury Microwave Utility (UC) and Stability (SC) test assemblies and the full range of test adapters.

Custom MMIC announced the appointment of **Aspen Electronics** as their new technical representative covering the United Kingdom. Aspen Electronics was founded in 1974 and has an established team of high-tech professionals offering premium, state-of-the-art components and related technologies for the RF/microwave and wireless markets.

Modelithics Inc. announced a new partnership with **Hi Tech RF & Microwave Solutions** in Maarssen, Netherlands for Modelithics library sales and services representation. Larry Dunleavy, president and CEO of Modelithics, and Olaf Biezeman, managing director of Hi Tech, have signed a representation and reseller agreement for new business in Belgium, Netherlands and Luxembourg. Hi Tech will offer convenient sales and coordination of support for Modelithics' RF and microwave simulation model libraries and measurement services in the representation area.

RFMW Ltd. and **XSYSTOR Inc.** announced a distribution agreement. XSYSTOR Inc. provides universal sequencers, controllers and fast switches to support implementation of GaN transistors in the latest generation RF and microwave power amplifiers. Under the agreement, RFMW is franchised for North America, Europe and the Middle East for XSYSTOR controllers and switches. XSYSTOR controllers incorporate voltage sequencers, modulators and voltage inverters to accommodate design alternatives in GaN transistor circuit implementations.

Around the **Circuit**

Richardson Electronics Ltd. announced a new global distribution agreement with **Anokiwave**, a provider of highly-integrated silicon core chips and III-V front-end integrated circuits (IC). The agreement aligns with Anokiwave's focus on supporting customers and new opportunities with highly-technical support to provide innovative solutions for the most challenging applications. Anokiwave is a provider of highly-integrated core chip and IC solutions that enables emerging millimeter wave and active electronically scanned array (AESA) markets.

TechPlus Microwave Inc. announced the appointment of **The Thorson Co. of Southern California** as their new representative in southern California. The Thorson Co. of Southern California is a professional organization that is a manufacturer's representative for RF/microwave and electrical mechanical devices, components and subsystems supplying the military, aerospace and commercial marketplace. The company's current space level manufacturing process allows for delivery in as quickly as four weeks depending on the test requirements. TechPlus Microwave also announced the appointment of **Microwave Component Marketing** as their new representative in Florida.

PLACES

EDI CON China announced that the **China Electrotechnical Society's** (CES) Electromagnetic Technology Conference & Exhibition (EMC) will be co-located on the 4th floor of the China National Convention Center (CNCC) taking place 19 to 21 April, 2016 in Beijing. The combined event forms the largest microwave, EMC/EMI and high-speed digital conference and exhibition in Beijing. This is a natural extension of the EDI CON China event that already covers EMC/EMI topics but will now feature a comprehensive parallel conference and expanded exhibition. EDI CON China has formed a pavilion specifically for EMC/EMI companies on the exhibition floor to congregate similar companies in one area providing easy access for delegates and visitors.

Accel-RF Instruments Corp., a provider of turn-key reliability and performance characterization test systems for compound semiconductors, announced that it has opened a permanent office on the East Coast. This new location will be focused on application support as well as equipment maintenance service, and will allow Accel-RF to better serve existing and future customers in the Eastern United States. The new Accel-RF office is located in the Innovation Center in Jackson Technology Park, at 94 Jackson Road, Suite 106A, Devens, Mass., 01434. For more information, visit www.accelrf.com.

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INVITED PAPER

PA Design Using Harmonic Balance Simulation With Only S-parameters

Ivan Boshnakov
Microwave Design Engineer

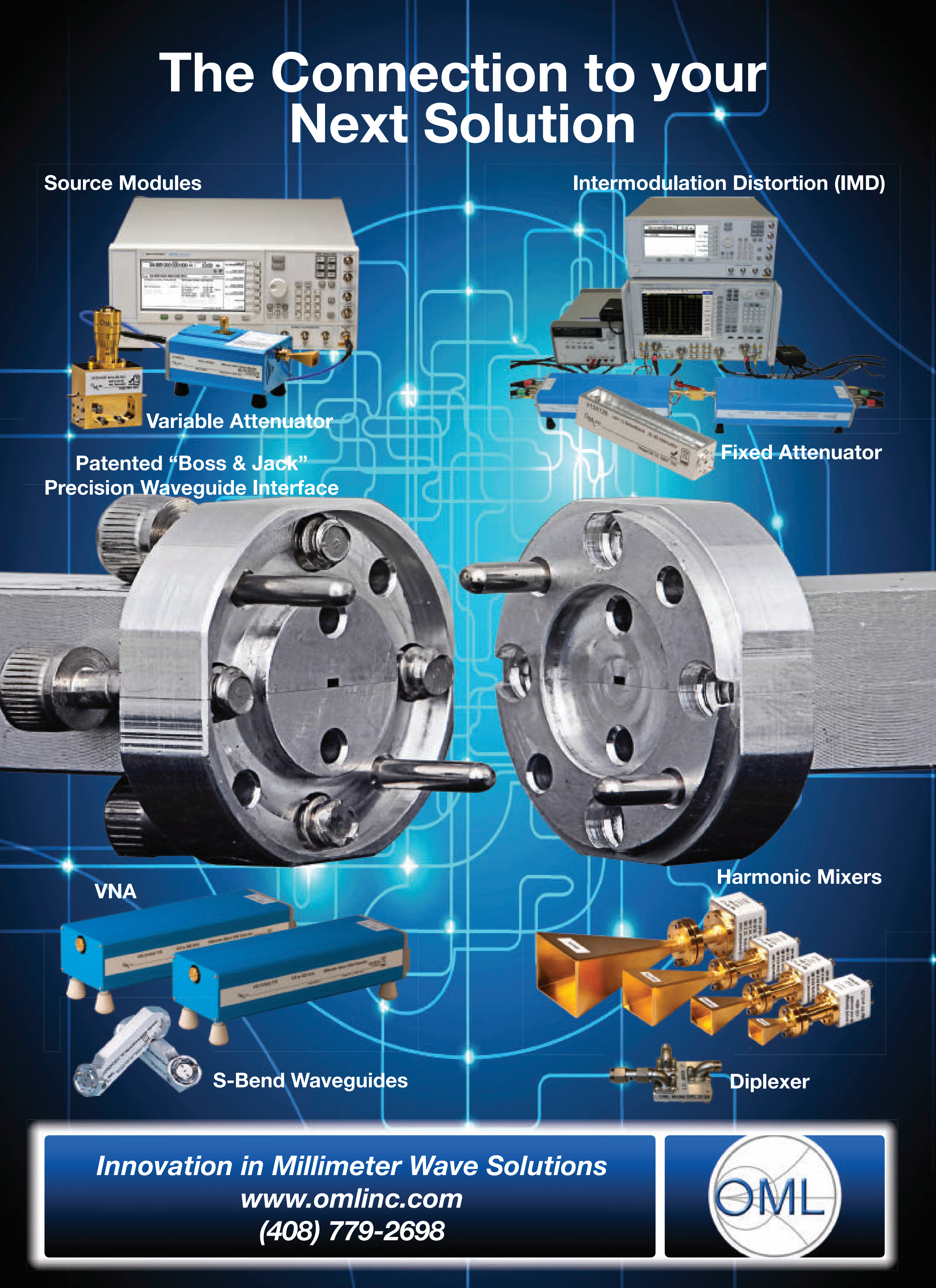
While it is widely held that S-parameters alone combined with harmonic balance (HB) cannot simulate the power performance of transistors, this article describes a method for designing and simulating amplifiers for maximum power using HB simulation, when the only available data is transistor S-parameters. The method is widely applicable when nonlinear transistor models are not available. It can also be very helpful even when the nonlinear models are available.

The amplifier design methodology described here is an extension of Steve Cripps' load line approach,[1-3] which was extended with the power parameters introduced by Pieter Abrie.[4] These techniques may be used to create useful approximations that allow HB simulation with transistors that do not have nonlinear models. This paper is a sequel to an earlier paper presented in April 2013 at ARMMS.[5]

Cripps' original paper was published in 1983 when HB simulation was not yet in use and load-pull measurements were the only option available for device characterization. When Cripps' technical note was published, HB simulation was available but, among other problems, was very slow. The Cripps approach offered a much simpler way to design for high power. Cripps expressed a hope that the simple math of his approach should be incorporated in the general linear simulators "in much the same way that most of the currently available packages compute noise figure."[2] He also stated that with "some slightly innovative use" the approach could be applied when there is feedback, for multi-stage design and, potentially, for other amplifier configurations. Unfortunately, his approach was never implemented in any of the general simulators. It was, however, implemented in a more advanced form in the specialized MultiMatch Amplifier Design Wizard[6] developed by Pieter Abrie. Abrie presented the power parameters in his book[4] and implemented them in MultiMatch for the design of Class A and Class AB amplifiers.

The mapping functions of the power parameters lifted any restrictions associated with the transistor's configuration, including feedback, resistive loading, grounding node position, parallel cells or chips, reference plane issues and multiple stages. There are interesting similarities with the noise parameters, such as series feedback allowing easier matching for maximum power.

Today, the HB simulations are as fast as the linear simulations were 20 years ago. While accurate nonlinear transistor models have been developed, they are still not provided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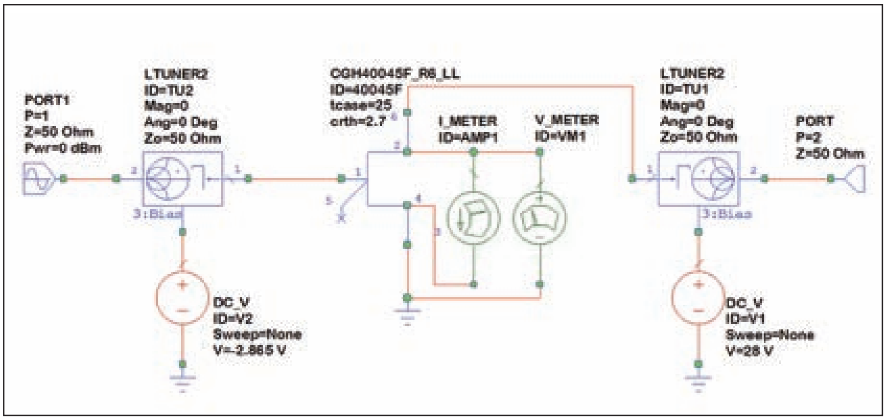


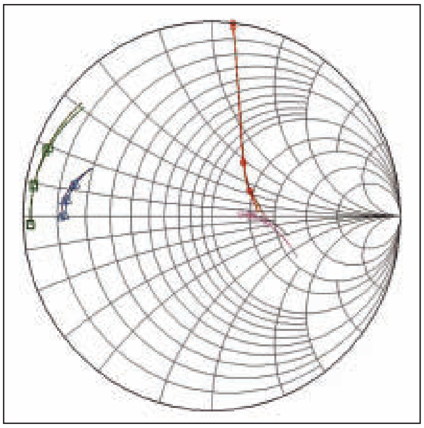
▲ *Fig. 1 Output stage in Microwave Office.*

for many useful transistors. Abrie's power parameters approach is a fully developed method which can easily be incorporated in any of the general simulators to speed up and enhance the design process for P_{1dB} and P_{sat}, especially when nonlinear models are not available.

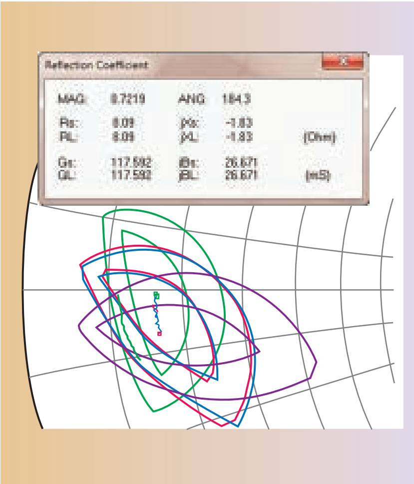
0.5 TO 2.5 GHz GaN PA DESIGN

The streamlined HB process[6] was used to design a three stage power amplifier covering 0.5 to 2.5 GHz, using a 45 W GaN HEMT. In addition to the design process, the results of the HB simulations of the dynamic load lines for each stage will be shown. This will enhance the understanding of the design process and explain how to extract the desired power from a transistor stage when a nonlinear model is not available.

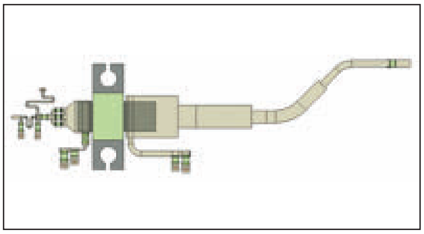
Figure 1 shows the start of the design output stage design in the NI AWR Microwave Office® simulator. The nonlinear model of the transistor and the tuners could be used to extract the impedances for maximum power and gain over the frequency band. Instead, only the S-parameters at the transistor's $I_{max}/2$ are extracted. The S-parameters are then imported into MultiMatch to fit a linear model (see ***Figure 2***). After defining the maximum current and voltage areas on the I-V curves (the clipping boundaries), the power parameters are used to extract the load-pull data (see ***Figure 3***). Then the output network is synthesized to provide the load impedance associated with the maximum pre-clipped power, followed by the input matching networks to provide maximum flat gain and stability. The MultiMatch layout is easily manipulated to the desired form, and the



▲ *Fig. 2 Fitting a linear model to the S-parameters in MultiMatch.*

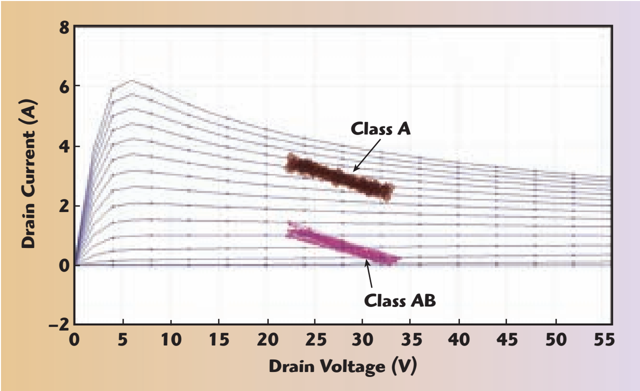


▲ *Fig. 3 Load-pull contours extracted in MultiMatch.*

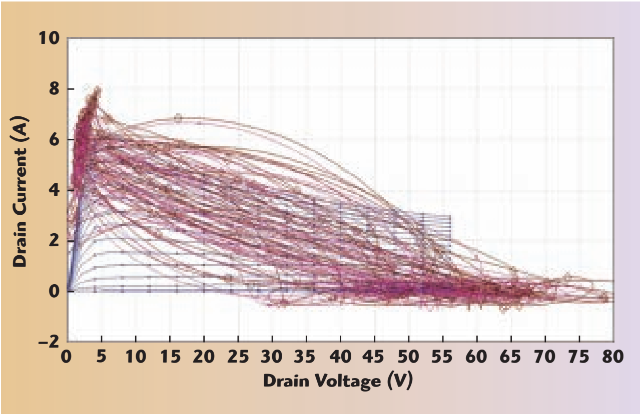


▲ *Fig. 4 Output stage layout in Microwave Office.*

schematic and the layout are exported to Microwave Office (see ***Figure 4***). With Microwave Office, the microstrip discontinuities are fully simulated, using either electromagnetic models or full electromagnetic simulation of parts of the layout. The nonlinear model and HB are used to simulate the powers of the fundamental and harmonic signals, the associated gain and gain compression, currents, voltages and efficiency. Using these simulations, small adjustments are made to achieve the best performance. After the output stage design is finalized, two are combined with hybrid couplers to form a balanced output.



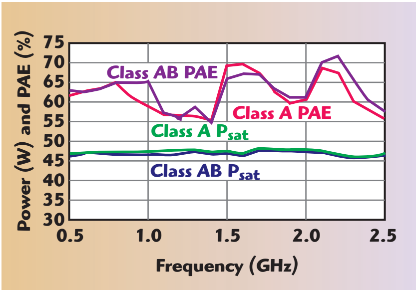
▲ *Fig. 5 I-V curves and Class A and AB DLLs at low output power.*



▲ *Fig. 6 I-V curves and Class A and AB DLLs at Psat.*

Cree supplied nonlinear models for the GaN HEMT used in the design, with access to the voltage and current across the intrinsic generator, as shown in Figure 1. The simulation of the voltage and current – the dynamic load line (DLL) – across the intrinsic generator provides better visualization, understanding and design capability. The simulated DLLs across the band for Class A and Class AB biasing at low power levels are plotted in ***Figure 5***, showing that Class A biasing provides the maximum voltage and current swing, hence maximum P_{sat}. Compare these DLLs with the Class A and Class AB DLLs at P_{sat} (see ***Figure 6***). ***Figure 7*** shows the Class A and Class AB P_{sat} and power-added efficiency (PAE) simulations across frequency, with about the same results for the two bias conditions. This illustrates the validity of the design method.

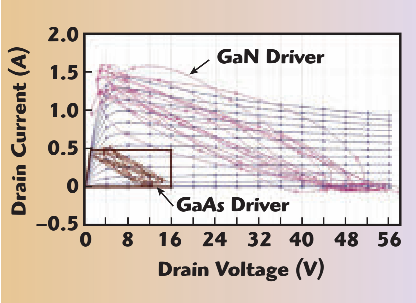
The two-stage driver design uses a Cree GaN HEMT at the output, for which a nonlinear model is available, driven by a GaAs HFET, with only S-parameters at a Class A bias



▲ *Fig. 7 Class A and Class AB Psat and PAE simulations.*

point. The S-parameters of the GaN transistor were extracted in Microwave Office, and the S-parameters of the GaAs transistor were used in MultiMatch to create linear models for these transistors. With the voltage and current boundaries defined, the power parameters and synthesis were used to design the two driver stages to provide maximum power and flat gain across the band.

The driver schematic was imported into Microwave Office, and the S-parameters of the two transistors were replaced with the nonlinear model for the Cree GaN transistor and the linear model for the GaAs HFET. Voltage and current meters were placed

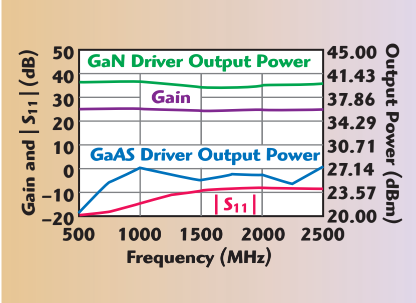


▲ *Fig. 8 I-V curves and the DLLs of the GaN and GaAs driver stages.*

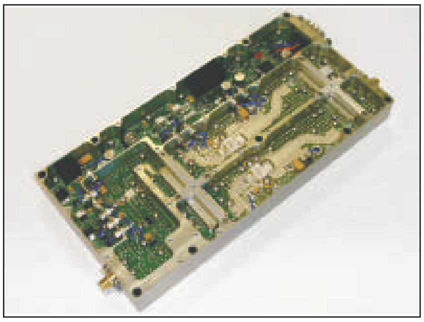
across the intrinsic generators, with an M-probe at the output of the GaAs transistor. The nonlinear model was used to simulate the I-V curves and the DLLs of the GaN transistor stage (see ***Figure 8***). Superimposed in the lower left corner of the plot are the boundaries that define the pre-clipped maximum voltage and current swings of the GaAs transistor. The DLLs are shown inside these boundaries.

These load lines were simulated using the HB simulator and the linear model of the transistor. The input power levels were selected and tuned so that the DLLs of the GaAs transistor stage just reach hard clipping. Figure 8 shows that the GaAs transistor is starting to compress after the GaN transistor is already in deep compression. The pre-clipped output power is typically 0.5 to 1 dB below P_{1dB}. This confirms that the GaAs stage has sufficient power to drive the GaN stage. The linear model of the GaAs transistor was extracted from the S-parameters in a special facility in MultiMatch. It is also possible to do this in Microwave Office. For the GaAs transistor, only the S-parameters were available; after using them to extract a linear model, the HB simulation was used to simulate and predict the pre-clipped maximum Class A output power. ***Figure 9*** shows the simulated driver output power, power gain and input return loss as well as the output power of the GaAs transistor, measured by the M-probe.

This method of simulating the DLL and the pre-clipped output power is also very useful when it is important to provide proper loading to each cell of a multi-cell transistor or when multiple transistors are connected in parallel, as is typical in MMIC power amplifiers. Optimization for the correct DLL is much faster when linear models are used. This is important



▲ *Fig. 9 Simulated output power, power gain and input return loss of the driver as well as the output power of the GaAs transistor.*

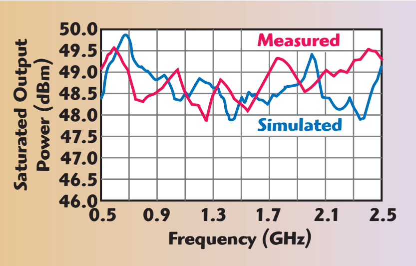


▲ *Fig. 10 50 W, 0.5 to 2.5 GHz power amplifier.*

because the networks are typically very complex, and the input networks also need to be optimized to provide equal drive. Typically, MMIC design kits provide linear and nonlinear models. Optimizing the initial circuit by using the linear models and checking the results using the nonlinear models provide for a better, faster and, arguably, more accurate design approach. The optimum load line for maximum output power can also be optimized relatively quickly using the nonlinear model of the transistor, if the input power for the simulation is low.

The method of HB simulation of the DLL using the linear model can extract the optimum load impedance for maximum output power of Class A amplifiers and, arguably, Class AB amplifiers. The approach uses a linear transistor model driven by a tunable power source, an impedance tuner at the output and a gamma probe to place the impedance of the tuner on the Smith chart.

This power amplifier design was built (see ***Figure 10***) and tested. The measured and simulated saturated output power are shown in ***Figure 11***; in both cases, the output is approximately 48.5 dBm average. The measured and simulated large-signal gain are also similar, generally between 52 and 54 dB from 500 MHz to 2.5 GHz.



▲ *Fig. 11 Measured vs. simulated saturated output power of the assembled amplifier.*

CONCLUSION

This article described a method for designing and simulating amplifiers for maximum power using HB simulation, when the only available data are the S-parameters of the transistors. The method is widely applicable, from low noise to high power amplifiers, narrowband to multi-octave. It can be used any time nonlinear transistor models are not available and the designer must know and design for the power deliverable by an amplifier stage. It is also useful when nonlinear models are available.

Pieter Abrie's power parameters approach is fast and versatile, but it exists only in MultiMatch Amplifier Design Wizard. If the power parameters method is incorporated in the general-purpose simulators, it will complement this methodology and, in general, dramatically enhance RF/microwave amplifier design. For example, extracting full load-pull data and contours would be near-instantaneous in many cases. While it is desirable to incorporate the power parameters in the general-purpose simulators, the MultiMatch synthesis techniques and procedures are also required. These are the only real frequency and real world synthesis techniques available in a commercial software product. Incorporating them will provide unprecedented levels of productivity and creativity in the design of matching networks from inside the general-purpose simulators.

The nonlinear models from Cree provide access to the voltage and current across the intrinsic generator, which gives deeper insight to these design methods and approaches and greater versatility using them. Qorvo GaN transistor nonlinear models developed by Modelithics also do so. Hopefully, this capability will be offered by other providers of linear and nonlinear models for RF/microwave transistors. ■

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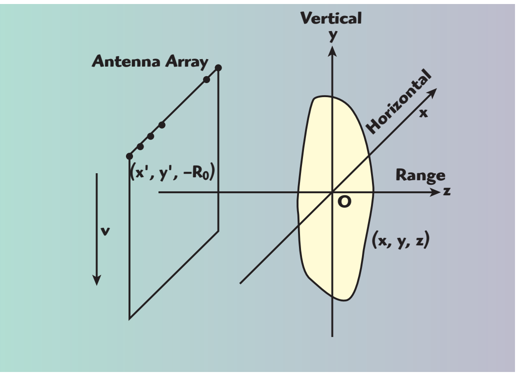
W-Band Active 3D Imaging System for Personal Security Inspection

Zheng Haitao, Zhao Guoqiang, Cheng Hang, Yu Liechen, Li Zhangfenga and Li Shiyong
Beijing Institute of Technology, Beijing, China

A W-Band active three-dimensional (3D) prototype imaging system for personal security inspection has a one square meter scanning area and demonstrates a cross-range resolution better than 0.5 cm.

Millimeter wave imaging techniques are often used for the detection of concealed weapons and contraband. Millimeter waves can penetrate clothing[1] and image hidden items with high resolution. Unlike X-rays, millimeter waves are non-ionizing and, thus, more suitable for human body security screening.[2] Millimeter wave imaging systems may be active or passive. Passive systems utilizing compact structures to identify temperature contrast are capable of performing real-time 2D imaging but can't easily detect dangerous items on the human body in an indoor environment.[3] They are also unable to produce 3D images.[4] Active systems allow the formation of a fully focused 3D image from data gathered over a 2D aperture optically or by using a Fourier transform.[5] Existing active imaging systems operate mainly in Ka-Band, driven by technology and cost. This limits their resolution. Terahertz technology offers the potential for high resolution and is a growing area of research, but the availability of stable sources and detectors at acceptable costs is a key limitation. In W-Band, on the other hand, good atmospheric absorption characteristics, short wavelengths and the ability to generate wide bandwidth signals offer the potential for high resolution without having to pay a considerable price.



▲ *Fig. 1 Holographic imaging system configuration.*

This article describes an active, broadband 3D imaging system operating in W-Band for personal security inspection. The prototype with a 1 × 1 m scan area and 3D wave number domain imaging algorithm[6] is used to image specific items such as a small metal ball, knife and transportation card.

IMAGING ALGORITHMS

3D planar scan imaging is derived from holographic imaging based on the Fourier trans-

form. The antenna continuously scans vertically and horizontally over the 2D scan plane to obtain a high quality image, while signal bandwidth is used to obtain range (see ***Figure 1***). A simplified diagram for a 3D active planar imaging system is shown in ***Figure 2***. Data collection is performed by scanning a transmitting source and receiver over a rectilinear aperture that has targets within its field. Target locations and scattering coefficients are obtained after mixing with a transmitter reference signal carrying the system delay and filtering.[7] Vertical and horizontal fast Fourier transforms (FFT) are performed and then compensated for the phase residual caused by antenna velocity and reference range. After 2D Stolt interpolation and 3D inverse Fourier transforms, we obtain target scattering coefficients and imaging.

To ensure target integrity and accuracy, the Nyquist sampling theorem must be considered during the planar 3D imaging process:

$$\Delta x\left(\Delta y\right) \leq \frac{2\pi}{4k_{\omega\, max}} = \frac{\lambda_{min}}{4} \qquad (1)$$

where Δx and Δy represent the biggest vertical and horizontal sampling intervals, respectively, λ_{min} denotes the shortest frequency wavelength and kω indicates the wave number.

To avoid range ambiguity, the corresponding time domain sampling rate should satisfy

$$f_s = \frac{1}{\Delta t} \geq \frac{c}{2D_z} \qquad (2)$$

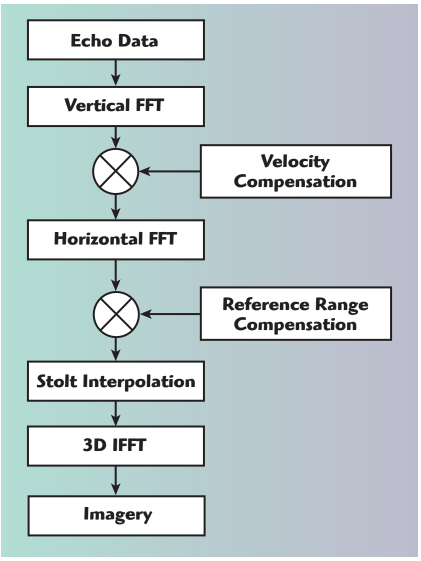


Fig. 2 3D planar aperture algorithm.

where D_z is the targets' maximum diameter in the range domain.

The system's working frequency spans from 90 to 94 GHz with a 4 GHz bandwidth. The system can theoretically realize a 3D resolution of

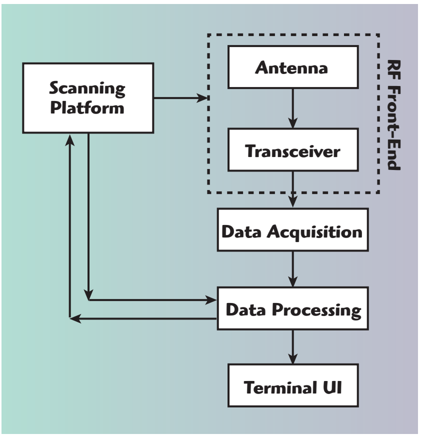


Fig. 3 Imaging system functional blocks.

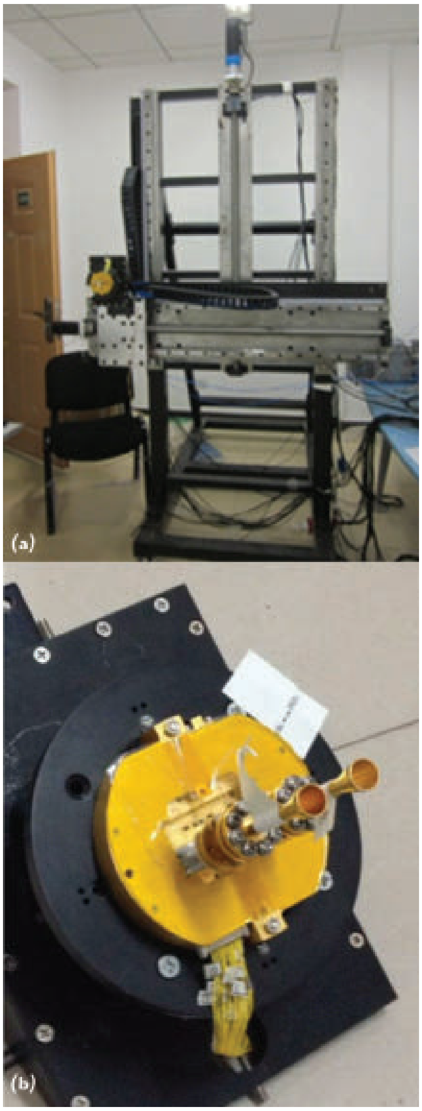
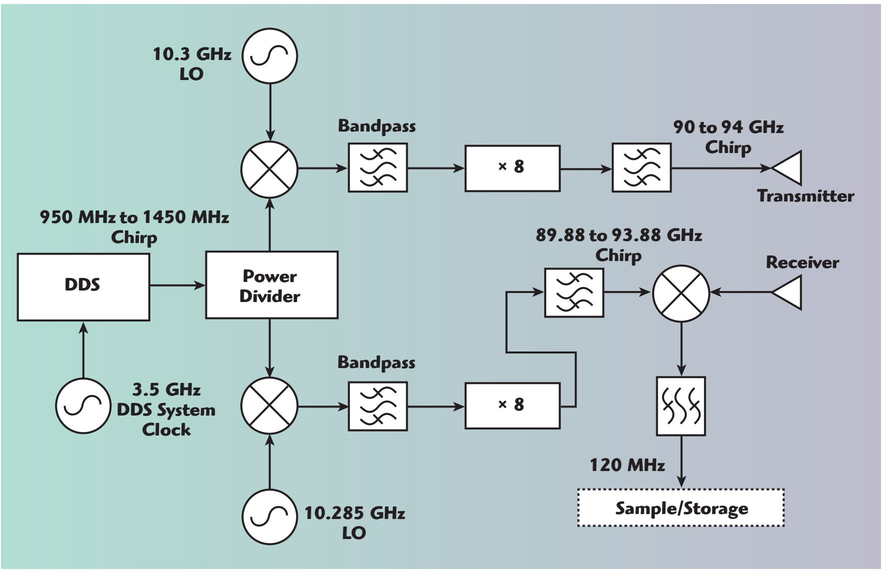


Fig. 4 Scanning platform (a) and W-Band detector (b).



▲ *Fig. 5 W-Band detector block diagram.*

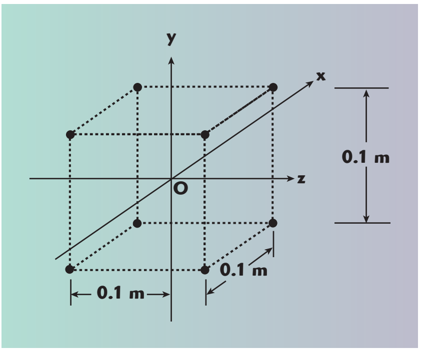
$$\delta z = \frac{c}{2KT} \tag{3}$$

$$\delta x = \delta y = \frac{2\pi}{2\left(2k_{\omega mid}\sin\left(\frac{\theta}{2}\right)\right)} \tag{4}$$

where θ is the antenna beamwidth.

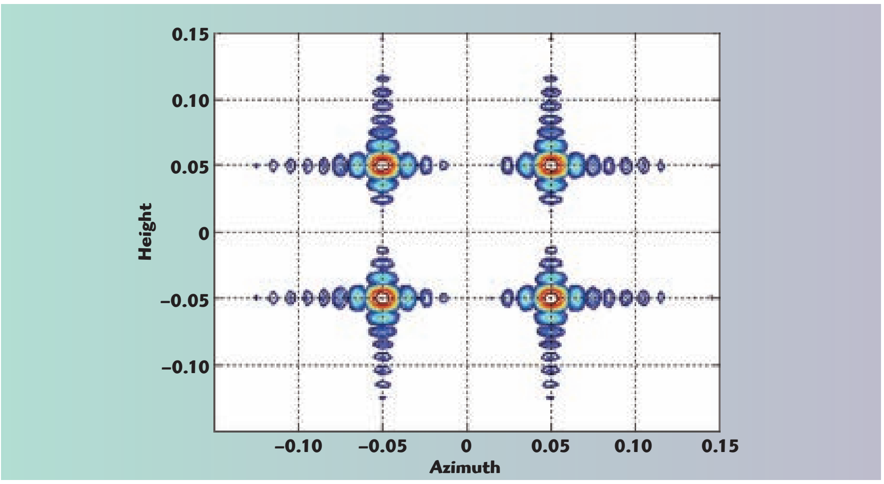
IMAGING SYSTEM

The W-Band imaging system includes an RF front-end module, data acquisition module, 2D mechanical scanning platform, processing module and a terminal user interface (UI), shown in ***Figure 3***. The millimeter wave signal is generated using an oscillator, then transmitted and received with a small 19 degree beamwidth conical horn antenna. The data acquisition and data processing modules act on the signal and develop the image. The UI shows the results.



▲ *Fig. 6 Cuboid model of eight scattering points.*

The W-Band antenna and detector are installed on a platform (see ***Figure 4***). The scanning driver controls the antenna to continuously scan a 2D plane while counting the step size for the servo motor. In accordance with



▲ *Fig. 7 Reconstructed image in cross-range plane.*

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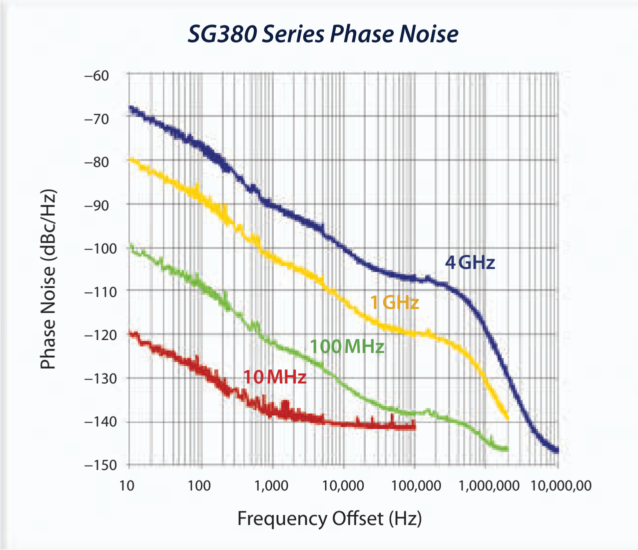

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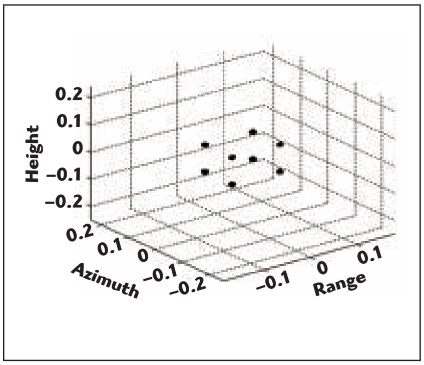
the sampling interval, a trigger controls the antenna send-and-receive synchronizing signal for data acquisition. The source is connected to the receiver with a phase-stable cable, ensuring stability of the local oscillator signal during mechanical scanning. The workstation reads and processes the stored 3D data gathered by the transceiver and reconstructs the 3D image.

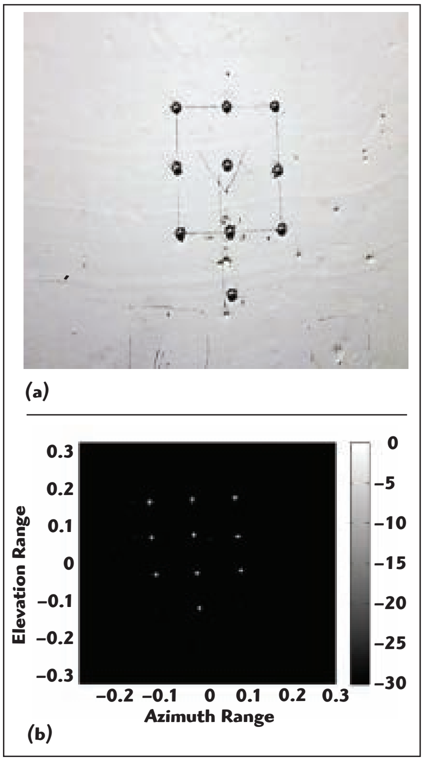
A block diagram of the detector is shown in ***Figure 5***. A direct digital synthesizer (DDS) generates a 500 MHz wide linear FM chirp. Mixing it with signals from the two phase-locked oscillators generates mid frequencies of 10.3 GHz and 10.285 GHz. After filtering and 8× frequency multiplication, two 4 GHz bandwidth linear FM signals are obtained. The 90 to 94 GHz signal is used for transmit, while the 89.88 to 93.88 GHz signal is the reference for down-conversion to an intermediate frequency of 120 MHz. Following A/D conversion, the imaging data is sent to the workstation for storage and processing.

SIMULATED AND MEASURED RESULTS

To verify the effectiveness of the theoretical analysis, a simulation was performed using eight ideal points. The system working frequency ranges from 90 to 94 GHz with a scan rate of 1 m/s. The reference distance, R_o, is 1.5 m. The simulation cuboid model (shown in ***Figure 6***) has a spacing between points of 0.1 m. It assumes that the radar scattering cross section (RCS) of all scattering points is 1 m^2



▲ *Fig. 8 3D image in Cartesian coordinate system.*

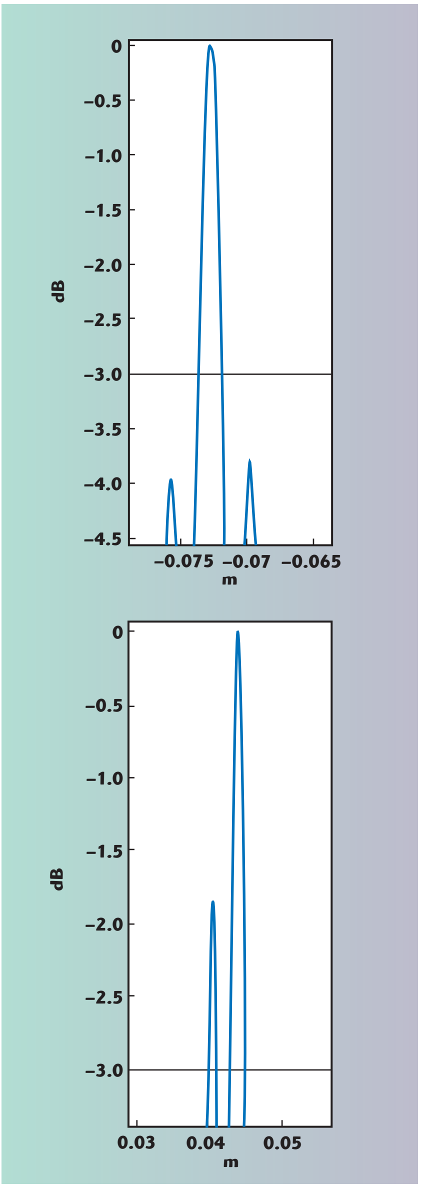


▲ *Fig. 9 Optical (a) and W-Band (b) images of metal balls.*

and uses the wave number domain imaging algorithm to image them in the cross-range plane (2D image) and Cartesian coordinate system (3D image). As shown in ***Figures 7*** and ***8***, the scattering points are located at the dotted line intersection. The imaging results in three directions is clear, with a 30 dB dynamic range and each single scattering point's sidelobe feature close to a sinc function. The image is a little out of focus due to velocity effect errors, and the range resolution can be improved by widening the signal bandwidth.

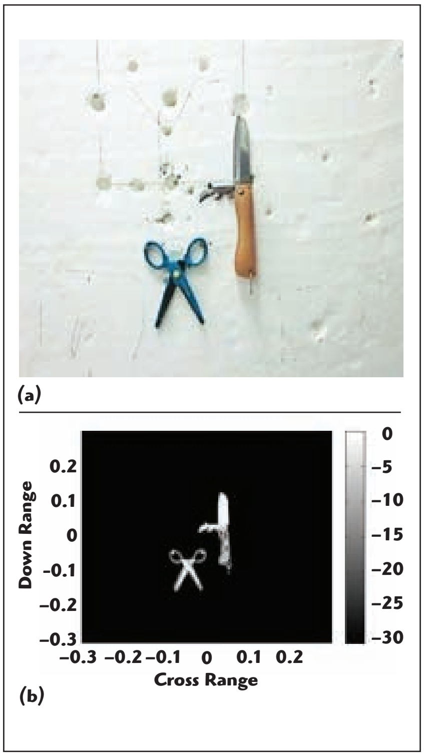
Test results from a 90 GHz proof-of-principle prototype built with a 1 × 1 m scanning area. are shown in ***Figures 9*** through ***12***. Figure 9 compares the images of 10, 1 cm radius metal balls embedded in a foam plate. Target location features, such as spacing, ball position and slant angle are clearly identified. The cross-range resolution of the ball with strongest RCS is approximately Δx = 0.36 cm, Δy = 0.48 cm, respectively (see Figure 10). Due to the features of a volumetric object versus an ideal point, this is estimated. Figure 10 shows the radius of the ball leads to a mismatch of the mainlobe and sidelobe. This may be due to a phenomenon similar to mainlobe splitting.

Different objects, including scissors, a knife and a transportation card were also tested. In Figure 11, for example, a tiny structure between the blade and corkscrew of the knife is easily seen, and the image is clear enough to differentiate the knife and scissors. Figure 12 shows that the system can penetrate the plastic cover

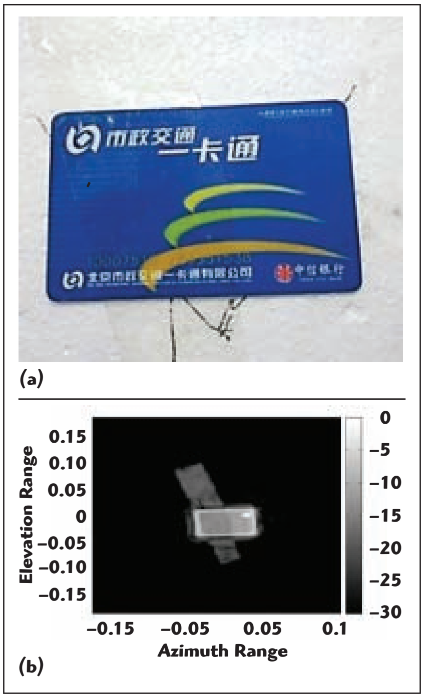


▲ *Fig. 10 Metal ball return on x-y cross-range plane.*

of a transportation card and image its chip in the top right corner, demonstrating that the system has penetrability. With planar imaging precision, the strip on the card is also discerned, which highlights the system's capability to identify plastics as well as metal items.



▲ *Fig. 11 Optical (a) and W-Band (b) images of scissors and knife.*



▲ *Fig. 12 Optical (a) and W-Band (b) images of transportation card.*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CONCLUSION

A prototype W-Band imaging system for security inspection provides large angle illumination of a target in the near field with a broadband frequency sweep. After compensating for channel error, high quality images of several different targets have been generated by the system. Test results prove its feasibility for obtaining detailed and accurate images of small carry-on objects such as a plastic transportation card, a folding knife and scissors. ■

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Design of Wide Stopband Microstrip Bandpass Filter Using Bandstop Centrally Embedded Resonators

Guoan Wu, Chao Guo, Qinfen Xu and Wenguang Li
Huazhong University of Science and Technology, Wuhan, China

A compact second-order microstrip bandpass filter with good frequency selectivity and a wide stopband consists of two dissimilar half-wavelength stepped impedance resonators (SIR) with centrally-embedded bandstop resonators. By adding one short-circuited stub, wideband spurious suppression is realized. Design and synthesis procedures are provided. Measurement is in good agreement with simulation. It exhibits a fractional bandwidth of 7.7 percent at 2.07 GHz with 17.4 dB of suppression from 2.25 up to 20 GHz. The size of the filter is only 0.19 × 0.19 λg (where λg is the guide wavelength at center frequency) without the use of any lumped elements.

Microstrip bandpass filters (BPF) with low insertion loss, compact size, high frequency selectivity and a wide stopband are essential components in the design of receivers and transmitters for microwave and wireless communication systems; however, they often suffer from spurious responses at multiples of their fundamental frequencies. Various methods have been proposed to suppress these responses. A compact, wide stopband, bandpass filter realized by bending the resonators to suppress harmonics was proposed by Hsu and Tu,[1] but only the second- and third-order harmonics were eliminated. Kuo et al.,[2] obtained a wide stopband using both stepped-impedance resonators and bandstop structures. With the assistance of two spur lines, the stopband performance was further improved.[3] By properly arranging the spurious harmonic frequencies of each resonator with an embedded transformed radial stub (TRS), an ultra-wide stopband with deep rejection has been realized.[4] Wu et al.,[5] developed a BPF consisting of two half-wavelength resonators loaded with two short-circuited stubs at both central planes, in order to provide more transmission zeros in the stopband. A zero-degree feed structure incorporated into the design of the microstrip filter added two transmission zeros, improving frequency selectivity.[6]

This article describes a compact second-order BPF with good frequency selectivity and a wide stopband. It is composed of two dissimilar half-wavelength SIRs with a bandstop resonator embedded into each SIR central plane. The bandstop resonators have different frequency ranges and one of them is loaded with a short-circuited stub to eliminate undesired spurious.

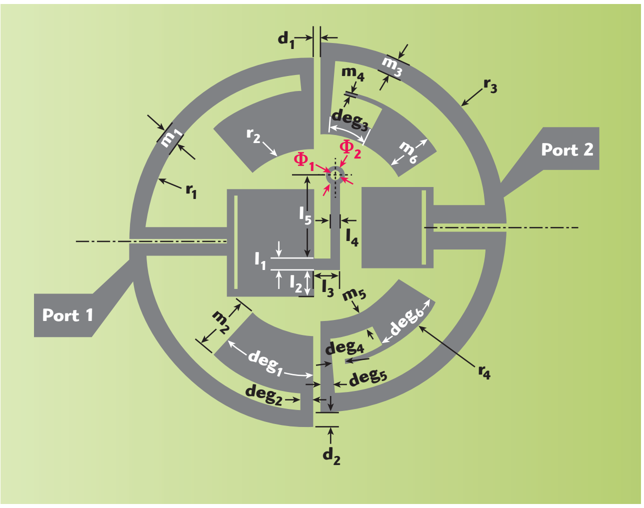
FILTER DESIGN

The filter layout is shown in ***Figure 1*** with dimensions (in mm and degrees): r1 = 9.1, r2 = 5, r3 = 10, r4 = 7.45, d1 = 0.34, d2 = 0.8, m1 = 0.9, m2 = 3.2, m3 = 1, m4 = 0.25, m5 = 1, m6 = 2.45, l1 = 0.6, l2 = 1.4 , l3 = 1.36, l4 = 0.5, l5 = 4.5, ϕ1 = 0.5, ϕ2 = 1, deg1 = 42, deg2 = 5, deg3 = 22, deg4 = 5, deg5 = 5 and deg6 = 30. Both the input and output impedances of the feed structure are 50 Ω.

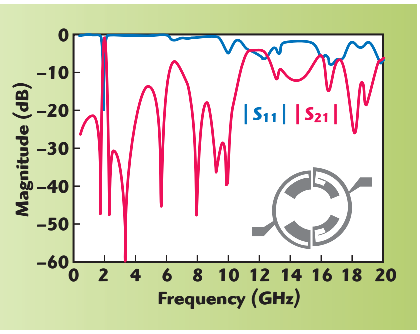
The second-order filter is designed using coupled-resonator procedures.[7] The design parameters are determined for a Chebyshev response with a center frequency of 2.02 GHz, return loss of about 20 dB and a fractional bandwidth of 7.7 percent. The associated external quality factor and coupling coefficients are

$$Q_{ei} = Q_{eo} = \frac{g_0 g_1}{FBW} = 8.66, \qquad (1)$$

$$M_{12} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.128$$



▲ *Fig. 1 Filter layout.*



▲ *Fig. 2 Simulated frequency response of the filter with dissimilar SIRs.*

where g_0, g_1 and g_2 are the element values of the lowpass prototype filter, and FBW is the fractional bandwidth. EM simulation software is employed to establish the required design curves for external quality factor and coupling coefficients and to determine the physical dimensions. The SIRs and bandstop resonators are well characterized and their frequency responses evaluated and adjusted. To analyze the performance of the BPF, frequency responses of each structure are studied separately.

As shown in ***Figure 2***, the filter exhibits two transmission zeros close to the passband, formed by a zero-degree feed structure.[6] The transmission zeros significantly improve frequency selectivity. By properly arranging the impedance ratio and length ratio of each SIR, both of which have the same fundamental resonant frequency but different spurious (harmonic) resonance frequencies, several higher-order spurious frequency bands are suppressed. Moving the right SIR up vertically by d2 is another way to suppress spurious frequency bands. It reduces the coupling between higher-order spurious resonances, while coupling between the fundamental resonances remains unchanged. The SIRs are also used to push spurious harmonics to a higher frequency region. As a result, stopband characteristics are improved in the lower stopband but worsen in the higher stopband. The SIR structure exhibits a slow-wave characteristic to reduce the circuit size.

Figure 3a shows the physical layout of one microstrip bandstop resonator structure, which consists of a coupling section and a shunt open-circuited resonator. Its dimensions (in mm) are: a_1 = 4.72, b_1 = 5.79, c_1 = 5.32, e_1 = 0.33, g_1 = 0.14, g_2 = 0.2, w_1 = 5 and w_2 = 0.7. To widen the upper stopband, a slot line is embedded into the shunt open-circuited resonator. Shown in ***Figure 3b***, this bandstop structure is modified from Hsieh and Wang.[8] They reported that the coupling section and shunt open-circuited resonator are a quarter guided-wavelength long at the center frequency. In this work, the lengths of the coupling section and shunt open-circuited resonator are not fixed at quarter guided-wavelength, allowing greater design freedom in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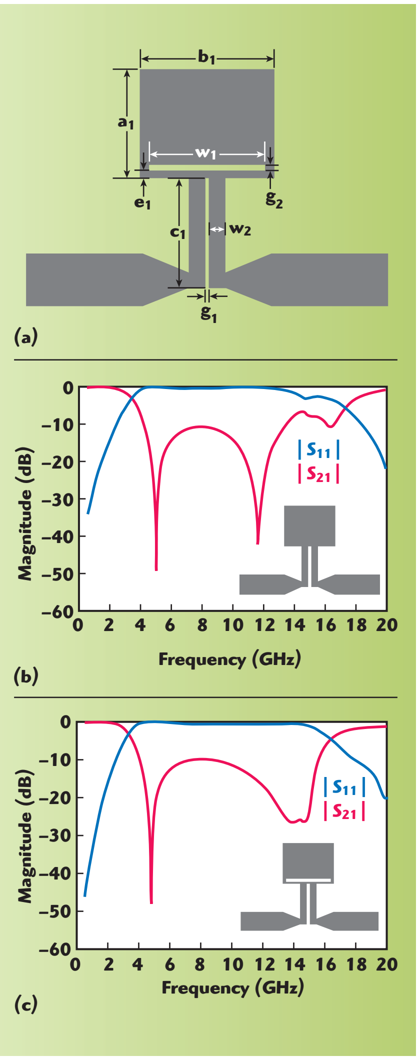
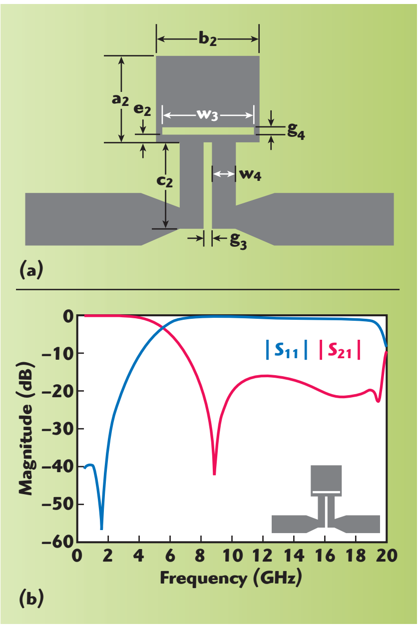


▲ *Fig. 3 Single microstrip bandstop structure (a) with simulated responses of bandstop resonator (b) and slot-loaded bandstop resonator (c).*

locating the transmission zeros to achieve a wider stopband and provide higher rejection. This structure exhibits a stopband from 4.2 to 13.4 GHz with rejection better than 10 dB (see Figure 3b). ***Figure 3c*** shows the simulated frequency response of a slot-loaded bandstop resonator where another transmission zero, determined by the slot line dimensions, is used to extend the stopband to 15.6 GHz. A bandstop embedded resonator (BER) is formed by embedding the bandstop structure into the center of the SIR. This structure can be

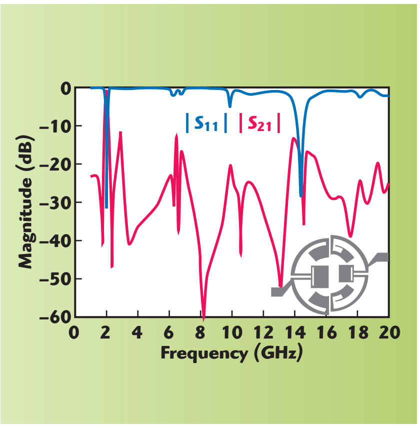


▲ *Fig. 4 Second microstrip bandstop structure (a) with simulated frequency response (b).*

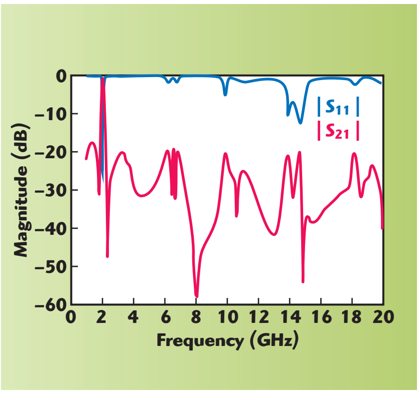
tuned to suppress the lower spurious SIR harmonics.

To extend the stopband, another slot-loaded bandstop resonator with a higher frequency response is introduced (see ***Figure 4***). Figure 4a shows the physical layout with dimensions (in mm): $a_2 = 3.9$, $b_2 = 4.4$, $c_2 = 3.9$, $e_2 = 0.45$, $g_3 = 0.4$, $g_4 = 0.2$, $w_3 = 4$ and $w_4 = 1$. Figure 4b shows the simulated frequency response. It exhibits better than 10 dB rejection from 7 to 20 GHz. With this structure to suppress the higher SIR spurious harmonics, one may implement a compact BPF with a widely extended stopband.

The circuit configuration and performance of the second-order microstrip filter is shown in ***Figure 5***. Two variable-sized slot-loaded bandstop resonators are embedded

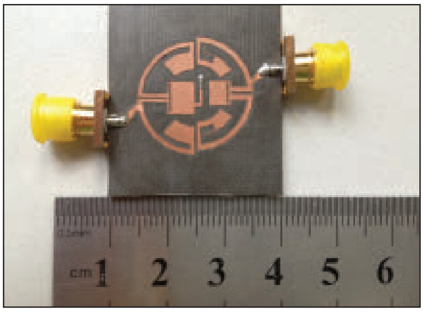


▲ *Fig. 5 Simulated frequency response of the filter with SIRs and slot-loaded bandstop resonators.*

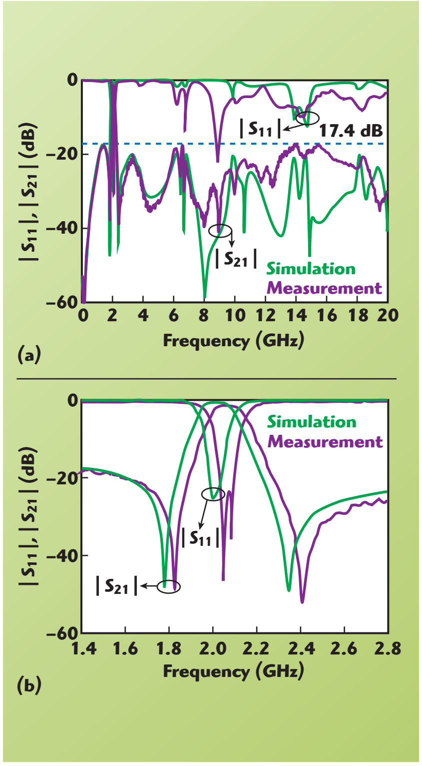


▲ *Fig. 6 Simulated frequency response of the proposed filter with SIRs, slot-loaded bandstop resonators and a short-circuited stub.*

into the SIRs at both central planes. These are key to broadening the stopband and making the circuit compact. By properly arranging the bandstop structures, the center frequency (f_0) of the filter is reduced with no insertion loss degradation in the passband. To analyze stopband performance, f_0 is set to 2.02 GHz (the same value shown in Figures 2 and 5). Since the structure of each BER in Figure 5 is symmetrical, odd- and even-mode analysis can be adopted. For odd-mode excitation, there is a voltage null along the symmetrical plane of each BER. The signal to the shunt open-circuited resonators in the bandstop structures is shorted to ground and the odd harmonics have a low degree of suppression, about 13.08 dB. If the symmetrical plane of each BER is replaced with a magnetic wall for even-mode excitation, the even harmonics are eliminated effectively by the bandstop structures. The first even-mode spurious passband (with about 11.32 dB suppression), however, occurs at 2.85 GHz because the frequency is not in the stopband range of the bandstop resonators. By attaching a short-circuited stub to the left BER while keeping the right BER unchanged (see Figure 1), symmetry of the left BER is destroyed, and this disturbs the even- and odd-mode excitations. Some harmonics of the left BER are shorted to ground through the via-hole, thus eliminating undesired responses. The effect of the stub on the passband frequency response can be ignored. The simulated microstrip bandpass filter frequency response in ***Figure 6*** shows that the spurious frequencies of the upper stopband are suppressed by greater than 19.8 dB from 2.23 to 20 GHz.



▲ *Fig. 7 Fabricated bandpass filter.*



▲ *Fig. 8 Simulated vs. measured filter response from DC to 20 GHz (a) and 1.4 to 2.8 GHz (b).*

EXPERIMENTAL RESULTS

The BPF (see ***Figure 7***) was fabricated on Rogers 5880 substrate, with dielectric constant, loss tangent and thickness of 2.2, 0.0009 and 0.76 mm, respectively. Simulation was performed with ANSYS HFSS 15.0 EM simulation software, and performance was measured with an Agilent N5244A network analyzer. ***Figure 8*** shows simulated and measured S-parameters of the second-order BPF. The measured center frequency was 2.07 GHz, which was shifted up by 50 MHz compared with the simulation (see Figure 8a). This is attributed to

tolerances in fabrication and assembly. Measured minimum insertion loss and 3 dB fractional bandwidth in the passband were about 1.39 dB and 7.7 percent, respectively. A passband return loss greater than 23 dB was also achieved. Two transmission zeros, located at 1.82 GHz and 2.41 GHz, improve frequency selectivity. Spurious harmonics were suppressed by greater than 17.4 dB from 2.25 to 20 GHz.

CONCLUSION

By leveraging the intrinsic characteristics of SIRs and bandstop centrally embedded resonators, and with the assistance of one short-circuited stub, an effective second-order BPF with good passband performance and a wide stopband has been demonstrated. The filter design achieved an ultra-wide stopband (greater than 10 times the fundamental operating frequency), low insertion loss, good frequency selectivity and compact size. The circuit's area was only 0.19 × 0.19 λg, where λg is the guided wavelength at 2.07 GHz. These features make it attractive for use in modern wireless communication systems.

This work was supported by the National Natural Science Foundation of China (grant 61001012). ■

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"Overview of 5G: Timeline, Requirements, and Enabling Technologies," Dr. Thomas Novlan, Samsung Research

"OFDM Inspired Waveforms for 5G," Prof. Behrouz Farhang-Boroujeny, University of Utah

"Practical Aspects and Considerations for High Instanteneous Bandwidth, High Data Rate, Millimeter Wave Wireless Prototyping Systems," Mr. Justin R. Magers, National Instruments

Workshop #2: Accelerating the Design of PA Systems for 5G and IOT Through Adequate Measurement Techniques

Chair: Marc Vanden Bossche, National Instruments
Andrea Ferrero, Keysight

Speakers: (Sunday, January 24, 2016)
"Preparing an engineering test organization for 5G," Neil Craig, Qorvo

"The development of efficient power amplifiers is really a 3-port design," Earl MCcune, EMC2

"Envelope Tracking Power Amplifier Measurement Techniques," Donald Kimball, Maxcentric

"Measuring and Evaluating EVM," Kate Remley and Robert Horansky, NIST

"PA design benefitting from wide-IF VNA measurements: characteristics and calibration topics," Jon Martens, Anritsu

Workshop #3: European Initiatives to Develop Wireless Power Supply for Sensor Node Evolution

Chair: Luca Roselli, University of Perugia

Speakers: (Sunday, January 24, 2016)
"Multi-harvesting technologies for wireless autonomous nodes," Luca Rosell, University of Perugia

"Combining UWB- and UHF-RFID for localization and sensing," Alessandra Costanzo, University of Bologna

"Exploitation of Nonlinear Characteristics of RFID Chips for Energy Harvesting," Smail Tedjini, Université Grenoble Alpes/LCIS

"Developments in co-located wireless power and data transfer," Dominique Schreurs, ESAT KU Leuven

"Design of Passive Wireless Networks," Nuno Borges Carvalho, University of Aveiro, Portugal

Workshop #4: PA Technologies for Future Broadband Wireless Communications

Chair: Jose Carlos Pedro, Instituto de Telecomunicacoes, Universidade de Aveiro

Speakers: (Sunday, January 24, 2016)
"BTS Power Amplifiers Past and Future: Industry View," Francesc Purroy, Huawei Technologies Sweden AB

"Wideband Power Amplifier Linearization: From Active Device Distortion to DPD Compensation," Telmo Cunha, Instituto de Telecomunicações

"Design of Highly Efficient Power Amplifiers by Generalization of the Doherty Theory," Christian Fager, Chalmers University of Technology

"Christian Fager, Chalmers University of Technology," Sergio Pires, NXP Semiconductors

"Digital Predistortion for Wideband Power Amplifiers: System Challenges and Future Directions," Anding Zhu, University College Dublin

Workshop #5: Physiological Monitoring towards m-Health

Chair: Hung Cao, University of Washington- Bothell
J.-C. Chiao, University of Texas - Arlington

Speakers: (Monday, January 25, 2016)
"Smart Radar Sensors for Human Localization and Health Monitoring," Changzhi Li, Texas Tech University

"Broadband CMOS RF/Microwave Complex Dielectric Spectroscopy Systems for Bio-sensing," TKamran Entesari, Texas A&M University

"Present and future of optical sensors in wearable and point-of-care healthcare devices," Luca Pollonini, University of Houston

"Low power analog and mixed-signal IC design for bio-signal detection," Nan Sun, University of Texas-Austin

"Sensor Fusion and Resource Management for Physiological Monitoring," Roozbeh Jafari, Texas A&M University

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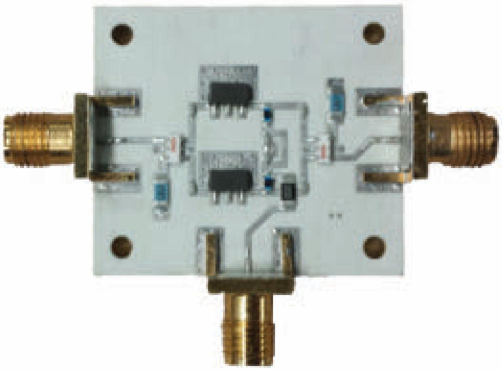


Extending the Bandwidth of Narrowband Matched MMIC Power Amplifiers

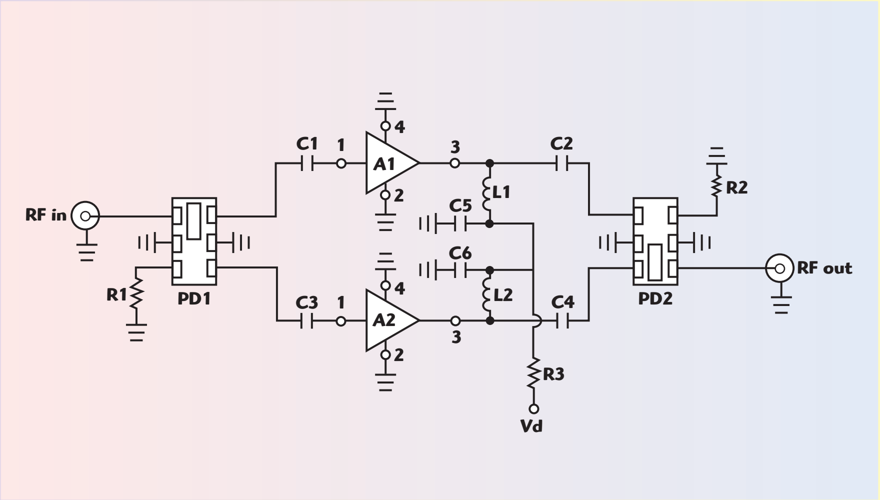
Mini-Circuits
Brooklyn, N.Y.

Today most MMIC power amplifiers (PA) operate with narrowband matching circuits, usually offering no more than 10 percent operational bandwidth. Market emphasis on wireless communication has driven the semiconductor industry to focus design efforts on these narrow wireless bands. Consequently, design activity on wideband performance in MMIC PAs has waned. Unfortunately, narrowband designs are not practical for wideband applications such as VHF/UHF radio, instrumentation and software-defined radios.

Where does this leave the engineer designing for wideband applications? The need for more versatile performance in MMIC PAs is still evident, and this need creates a basis for developing an application circuit to increase the bandwidth of MMIC amplifiers that usually employ narrowband matching. This article discusses an application circuit for Mini-Circuits' GVA-91+ MMIC PA and presents test results demonstrating excellent amplifier performance significantly beyond the specified operating frequency range.

Mini-Circuits' model GVA-91+ is a high efficiency GaAs HBT PA that operates with +5V bias and is packaged in the industry standard SOT-89. The GVA-91+ offers excellent performance over the cellular and LTE bands. With excellent matching, the PA delivers +29 dBm output power at 1 dB compression (P_{1dB}) from 869 to 960 MHz and +27 dBm over 2110 to 2170 MHz. Power-added efficiency (PAE) at P_{1dB} is 41 to 54 percent over these bands. This level of performance, however, is restricted to the narrow bandwidths defined by the matching circuits.

To improve and extend the usability of the amplifier in a greater variety of applications, Mini-Circuits developed a board-level circuit that uses the GVA-91+ in a balanced configuration. Such a configuration using 90° hybrids offers excellent matching, limited only by the matching performance of the hybrids. Any mismatches introduced by the amplifiers, at either the input or output, will largely be dissipated in the load of the isolated port of the 90° hybrids. The balanced configuration also

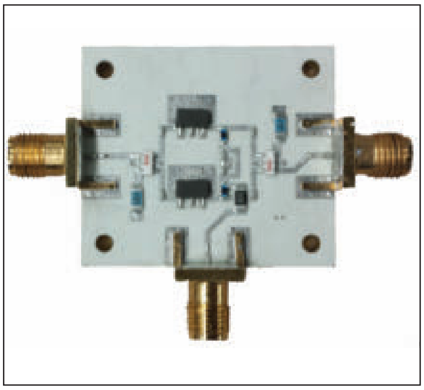


▲ *Fig. 1 Balanced amplifier schematic.*

delivers approximately 3 dB higher output power than the individual amplifiers, while maintaining the same gain as a single amplifier.

To demonstrate this approach, a proof of concept design was created using the GVA-91+ outside of its normal frequency band. To keep the circuit small, the design used Mini-Circuits' QCN series of LTCC 90° hybrids, which are housed in 1206 packages. The QCN series comprises 34 models with frequency bands spanning 330 MHz to 4.5 GHz and each model covering about a 2:1 bandwidth. Bandwidth is limited by the amplitude and phase unbalances intrinsic to the non-ideal 90° hybrid.

As the bandwidth of the balanced PA is limited primarily by the hybrids, using the QCN series in the application circuit enables designs to cover a range of octave frequency bands. For this article, the prototype used the QCN-5+ hybrid, which covers 330 to 580 MHz. The GVA-91+ PA and QCN-5+ hybrids were assembled in a 50Ω microstrip circuit on a printed circuit board using 0.010" thick Rogers 4350B. A schematic and photograph of the assembled application circuit are shown in ***Figures 1*** and ***2***, respectively, and the bill of material is provided in ***Table 1***.



▲ *Fig. 2 Balanced amplifier prototype.*

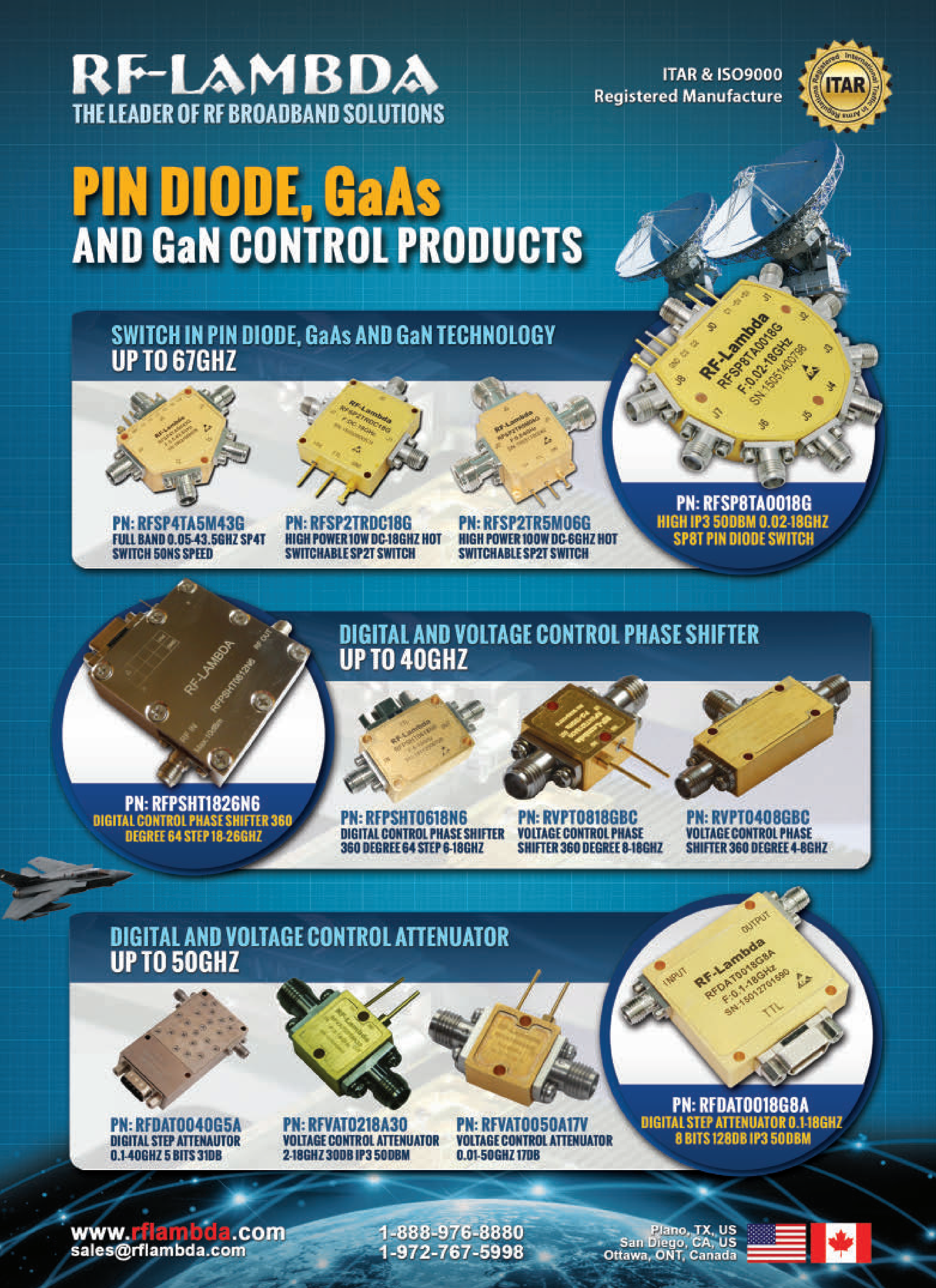
MEASURED RESULTS

The amplifier's small-signal performance from 300 to 600 MHz is shown in ***Figures 3, 4*** and ***5***. The measurement reference planes are at the interface of the SMA connectors and the coaxial cables that connect the application circuit to the vector network

TABLE 1

BALANCED AMPLIFIER BILL OF MATERIAL

Component	Value/Part Number	Size/Package
A1, A2	Mini-Circuits GVA-91+	SOT-89
PD1, PD2	Mini-Circuits QCN-5+	1206
L1, L2	180 nH	0603
C1 – C6	0.001 µF	0402
R1, R2	49.9 Ω	1206
R3	0 Ω	1206



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PN: RFSP2TR5M06G
HIGH POWER 100W DC-6GHZ HOT
SWITCHABLE SP2T SWITCH
RF-Lambda
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F:0.02-18GHz
SN:1505140798
PN: RFSP8TA0018G
HIGH IP3 50DBM 0.02-18GHZ
SP8T PIN DIODE SWITCH
DIGITAL AND VOLTAGE CONTROL PHASE SHIFTER
UP TO 40GHZ
RF-LAMBDA
PN: RFPSHT1826N6
DIGITAL CONTROL PHASE SHIFTER 360
DEGREE 64 STEP 18-26GHZ
PN: RFPSHT0618N6
DIGITAL CONTROL PHASE SHIFTER
360 DEGREE 64 STEP 6-18GHZ
PN: RVPT0818GBC
VOLTAGE CONTROL PHASE
SHIFTER 360 DEGREE 8-18GHZ
PN: RVPT0408GBC
VOLTAGE CONTROL PHASE
SHIFTER 360 DEGREE 4-8GHZ
DIGITAL AND VOLTAGE CONTROL ATTENUATOR
UP TO 50GHZ
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SN:15012701590
TTL
PN: RFDAT0040G5A
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PN: RFVAT0218A30
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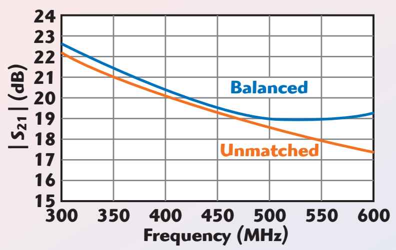
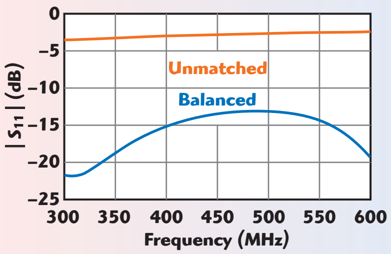
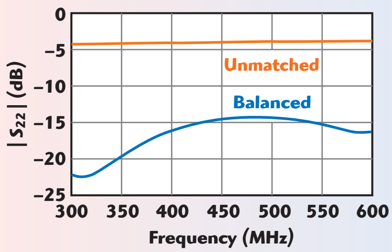


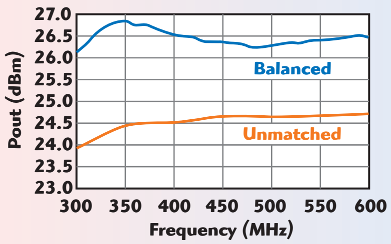
▲ *Fig. 3 Small-signal gain of the single unmatched GVA-91+ compared to the balanced amplifier.*



▲ *Fig. 4 Input return loss of the single unmatched GVA-91+ compared to the balanced amplifier.*



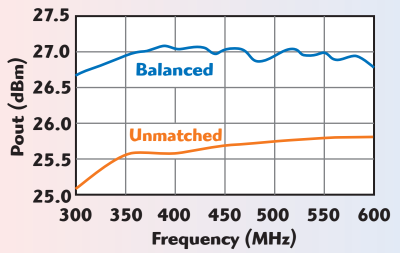
▲ *Fig. 5 Output return loss of the single unmatched GVA-91+ compared to the balanced amplifier.*



▲ *Fig. 6 Output power at 1 dB compression of the single unmatched GVA-91+ compared to the balanced amplifier.*

analyzer. The small-signal plots compare the balanced PA to an individual GVA-91+ without an external matching circuit. Figure 3 shows that the mismatches of the individual amplifiers degrade their gain; the small-signal gain of the balanced configuration is slightly higher than that of a standalone amplifier. The return loss plots in Figures 4 and 5 show the expected improvement from the balanced amplifier compared to the individual GVA-91+. The balanced configuration maintains 13 dB or better input return loss and output power over a 2:1 bandwidth.

The other advantage of the balanced configuration is increased output power. ***Figures 6*** and ***7*** compare the output power at 1 and 3 dB compression to that of a single GVA-91+. From 300 to 600 MHz, the balanced amplifier delivers approximately 2 dB higher output power than a standalone GVA-91+. However, a design tradeoff is reduced power-added efficiency. Compared to the individual GVA-91+, which has 45 percent PAE at 920 MHz, the balanced configuration achieves a PAE of 27 percent at 500 MHz. Nonetheless, this compares favorably to the efficiency obtained using other wideband amplifier design topologies, such as the Darlington configuration.



▲ *Fig. 7 Output power at 3 dB compression of the single unmatched GVA-91+ compared to the balanced amplifier.*

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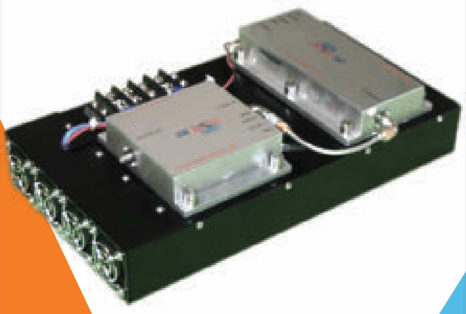
Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(dc)
M10207B3	500	2500	50	50	48
M10212B3Q2	800	1000	200	40	28
M10024B	100	1000	80	40	28
M10213B4	850	2100	150	50	48
M10004A2	20	1000	10	45	28
M10046B4	2000	18000	5	40	28
M10028B4	1000	6000	5	40	28



RF Amplifier Sub Assembly

Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(dc)
A10200A3Q2	500	2500	50	50	48
A10024B3Q2	100	1000	150	50	28
A10027B3	30	512	150	40	28
A10031B3	2000	6000	5	40	28
A10017B3Q2	200	2200	100	50	48
A10056B4	1000	1600	500 PK	40	48
A10067B4	6000	10000	25	40	48

19 " Rack Mount RF Amplifier

Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(ac)
R10204B4Q4	700	1000	350	50	120/240
R10205B4Q4	1700	2700	250	50	120/240
R10202B4Q8	400	1000	1000 PK	50	120/240
R10202A4	7000	10000	5	50	120/240
R10207B5Q8	20	500	1000	60	120/240
R10201A2	2000	18000	5	40	120/240
R10244B	8000	10000	25	45	120/240

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IMPROVED PERFORMANCE

This application circuit was designed to give designers flexibility when using the GVA-91+ or any SOT-89 MMIC amplifier that normally requires narrowband matching but is capable of delivering excellent performance over a much wider frequency range. The application circuit will increase the output power compared to a single amplifier specifically designed for wideband operation, such as Mini-Circuits' PHA, PGA and GALI series and other members of the GVA family. In addition to higher output power, the design improves the matching compared to the performance of an unmatched GVA-91+ over the same frequency band.

The QCN series of LTCC 90° hybrids has a common footprint for models spanning 330 MHz to 4.5 GHz, so simply changing the 90° hybrid and amplifier, with proper modification of the bias circuit, enables designers to easily adjust the frequency coverage of the PA design.

The performance of this design can be improved further, and the bill of material reduced, with a dual matched amplifier in a single package. Mini-Circuits is developing a dual amplifier integrated circuit that combines two GVA-91+ die into a single package. This will improve amplifier matching by minimizing effects introduced by minor process variations.

VENDORVIEW

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

E-Band Low Noise and Power Amplifiers

SAGE Millimeter Inc.
Torrance, Calif.

The 71 to 76 GHz and 81 to 86 GHz frequency spectrum, widely known as E-Band, is allocated for ultra-high capacity point-to-point communications worldwide. E-Band communication systems offer full-duplex network connectivity at data rates from 1 to 10 Gbps for links of several miles. Between the 71 to 76 GHz and 81 to 86 GHz bands, 76.5 and 79 GHz have been allocated to automotive radar. Reliable and high performance amplifiers are key components in these systems.

TABLE 1

LOW NOISE AMPLIFIER SPECIFICATIONS

		Model Number	
Parameter	**Units**	**SBL-6039033050-1212-E1**	**SBL-7138632040-1212-E1**
RF Frequency Range	GHz	60 to 90	71 to 86
Small Signal Gain	dB	30	20
Noise Figure	dB	5	4
Output P_{1dB}	dBm	-5	-5
Input/Output VSWR		3.5:1	3.5:1
Typical DC Bias	V / mA	+5 to 12/30	+5 to 12/30
Size	in	1.50 × 1.10 × 0.75	1.50 × 1.10 × 0.75
Weight	oz	1.5	1.5

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- 2.2:1 max. VSWR
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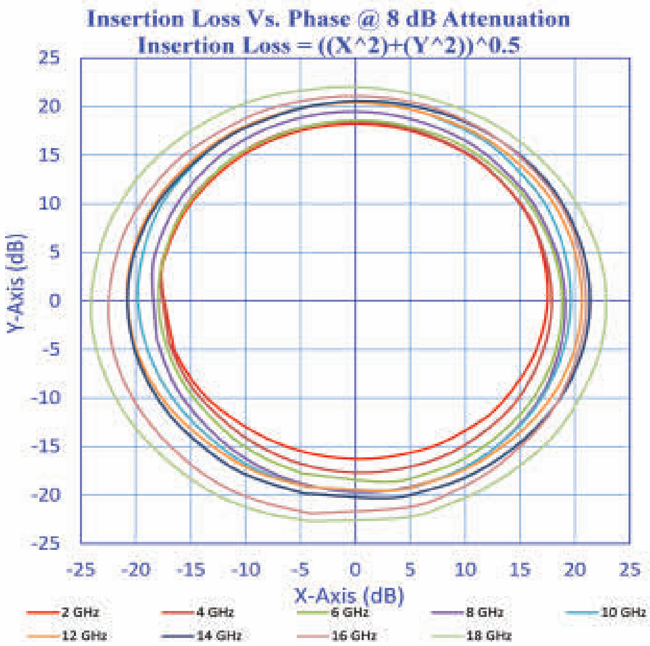
  ±2.72 dB @ 16 dB Attenuation
- Phase vs. Frequency
  ±8.28° @ 0 dB Attenuation
  ±19.92° @ 16 dB Attenuation
- ±12V to ±15V @ +95 mA, -78 mA
- 2 X 12 Bit (I & Q) TTL Control
- Linear Control Slopes
- 500 nsec max. Switching Speed
- Size: 4.25" X 3.50" X 1.00"



BROADBAND PHASE SHIFTER

PMI MODEL No: PS-2G18G-360-8D

- 360° Phase Range
- RF Input Power 1 Watt max.
- 16.0 dB max. Insertion Loss
- 2.2:1 max. VSWR
- Amplitude vs. Phase (PM/AM) ±1.17 dB
- Phase vs. Frequency ±8.28°
- ±12V to ±15V @ +95 mA, -78 mA
- 8-Bit TTL Compatible
- 500 nsec max. Switching Speed
- Size: 4.25" X 3.50" X 1.00"

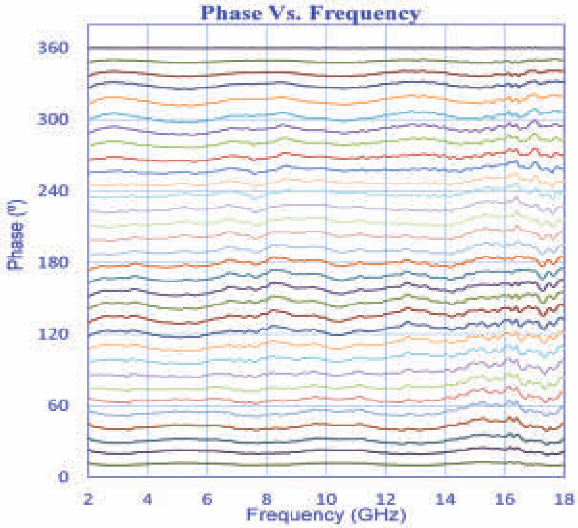


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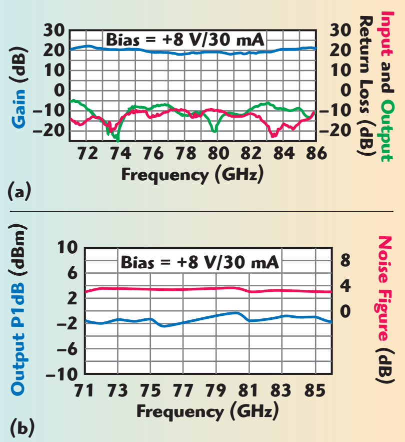
TABLE 2
POWER AMPLIFIER SPECIFICATIONS

Parameter	Units	Model Number SBP-7137633223-1212-E1	Model Number SBP-8138632520-1212-E1
RF Frequency Range	GHz	71 to 76	81 to 86
Small Signal Gain	dB	32	25
Output P_{1dB}	dBm	25	22
Input/Output VSWR		2:1	2:1
Size	in	1.50 × 1.10 × 0.75	1.50 × 1.10 × 0.75
Weight	oz	1.5	1.5

SAGE Millimeter has introduced a series of E-Band low noise and high power amplifiers with WR-12 waveguide interfaces. These amplifiers combine state-of-the-art semiconductor devices with innovative packaging to achieve the highest RF performance. Package styles include inline and right angle, offering system integrators great flexibility in meeting various configuration requirements.

LNAS

Table 1 summarizes the performance of two low noise amplifier (LNA) standard products, one covering the full 60 to 90 GHz WR-12 band, the other 71 to 86 GHz. The communication band model achieves 4 dB maximum noise figure, the lowest noise figure in its class. The full-band model has slightly higher noise figure at 5 dB. The typical measured performance of the communication



▲ *Fig. 1 Measured gain and return loss (a) and noise figure and output power at 1 dB compression (b) of the SBL-7138632040-1212-E1.*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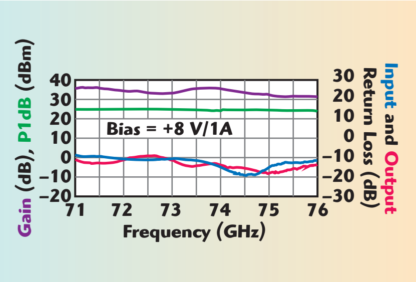
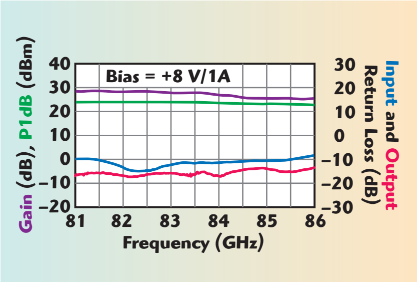


▲ *Fig. 2 Measured gain, output power at 1 dB compression and return loss of the 71 to 76 GHz power amplifier.*



▲ *Fig. 3 Measured gain, output power at 1 dB compression and return loss of the 81 to 86 GHz power amplifier.*

band LNA vs. frequency is shown in ***Figure 1***. Noise figure is below 4 dB across the band, and the small-signal gain is 20 ±2 dB. The nominal return loss is 10 dB.

POWER AMPLIFIERS

The power amplifiers can be biased from +5 to 12 V and typically draw 1 A. ***Table 2*** summarizes the performance of two power amplifier (PA) standard products. To offer the best performance, separate power amplifiers are designed for each of the two sub-bands: 71 to 76 GHz and 81 to 86 GHz. The measured output power, gain and return loss of the 71 to 76 GHz PA is shown in ***Figure 2***. Typical output power at 1 dB compression is greater than 23 dBm, and the small-signal gain is 32 ±3 dB. ***Figure 3*** shows the typical performance of the 81 to 86 GHz PA: better than 22 dBm P1dB and 25 ±2 dB small-signal gain.

Each of the amplifiers shown in Tables 1 and 2 use inline, WR-12 connections for the RF input and output. Having the waveguide interfaces inline makes insertion in the system straightforward. To serve a variety of system requirements, SAGE also offers E-Band amplifiers with right angle waveguide and 1 mm coaxial connectors. In all configurations, bias is applied by a solder connection to a pin on the amplifier housing.

Above E-Band, SAGE Millimeter offers amplifiers with frequency coverage up to 160 GHz. In addition to amplifiers, the company offers a wide range of millimeter wave components, including frequency converters, control circuits, ferrite devices, oscillators, antennas and multi-function assemblies and subsystems.

VENDORVIEW

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- **I-Tera® MT** materials are suitable for both high-speed digital and RF/microwave designs. A full compliment of cores and prepregs allowing flexibility in design is available in core thicknesses from 0.002" to 0.018". I-Tera MT has been used in designs up to 24 GHz.
- **TerraGreen®** halogen-free, very low-loss, thermoset materials are available in a variety of laminate and prepreg offerings. This material is inexpensive to process – improving your company's bottom line, as well as the environment.
- The revolutionary **Astra® MT** ultra low-loss thermoset laminates are a replacement for PTFE. Astra MT is available in core and prepreg for double sided, multilayer and hybrid designs using isola 185HR, 370HR or IS415. Astra MT has been used in designs up to 77 GHz.

	RF/MICROWAVE MATERIALS				
	IS680	I-Tera® MT RF	I-Tera® MT	TerraGreen®	Astra® MT
Tg	200°C	200°C	200°C	200°C	200°C
Td	360°C	360°C	360°C	390°C	360°C
Dk @ 10 GHz	2.80 - 3.45	3.38, 3.45 & 3.56	3.45*	3.45*	3.00
Df @ 10 GHz	0.0028 - 0.0036	0.0028, 0.0031 & 0.0034	0.0031*	0.0030*	0.0017
CTE Z-axis (50 to 260°C)	2.90%	2.80%	2.80%	2.90%	2.90%
T-260 & T-288	>60	>60	>60	>60	>60
Halogen free	No	No	No	Yes	No
VLP-2 (2 micron Rz copper)	Available	Available	Available	Standard	Standard
Stable Dk & Df over the temperature range	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-40°C to +140°C
Optimized global constructions for Pb-free assembly	Yes	Yes	Yes	Yes	Yes
Compatible with other Isola products for hybrid designs	For use in double-sided applications	Yes	Yes	Yes	Yes
Low PIM < -155 dBc	Yes	Yes	Yes	Yes	Yes

* Dk & Df are dependent on resin content NOTE: Dk/Df is at one resin %. Please refer to the Isola website for a complete list of Dk/Df values. The data, while believed to be accurate & based on analytical methods considered to be reliable, is for information purposes only. Any sales of these products will be governed by the terms & conditions of the agreement under which they are sold.

RF Conversion Service

- Isola's **Design Review Service** can facilitate your conversion to Isola's RF/microwave products and get you to market faster with the newest, ultra-low-loss materials.
- As part of this new service, Isola's technical staff will provide turn-key calculations, testing, characterizations and material recommendations to assist PCB fabricators and OEMs in converting to Isola's RF-materials, which will help overcome the current material shortages of other vendors and accelerate time-to-market. The design review service also addresses the perceived conversion issues when migrating from a currently used material to an Isola material.

http://www.isola-group.com/conversion-service

FREE! Impedance and Power-Handling Calculator

- Isola's free **Impedance and Power-Handling Calculator** predicts the design attributes for microstrips and striplines based on the design's target impedance and dielectric properties of the company's RF, microwave and millimeter-wave laminate materials.
- This software tool provides a design or an equivalent dielectric constant to facilitate modeling for PCB designers to predict impedance and other design attributes. The software computes changes in the effective dielectric constant due to dispersion at higher frequencies. The software then computes the total insertion loss—a measure of power lost through heat for power handling calculations, including the dielectric loss, conductor loss, and the loss due to the surface roughness. The main factors affecting the typical power-handling capability of a material are its thermal conductivity, the maximum operating temperature, and the total insertion loss.

https://isodesign.isola-group.com/phi-calculator

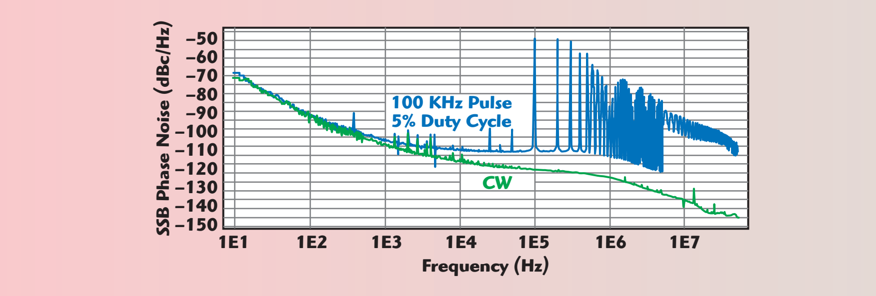
www.isola-group.com/RF

Automated Pulsed Phase Noise Measurements

Berkeley Nucleonics
San Rafael, Calif.

Berkeley Nucleonics has enhanced the 7000 series of fully automated signal source analyzers and extended the measurement capability to 26 GHz. In addition to measuring absolute phase noise on a large variety of CW sources with offsets from 0.01 Hz to 50 MHz, the 7000 series performs residual and absolute phase noise characterization of CW and pulsed signals, transient analysis and VCO characterization. High speed measurement modes are optimized for automated testing, making the 7000 series a very versatile signal source analyzer for both R&D and production testing. The instrument is simple to use and offers high accuracy and reproducibility combined with measurement speed. It has a high dynamic range with low system noise floors, while offering an attractive cost for labs and production environments. Two models are available that are application dependent: Model 7070 covers 5 MHz to 7 GHz and Model 7300 covers 5 MHz to 26 GHz. The instruments are Ethernet, USB or GPIB controlled and "plug and play" with any standard computer. The entire instrument is enclosed in a compact, fanless, 3U, 19 inch chassis and weighs 10 kg.

Developing the product on a fully integrated, low power platform avoided fan cooling, as well as eliminated spurious signals, ground loops and power line loops. By using an external battery, this unit can be operated



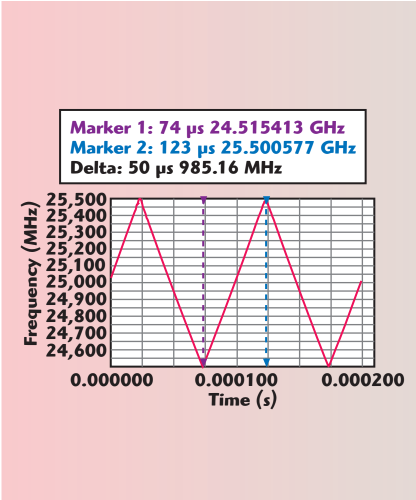
▲ *Fig. 1 Pulsed phase noise measurement of a 2.5 GHz signal with a pulse rate of 100 kHz and 5 percent duty cycle.*

anywhere, without needing AC power. The instrument includes multiple accessible tuning voltages, and the dual programmable low noise power supplies each provide up to 15 V and greater than 500 mA current. The ultra-low noise close to carrier phase noise internal reference synthesizers are adequate for most applications, even when very low close-in phase noise or noise floors are measured; however, external references can be applied to maximize the use and flexibility of the instrument. A PC, laptop or tablet serves as the control unit, so no displays are incorporated in the instrument. This minimizes cost and increases reliability.

SPECIAL CAPABILITIES

ATE Measurement: In addition to benchtop use, the 7000 series is a strong automatic test equipment (ATE) solution for accurate phase noise measurements below 200 milliseconds per device under test (DUT) in a production environment. The unit can be controlled and triggered using SCPI commands via USB or Ethernet. The measurement process itself is fully automatic and very easy to set up. Example programs are available in various programming languages, such as VBA, Java, C, Matlab or Labview. The ATE SCPI command set allows for phase noise plots, spot phase noise values, spurious extraction, and calculation of RMS jitter and integral phase noise.

Pulsed Phase Noise: Measuring the phase noise of a pulsed RF system poses unique challenges to the test



▲ *Fig. 2 Transient analysis of a 25.5 GHz carrier with a 1 GHz bandwidth chirp and 50 μs chirp time.*

system, which are met with the BNC 7000 series signal source analyzer. By detecting the pulses (or with external triggering), the hardware adjusts its parameters to increase the reliability and accuracy of the measurement. The current system handles pulse rates up to 1 MHz with duty cycles below 5 percent. ***Figure 1*** shows the measurement of a signal at 2.5 GHz with a pulse rate of 100 kHz and 5 percent duty cycle.

Frequency Transients: The 7000 series also works like a high performance modulation domain analyzer, providing a view of frequency and phase measurements over time. This intuitive way of seeing data allows frequency switching, jitter or modulation to be viewed directly. In effect, the Model 7000 series becomes a frequency oscilloscope, measuring carrier frequencies versus time up to 26 GHz with 16 ns time resolution.

Figure 2 shows the measurement of a 1 GHz bandwidth chirp at 25.5 GHz and 50 µs chirp time. The Model 7300 series observes wide frequency span transients up to 20 GHz bandwidth. With a time resolution of 16 ns and a continuous time span of several hours, a large number of applications can be addressed: measuring the frequency droop on individual channels in frequency hopping systems, analyzing chirp radar performance, measuring pulse jitter and viewing the distribution histogram, calibrating frequency sweep signals and calibrating intentional modulation (FM or FSK) as well as analyzing phase-locked loops (PLL) and frequency-locked loops, discovering phase jumps in synchronization clocks, detecting missing periods from rotational encoders, measuring VCO frequency settling times and characterizing the start-up/warm-up of oscillators.

Automatic VCO Characterization: At least two (low noise) DC sources and one signal analyzer are needed to characterize a VCO, to measure power, frequency, phase noise, etc. With four independent, programmable, DC voltages to power and control the DUT, the 7000 Series automatically characterizes a VCO for tuning voltage versus frequency, tuning sensitivity, output power, current consumption, supply pushing and SSB phase noise. The desired VCO parameters are captured in a single sweep.

The Berkeley Nucleonics 7000 series signal source analyzer has been extended with new measurement capabilities. Besides the powerful CW and pulsed phase noise measurements (additive and absolute), transient time domain, fast Fourier transform (FFT) analysis and VCO characterization are also supported. These independent measurement capabilities are easily implemented using the single, intuitive, graphical user interface. For production testing (ATE), a remote SCPI-based programming language is supported with throughput optimized measurement times.

Berkeley Nucleonics
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CALL FOR PAPERS

Come join us in San Francisco and enjoy the flagship Microwave Theory and Techniques Society (MTT-S) Conference in the Golden State of California!

The IEEE Microwave Theory and Techniques Society's International Microwave Symposium (IMS2016) will be held 22 - 27 May 2016 in San Francisco, California as the centerpiece of a week dedicated to RF and Microwave Technology. IMS2016 offers technical sessions, interactive forums, plenary and panel sessions, workshops, short courses, industrial exhibits, application seminars, historical exhibits, and a wide variety of other technical and social activities including a guest program.
Co-located with IMS2016 are the RFIC symposium (www.rfic-ieee.org) and the ARFTG conference (www.arftg.org).
With over 10,000 participants and 1000 industrial exhibits of state-of-the-art microwave products, IMS2016 is the world's largest gathering of Radio Frequency (RF) and microwave professionals and the most important forum for the latest research advances and practices in the field.

PAPER SUBMISSION:

Authors are invited to submit technical papers describing original work and/or advanced practices on Radio-Frequency, microwave, millimeter-wave, and terahertz (THz) theory and techniques. The deadline for submission is 5pm Central Standard Time 7 December 2015. Papers should be 3 pages in length (PDF format), and should not exceed one megabyte in file size. Hardcopy and email submissions will not be accepted. Please refer to the IMS2016 website (www.ims2016.org) for detailed instructions concerning paper submission. Authors must adhere to the format provided in the conference paper template available on the symposium's website. It is the authors' responsibility to obtain all required company and government clearances prior to submission. Please don't wait until the last day to start using the paper submission process. Those unfamiliar with the process may encounter paper formatting or clearance issues that may take time to resolve.
A double blind review process will be used to ensure anonymity for both authors and reviewers. Detailed instructions on submitting a double-blind compliant paper can be found on the IMS2016 website (www.ims2016.org). Papers will be evaluated on the basis of originality, content, clarity, and relevance to the symposium. For accepted papers, the electronic submission of a final manuscript along with a copyright assignment to the IEEE will be required no later than 29 February 2016. Accepted papers will be included in the Symposium Proceedings and submitted for inclusion in the IEEE Digital Xplore Library. Authors of accepted papers should consider submitting an extended version of their symposium paper for possible publication in the IEEE Transactions on Microwave Theory and Techniques.

EMERGING TECHNICAL AREAS:

IMS2016 enthusiastically invites submission of papers that report state-of-the-art progress in technical areas that are outside the scope of those specifically listed in this Call for Papers, or that may be new to the symposium, but are of interest to our attendees.

SPECIAL SESSIONS, WORKSHOPS, PANEL AND RUMP SESSIONS, AND SHORT COURSES:

Topics being considered for these areas include Next Generation Wireless Systems, Latest Technologies for RF/Microwave Measurements, and Advances in RFIC Technology. Please consult the IMS2016 website for a more detailed list of topics and instructions on how to prepare a proposal. Proposals must be received by 8 September 2015.

STUDENT PAPER AND STUDENT DESIGN COMPETITIONS:

Eligible students are encouraged to submit papers for the student paper competitions. The papers will be evaluated using the same standards as all contributed papers. In addition, eligible students or student teams are invited to consider taking part in student design competitions during the IMS2016, which are organized and sponsored by various Technical Committees (TC) of the MTT-S Technical Coordination Committee (TCC). Please visit the IMS2016 web site for full details.

MICROAPPS:

The Microwave Application Seminars serve as a forum for exhibitors at the IMS to present the technology behind their commercial products and their special capabilities. The presentations are open to all conference and exhibit attendees. Please refer to the IMS2016 website (www.ims2016.org) for more information on submitting MicroApps technical papers.

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Low Cost Wideband RF Signal Generator Doesn't Rely on a PC

Red Oak Canyon LLC
Spicewood, Texas

Many start-up developers; Wi-Fi, alarm and other product installers; university labs and electronic hobbyists may not have the budget or desire for expensive equipment, yet they still need a good, basic, calibrated signal generator. Generally, low cost RF generators must be attached to a PC via USB to operate or be programmed, which hinders portability. Many are too heavy or cumbersome to take into the field.

However, the RF Pro Touch RF generator developed by Red Oak Canyon LLC is truly portable. Weighing only 12 ounces and small enough to fit in your hand, this compact RF signal generator can be used in an office, classroom, lab or in the field. The unit is fully self-contained and small enough to take to remote, hard-to-reach places. With its simple touch-screen interface, the RF Pro Touch is quick to set up and versatile enough to accomplish many filter and cable characterization and alignment tasks.

The RF Pro Touch contains an internal temperature-controlled reference with only 2.5 ppm variation from -30° to 85°C. The reference combined with the ADF4351 wideband and low phase noise synthesizer enables the RF Pro Touch to generate a low phase noise output from 35 MHz to 4.4 GHz. At 1 GHz, the phase noise is -91 dBc/Hz at 10 kHz offset; at 2.4 GHz, it's -86 dBc/Hz. The phase-locked loop (PLL) setup of the ADF4351 has been optimized to give the best noise performance for both integer and fractional synthesis, with 1 kHz RF output resolution. The output power is adjustable from +10 to -55 dBm, enough range for most sensitivity measurements. For lower power, a fixed attenuator can be added to the output.

OPERATION

To operate the RF Pro Touch, a 50 Ω load is connected to the RF output SMA connector, and the frequency and output power are set with the touch of a few buttons before pressing RF ON on the screen. No complicated setup.

The RF Pro Touch simplifies frequency response and linearity-saturation characterization with easy-to-use frequency and power scan modes. The "Loop Forever" mode scans between a starting and ending frequency or power, with pre-defined steps and time delays

ProductFeature

between steps. Pressing start begins the programmed scan until it is stopped. For more timing control of the start of a scan pass, the "Once" mode starts at the initial frequency or power, runs to the ending frequency or power with the applied step increment and then stops, waiting to start again. In "Step" mode, scanning pauses at each frequency or power step. In any mode, the scan can increment or decrement in frequency or power.

Some measurements require two RF generators or that the RF generator synchronize with another source. Since no two reference sources are identical, two generators using separate frequency references will produce unwanted noise in the measurement. The RF Pro Touch provides both an external reference input and a buffered reference output, so the frequency reference of the RF Pro Touch can be used as the source or can be driven with another instrument. A button on the Settings screen switches between internal and external references. When using an external reference, the external reference frequency in the Settings screen should be set to ensure the correct RF output frequency.

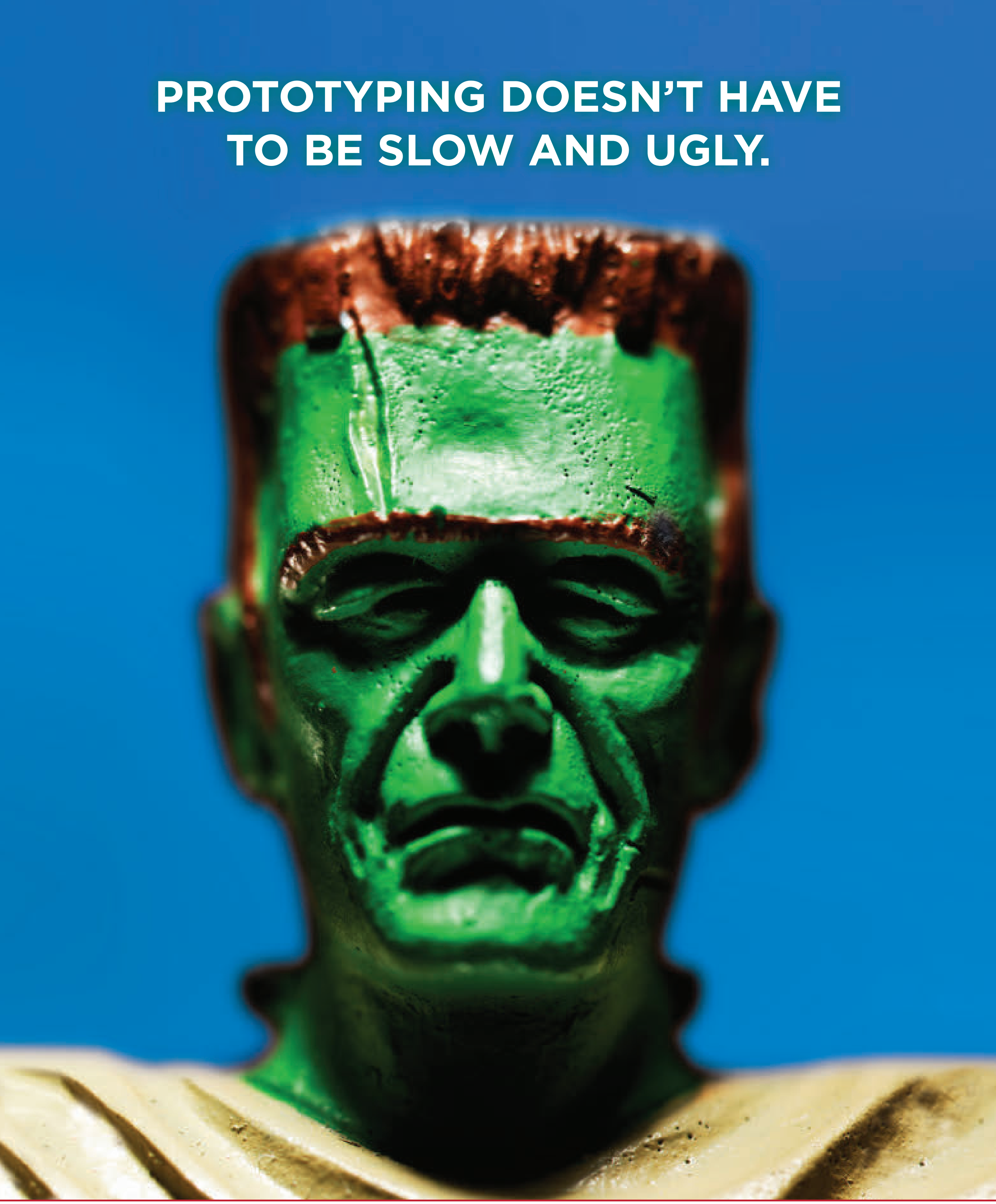
The modulation input provides a convenient way to either frequency modulate or pulse the RF output (OOK modulation). When FM is selected, varying the peak-to-peak modulation input voltage, up to a maximum of 15 V, sets the desired frequency deviation. A 4 V_{pp}, 1 kHz sine wave develops a 250 kHz deviation at 915 MHz, while a 200 mV_{pp}, 1 kHz sine wave develops a 30 kHz deviation at 2.4 GHz. A digital, 3 to 5 V signal controls the RF output in OOK mode, enabling high frequency switching that is useful for compliance testing.

In the office or lab, the RF Pro Touch can be powered with the 5 V power adapter. In the field, the RF Pro Touch operates for at least two hours on a single charge. To extend the life of the internal Li-ion battery, the screen can be set to auto-blank after it hasn't been touched for a defined time. Normally, if the RF is on while using the constant or scanning modes, the display won't blank, although this can be configured in the settings screen to extend battery life. If the screen has auto-blanked after timeout, and the RF is off, an auto shutdown timer can be set to turn off the unit to save the battery. The next time the unit is turned on, it will have the same configuration as when it turned off.

APPLICATIONS

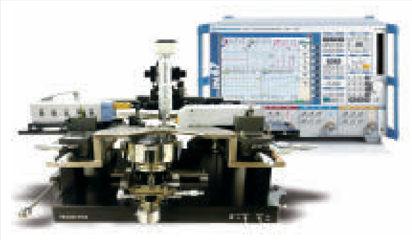
As a practical, low cost tool, the RF Pro Touch is ideal for teaching seminars, antenna calibration, as well as pre-compliance testing to assess possible interference with radio and TV reception and radiated immunity testing. Signals generated by the RF Pro Touch and amplified by a separate power amplifier are transmitted using antennas aimed directly at a product to determine whether the product will be disrupted. Contractors who install coaxial and fiber-optic cable inside buildings, for distributed antenna systems (DAS) or small cells, can use the RF Pro Touch to verify RF signal integrity. Ham radio operators can use the RF Pro Touch to measure filter response and experiment with receiver and transmitter circuits.

Red Oak Canyon LLC
Spicewood, Texas
www.redoakcanyon.com


PROTOTYPING DOESN'T HAVE
TO BE SLOW AND UGLY.

Integrated Solution for On-Wafer Measurements

Due to the complex measurements required to characterize modern RF semiconductor components, the proper integration of test and measurement equipment with a probe system is time-consuming and costly. Setting up a measurement system to deliver accurate and repeatable results is challenging, given the number of factors that come into play: the user interface, mechanical properties of the probe system, the electrical and mechanical properties of the RF probe tips, the mechanical connection and integration of the network analyzer with the probe system and the functionality and usability of the software. Also, the vector network analyzers (VNA) must provide the RF performance and functionality required for complete and accurate characterization for demanding devices, such as amplifiers and converters, over a wide frequency range.



To address these challenges, MPI and Rohde & Schwarz worked together to successfully integrate R&S VNAs and MPI engineering probe systems and RF accessories. The companies say this is the first probe system specifically designed for high precision measurements at millimeter wave and sub-millimeter wave (THz) frequencies, based on a seamless integration of millimeter wave converters.

The TITAN™ RF probes provide excellent, real-time visibility of the probe tip contacts for highly accurate positioning of the probes. Alongside qualified MPI calibration substrates, TITAN probe technology covers frequencies up to 110 GHz. MPI provides the complete system, including probes, calibration standards and other accessories. Intuitive QAlibria™ calibration software with multi-touch functionality and multi-language interface supports the R&S®ZVA and R&S®ZNB VNAs. Tight integration with StatistiCAL® from NIST enables easy and confident metrology-level calibration of the R&S VNAs.

Featuring highly stable sources, the R&S®ZVA with Rohde & Schwarz frequency converters are ideally suited for on-wafer component characterization at millimeter wave frequencies. The converters have been optimized mechanically for on-wafer measurements.

MPI Corp.
Chu-pei City, Taiwan
www.mpi-corporation.com

VENDORVIEW
Rohde & Schwarz
Munich, Germany
www.rohde-schwarz.com

Innovative YIG Technology Dramatically Improves Band-Reject Filters

Historically, the performance of YIG-tuned band-reject filters has been limited by trade-offs between 3 dB bandwidth at the high end of the frequency range and notch bandwidth at the low end. Teledyne Microwave Solutions has developed a new patent-pending technology that enables the 3 dB bandwidth at the high end to be much narrower and the notch at the low end deeper and wider than previously achievable – without degrading any other electrical parameter. The new technology also offers enhanced performance at much lower frequencies than possible with previous capabilities. With the added benefit of reduced spurious response, this filter line delivers unequalled performance.

The six new YIG-tuned band-reject filters from Teledyne Microwave Solutions cover frequency bands from 125 MHz to 18 GHz. The products include:

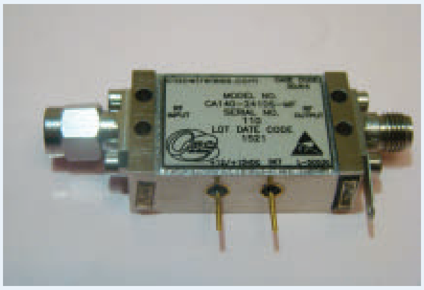
- Two filters for 125 to 1500 MHz, a frequency range never before available with YIG technology.
- A single 500 to 2600 MHz filter with 40 dB rejection bandwidth of 6 MHz (minimum), 3 dB bandwidth of only 70 MHz (maximum) and 3 dB maximum rejection spurs.
- A single 2 to 18 GHz filter with 40 dB rejection bandwidth of 12 MHz (minimum), 3 dB bandwidth of only 125 MHz (maximum) and 4 dB maximum tracking spurs.

Used primarily for electronic warfare, electronic countermeasures and microwave receivers, these filters achieve a previously unobtainable trifecta: wider notch bandwidth, greater notch depth and narrower 3 dB bandwidth.

Teledyne Microwave Solutions
Mountain View, Calif.
www.teledynemicrowave.com

1 to 40 GHz Amplifiers with Integrated Power Detector

Ciao Wireless's new low noise amplifiers have instantaneous, ultra-wideband coverage from 1 to 40 GHz, making them suitable for multiple communication band applications. The amplifier line offers multiple gain options: 20, 25, 30 and 35 dB with flat response, typically less than ±3.0 dB over the band. Amplifier output power is typically +15 dBm minimum with a two-tone, third-order intercept of +23 dBm and non-harmonic spurious levels better than -60 dBc. All units are well matched, with input VSWR typically 1.6:1 over the band (2.3:1 maximum) and output VSWR 1.8:1 (2.3:1 maximum). Typical noise figure is as low as 4 to 5 dB at +23°C.



The design features an integrated output power detector that covers 10 MHz to 40 GHz and has the flexibility to tailor the output voltage to meet the customer's desired voltage vs. output power. The detected output is scalable up to a 10 dB dynamic range with very repeatable performance and settling times typically 50 µs or less. Units can be ordered without the output detector, if only the amplifier is desired. The detector can also be ordered separately, without the amplifier, for applications that require a small, competitively priced power detector covering 10 MHz to 40 GHz. The detector can be optimized over a narrower frequency band.

The amplifier with the integrated detector assembly occupies a small footprint, with 2.9 mm connectors and hermetic feedthroughs. Hermetic sealing is available, and the line is qualified for all commercial and high-rel applications. The nominal operating temperature range is -20° to +70°C, although the design can be optimized for alternate operating conditions. These units require +12 to +15 V bias and have integrated voltage regulation and reverse polarity protection.

Ciao Wireless Inc.
Camarillo, Calif.
sales@ciaowireless.com
www.ciaowireless.com

ATC 100 Series Superchips® and 700 Series Case Sizes A, B, C & E

Supports a Wide Range of Critical Large and Small Signal Minimal Drift Applications

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- Induction Heating
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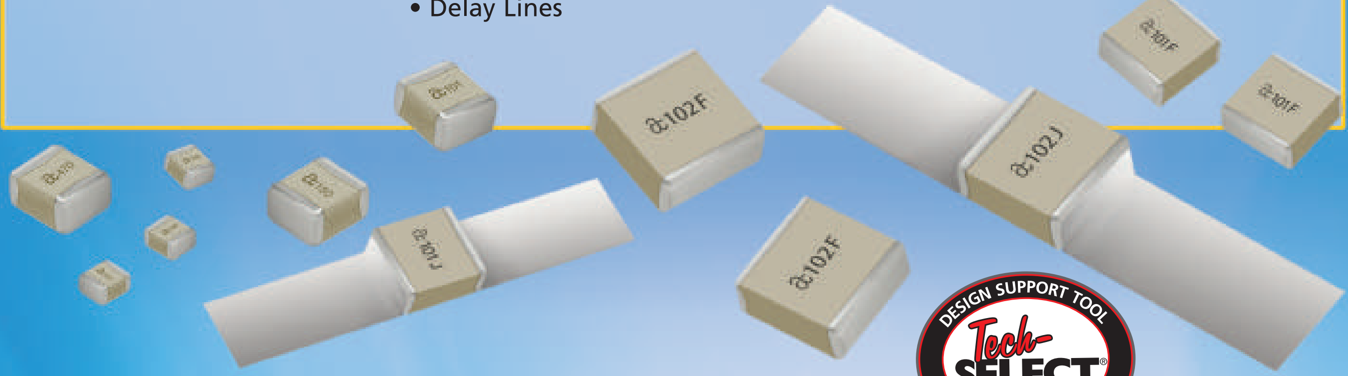
High Reliability

- Qualified to MIL-PRF-55681
- S-Level Reliability*
- QPL Approved (CDR Availability)
- Supported by COTS

*ATC Capacitors are Qualified to S-Level Failure Rate = 0.001%/1000 Hrs. @ 125°C with 2X Rated Voltage Applied



DESIGN SUPPORT TOOL Tech-SELECT® FOR ATC PRODUCTS

ATC Series		Dimensions	Capacitance Range (pF)		Working Voltage (WVDC) max.
			100 Series	700 Series	
100A	700A	.055 X .055 (1.40 X 1.40)	0.1 to 100	0.1 to 1000	Up to 250
100B	700B	.110 X .110 (2.79 X 2.79)	0.1 to 1000	0.1 to 5100	Up to 1500
100C	700C	.250 X .250 (6.35 X 6.35)	1 to 2700	1 to 2700	100C: Up to 3600 / 700C: Up to 2500
100E	700E	.380 X .380 (9.65 X 9.65)	1 to 5100	1 to 2200	Up to 7200

inches (mm)

AMERICAN TECHNICAL CERAMICS

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THE ENGINEERS' CHOICE™ www.atceramics.com

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Software and Mobile Apps

Mobile Device App

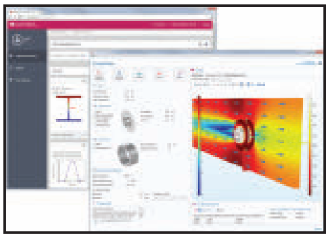
VENDORVIEW

AR RF/Microwave Instrumentation's mobile app is now available as a free download from Apple iTunes and Google Play. This application is a quick and easy tool to access a variety of content from AR. The home screen icons allow easy navigation to view basic and full product descriptions, app notes, AR's literature library, YouTube videos, contact information and social media activity – all from your mobile device. To download the app, visit www.arww-rfmicro.com/html/ar-moblie-app.asp.

AR RF/Microwave Instrumentation

www.arworld.us

COMSOL Multiphysics 5.2

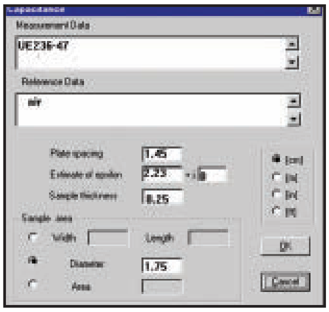


As a leading provider of multiphysics modeling and simulation software, COMSOL Multiphysics 5.2 delivers major productivity updates to COMSOL Multiphysics and COMSOL Server with new features, improved stability and robustness, and faster execution. Version 5.2 offers a more intuitive and improved user experience for building multiphysics models and converting them into simulation apps. Major upgrades to the Application Builder include the new editor tools for easy creation of user interface components, commands for dynamic updates of graphics and more control over the deployment of simulation apps.

COMSOL Inc.

www.comsol.com

MU-EPSLN™ Software Extended Capability



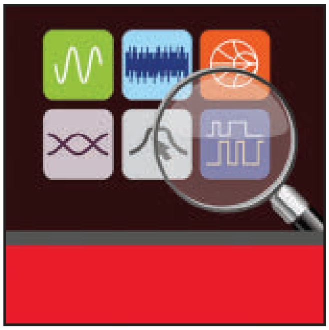
In support of its newly developed Model 400C capacitance cell (operating band 100 KHz to 50 MHz), Damaskos Inc. has incorporated instrument control and data processing for dielectric constant measurement of small samples, in the range of 2-3 mm thickness and area up to 25.4 cm^2. The upgrade performs calibration of the 400C cell and measurement and display of material parameters at about 5 percent for DK and a factor of 5 to 10 for DF, employing common analyzers.

Damaskos Inc.

www.damaskosinc.com

Software Selector Mobile App

VENDORVIEW



The new Keysight SW Selector Mobile App helps engineers find the ideal stand-alone and/or embedded software application(s) to best meet their test and measurement needs. The new mobile app allows for easy search of more than 230 test and measurement software applications. Engineers can search by application, technology or instrument. The app is available for download now for Android and iOS devices.

Keysight Technologies Inc.

www.keysight.com/find/swselector

Microwave Calculator Mobile App

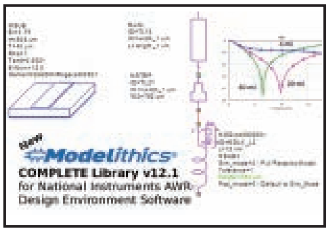
VENDORVIEW

Mini-Circuits' Microwave Calculator app for Android mobile devices gives engineers a quick and easy tool to perform three common calculations on the fly: the effect of VSWR/return loss on transmitted power, cascaded noise figure and power to voltage conversion. It also provides the formulas for each of these computations as a convenient reference. It is the perfect tool to simplify and expedite problem solving whether you're working in the lab or in the field. The app is available for FREE download from the company's website and on Google Play™.

Mini-Circuits

www.minicircuits.com

COMPLETE Library v12.1



Modelithics released the latest version (v12.1) of the Modelithics® COMPLETE Library™ for NI AWR Design Environment software. The release includes over 50 new high accuracy simulation models, representing over 1,500 individual devices. New models have been added for components from AVX, Cobham Aeroflex, Würth Elektronik, ATC, Passive Plus, Piconics, Skyworks, Freescale, Qorvo, CoilCraft, Murata, Darfon, Taiyo Yuden, TDK and IPDiA. The Modelithics COMPLETE Library now represents over 50 vendors and over 11,000 RF and microwave devices. Visit www.modelithics.com for details.

Modelithics Inc.

www.modelithics.com

Software and Mobile Apps

NI AWR Design Environment V12.01

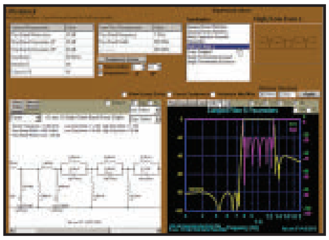
VENDORVIEW

NI AWR Design Environment™ is complete high-frequency design software for system simulation, circuit simulation and electromagnetic analysis. V12.01 has been released and continues to build upon the new load-pull features of V12. In addition, the V12.01 update includes multiple improvements to system simulation within Visual System Simulator™, layout, tuning, yield analysis and optimization capabilities within NI AWR Design Environment, inclusive of Microwave Office and AXIEM and Analyst™ 3D EM simulators.

National Instruments

www.ni.com

Asymmetrical Bandpass Filter Design



Nuhertz announces improved capability in FilterSolutions®, synthesis software. The program now instantly and accurately automates design of asymmetric bandpass filters which do not require symmetric attenuation response on each side of the passband. Rather than utilizing optimization or manual pole-zero tuning, FilterSolutions provides an accurate, automated method for setting asymmetric design parameters. The only data needed are the independent attenuation goals and the number of poles for each side of the passband. FilterSolutions instantly provides the exact solution.

Nuhertz Technologies LLC

www.nuhertz.com

Mobile-Friendly Website

VENDORVIEW

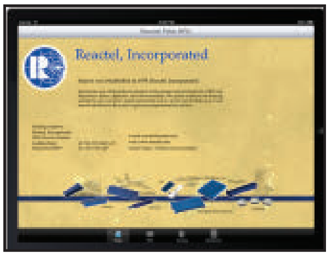
Pasternack Enterprises Inc. launched its new mobile website which marries powerful parametric search capabilities with a sleek, simplified and user-friendly interface specifically intended for smart phones and tablets. The mobile site will provide engineers in the field the easiest, most intuitive process for searching and finding any of the company's +40,000 RF components and cable assemblies with as few finger and thumb swipes as possible. Other notable features include easy access to product datasheets as well as real-time stock levels and pricing for every product.

Pasternack Enterprises Inc.

www.pasternack.com

Filter RFQ Mobile App

VENDORVIEW

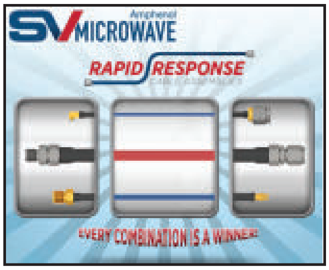


Submitting RFQ's for filters, multiplexers and multifunction assemblies has never been easier or more convenient with Reactel's new mobile app for Apple and Android devices. Filter RFQ is available now for Apple and Android devices. In addition to the RFQ element, this full featured app also contains the company's complete catalog and a growing number of datasheets. Download your copy from iTunes or GooglePlay today.

Reactel Inc.

www.reactel.com

Rapid Response

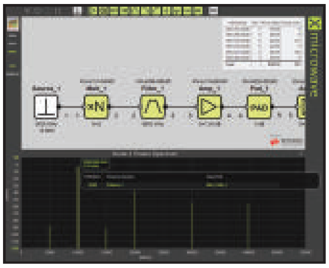


SV's New Rapid Response Cable Assemblies are built-to-order and ship within 5 business days. Using the best interactive RF cable builder application in the market, customers can build cable assemblies designed for their specific application, instantly view pricing, technical specifications and electrical performance graphs and place an order. Choose from a variety of in-stock standard connector series and cable types with length up to 99" for miniature and low loss coaxial assemblies. The RF Cable Builder application accepts credit cards and is mobile compatible with Android/iOS.

SV Microwave

www.svmicrowave.com

Online Simulator



X-Microwave introduced its Online Nonlinear System Simulator powered by Keysight's Genesys Spectrasys. Simulate with hundreds of models of real system components using the intuitive user interface. X-parameter or S-parameter models are extracted from X-Microwave's drop-in components (X-MWblocks) using Keysight's PNA-X analyzer. An X-parameter model of an amplifier serves as a live datasheet to determine the P1dB or IP3 at a given operating point of interest. Quickly cascade microwave components and simulate to view the spectral content at any node of the block diagram.

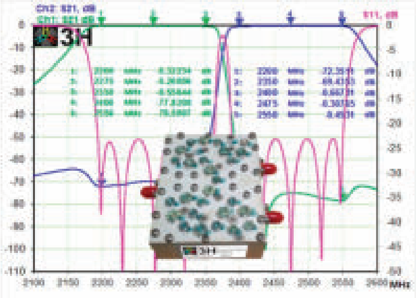
X-Microwave LLC

www.xmicrowave.com

Components

1030/1090 Duplexer

VENDORVIEW



3H Communication Systems' new high performance 1030/1090 duplexer offers < 1 dB insertion loss in the transmit band while rejecting the received band by > 70 dB. The receive band offers < 1.25 dB insertion loss while rejecting the transmit band by > 70 dB. The duplexer offers 250 W peak and 25 W average.

3H Communication Systems
www.3Hcomm.com

180° Hybrid Coupler

VENDORVIEW

The AH180-020180 compact ultra-broadband stripline hybrid coupler provides 180° phase shift and in-phase outputs from two combined signals in the 2 to 18 GHz range with maximum amplitude unbalance of ±1.2 dB and maximum phase unbalance of 12°. It measures 82 × 36 × 11 mm. The stripline construction is contained within a rugged aluminum alloy housing and features four hole flange-mount SMA connectors with mating interface to MIL-C-39012. The operating temperature range is the full military -55° to +85°C.

AtlanTecRF
www.atlantecrf.com

10 W Resistive Power Divider

Model series 151-285-XXX is a family of resistive power dividers in 2, 4, 6 and 8 way configurations. These 50 ohm, 10 W average power devices have an operating frequency range of DC to 6 GHz. Insertion loss above theoretical loss is +1 dB nominal for 2 and 4 way configurations. Insertion loss above theoretical loss for 6 and 8 way configurations is +1 dB nominal DC to 5 GHz and +1.6 dB nominal 5 to 6 GHz. Maximum VSWR is 1.50:1 and the RF connectors are SMA female.

BroadWave Technologies Inc.
www.broadwavetech.com

40 GHz Switch

The TK4 series features K connectors and a frequency range of DC to 40 GHz. This series is available with failsafe, latching self-cut-off or pulse latching functions. Ducommun's design engineers can create custom versions for your specific applications.

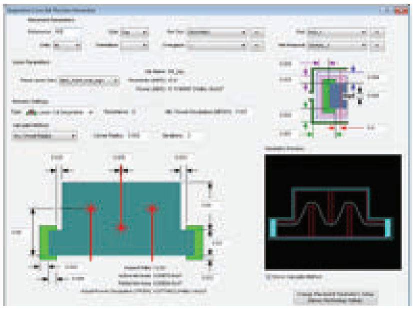
Ducommun Inc.
www.ducommun.com

Class 2 Transformer

The model 14359 UL/C-UL Listed Class 2 transformer accepts line voltages of 120, 208, 240 and 480 V, 50/60 Hz, allowing near universal application. Encapsulated with a UL 94VO flame retardant epoxy, and housed in a 304 stainless steel enclosure, it is virtually impervious to dirt, moisture and corrosive elements, making this transformer ideal for equipment.

Foster Transformer
www.foster-transformer.com

Pantheon Ink Resistor Technology



Intercept Technology Inc. announced enhancements to its Pantheon Ink Resistor functionality. In line with Intercept's mission to provide the highest in advanced design technology, enhancements include the ability to create rectangular as well as complex ink resistor shapes parametrically on the fly during layout, or from information obtained from a schematic. Ink resistor components reside in the design database as parametric types, allowing for flexible modifications as needed at any point during the design process.

Intercept Technology Inc.
www.intercept.com

Extreme Ultra-Thin Filters

When size is critical, Lark offers a full line of extreme ultra-thin (XUMTS series) filters. Lark's new extreme ultra-thin package offers superior performance with a size reduction of up to 70% from current ultra-thin filters. The extreme ultra-thin filter series offers low insertion loss and ultimate rejection levels of 60 dB while maintaining better than 1.5:1 VSWR. These units are lightweight and ruggedized for today's military applications.

Lark Engineering
www.larkengineering.com

Hot Swap Controller

VENDORVIEW

Linear Technology Corp. introduced the LTC4282, an energy monitoring Hot Swap controller with dual MOSFET drive to enable 100A and higher current board designs. The LTC4282 ensures safe board insertion and removal from live 2.9 to 33 V backplanes by controlling external N-channel MOSFETs to gently power up capacitors, avoiding sparks, connector damage and system glitches. High current hot-pluggable boards utilize parallel MOSFETs to reduce voltage drop, but all of these MOSFETs require large safe operating area (SOA) to ride through overcurrent faults.

Linear Technology
www.linear.com

MMIC Mixers

The best MMIC mixers on the market are now available in surface-mount packages. Four models are available in standard diode level formats, in addition to the high level diode MM1-0424SSM. Each of these mixers is in a 3 mm QFN with a commercial standard layout, making them form fit compatible replacements for many competing MMIC mixers. Please contact support@markimicrowave.com for more information or a competitor cross list.

Marki Microwave
www.markimicrowave.com

6 GHz RF Attenuators

VENDORVIEW

MECA announced the addition of the 662 series, 2 W SMA attenuators operating now up to 6 GHz. The 662-dB-1F6 series attenuators cover all wireless applications from Hz to 6 GHz and are available in standard values of 3, 6, 10, 20 and 30 dB. As always products are made in the U.S. and carry MECA's 36-month warranty.

MECA Electronics Inc.
www.e-meca.com

NewProducts

N-Type Fixed Attenuator

VENDORVIEW

Mini-Circuits' BW-30N100W+ is a 30 dB coaxial precision fixed attenuator providing high power handling of up to 100 W over the DC to 6 GHz frequency range. This model supports many high power applications requiring precise attenuation over a broad frequency range including high-power measurement, matching and instrumentation. It provides good VSWR (1.25 typ.), outstanding attenuation flatness (±0.65 dB) and excellent thermal stability from -55° to 100°C. It features rugged construction with N-male to N-female connectors and heat dissipation fins for efficient cooling.

Mini-Circuits
www.minicircuits.com

RF Couplers

P1dB announced in-stock availability of a series of broadband RF couplers that operate from 0.5 to 18 GHz. The SMA directional couplers, series number P1CP-SAF-R518G30W, come in 10, 20 and 30 dB values as standard items, but other values are available upon request. The directional couplers are designed to handle 30 W of input power and have a directivity performance of up to 20 dB. A common coupling value for SMA couplers is 10 dB and its part number is P1CP-SAF-R518G30W-10. All coupler values and frequency ranges can be found in the coupler category page on the P1dB website.

P1dB RF & MW Components
www.p1db.com

Threshold Detectors

VENDORVIEW

Pasternack's latest release of threshold detectors consists of 3 unique models covering broadband frequency bands from 2 to 40 GHz. Designs incorporate gain stages for higher dynamic range that cover input power levels ranging from -45 dBm to 0 dBm with a typical threshold variation over frequency of ±0.5 dB. One model supports a fixed threshold while the other 2 models support an adjustable threshold setting.

Pasternack
www.pasternack.com

Power Divider

RADITEK's newest model, the R2PD-500-6000M-Nf-150W-w18 (wideband) power divider can operate at 500 MHz to 6 GHz at 150 W. It comes standard with N-female straight connectors. Operating temperature to -10° to +70°C. Adequate heat-sinking is required for continuous use at full power. Dimensions are: length 8.5" × width 2.0" × thickness 0.9".

Raditek Inc.
www.raditek.com

14 to 16 GHz Circulator

VENDORVIEW

Looking for a surface-mount K-Band circulator? Renaissance Electronics has designed a 14 to 16 GHz true surface-mount, coplanar, stripline circulator that can handle up to 30 W with less than 0.3 dB insertion loss. It features Ku-Band, surface-mount, low loss, high isolation, temp stable and 30 W power handling.

Renaissance Electronics & Communications LLC
www.rec-usa.com

Multi-Octave Band Power Divider

Response Microwave Inc. announced the availability of its new multi-octave band power divider for use in ATE and production applications. The new RMPD4.2-18Sfb covers the 2 to 18 GHz band offering typical electrical performance of 1.5 dB max insertion loss, VSWR of 1.40:1 maximum and minimum isolation of 20 dB. Power handling is 25 W and the unit is operational over the -35° to +85°C range. Mechanical package is 2.15" × 2.25" × 0.50", plus SMA female connectors. Unit configurations are currently available in 2, 4, 6 and 8 way splits.

Response Microwave Inc.
www.responsemicrowave.com

SPDT Switch

VENDORVIEW

RFMW Ltd. announced design and sales support for Peregrine Semiconductor's PE42920 dual differential SPDT switch operating from 10 kHz to 6 GHz. The PE42920 targets test and measurement applications where two independent differential signals are required to be switched. Having both switches in a small, 3×3 mm QFN package saves both board space and BOM cost as well as improving performance. Operating from a single 3.3 V supply, the Peregrine DDSPDT uses only 100 microamps in typical operation. Yet, this switch has 30 dB of isolation between opposite active channels and 26 dB isolation between same channel inputs at 6 GHz.

RFMW Ltd.
www.rfmw.com

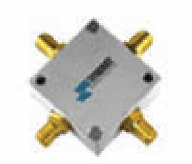
Cable Filter

RLC Electronics' cable filters can be designed as either lowpass, high-pass or bandpass constructions, covering frequency ranges up to 50 GHz. These filters are

available in conformable (FCLPF Series) and semi-rigid cable styles (CLPF Series) that are built to your cutoff, rejection and mechanical specifications, including cable length, bend position and angle. Computer designed and advanced coaxial techniques ensure optimal performance in a minimum amount of space.

RLC Electronics Inc.
www.rlcelectronics.com

Connectorized High Performance 180° Hybrid



The DJK-2100 is a connectorized 4-port 0/180 degree hybrid that spans the multi-decade frequency bandwidth of 20 to 1000 MHz. It maintains phase and amplitude error tracking between outputs of ±5 degrees and 1 dB maximum. The typical VSWR is 1.3:1 and insertion loss is 1.8 dB. This product is perfect for applications in HF through UHF-band in signal combining, canceling and sideband detection. The power handling capability is up to 1 W maximum. The product is packaged in a small SMA housing measuring 1.25" × 1.25" × 0.75" (L×W×H).

Synergy Microwave Corp.
www.synergymwave.com

SP2T Pin Diode Switch

VENDORVIEW

UMCC model SW-B310-2S is an absorptive SPDT Pin switch with TTL-driver. Switch features: 20 to 6000 MHz operating band, 2 dB loss at 3 GHz, 2.7 dB loss at 6 GHz, 75 dB arm-to-arm isolation, 150 ns rise/fall time, +27 dBm operating power, +5/-12 V supplies, all removable connectors. Unit measures 0.85" × 1.10" × 0.38".

Universal Microwave Component Corp.
www.umcc111.com

Attenuators and Terminations

Weinschel Associates announced the new 2 kW model WA80 attenuators and 2 kW model WA1480 terminations. The new products support the DC to 3 GHz frequency band, utilize forced air cooling to allow continuous operation, and come with either N-Type or 7/16 DIN connectors. Standard attenuation values offered are 20, 30 and 40 dB.

Weinschel Associates
www.weinschelassociates.com

Cables & Connectors

0.35 mm Pitch Board to Board Connector

The 5857 Series newly developed by KCP are space-saving, board to board connectors featuring a fine pitch of 0.35 mm, stacking height of 0.7 mm (between boards) and a width of 1.9 mm. With the fine-pitch and low-profile features, the connector achieves high robustness by covering both ends with metals, which prevents the connector from damage caused by misalignments. The new product has a unique contact structure like the KCP's existing products, attaining high contact reliability against vibrations or drops.

KYOCERA Connector Products Corp.

www.kyocera-connector.com

Aerospace Cables

W. L. Gore & Associates Inc. announced its family of high speed data cables for civil aerospace applications. These products address the industry's ever-increasing data needs in aircraft, including passenger in-flight entertainment (IFE) and essential electronic systems while reducing maintenance downtime and operating costs. GORE® Aerospace cables deliver excellent signal integrity for high speed data transmission up to 10 gigabits over longer distances. They support standard protocols such as Ethernet Cat5e and Cat6a, USB 3.1 and HDMI 2.0.

W.L. Gore Inc.

www.gore.com

Amplifiers

350 W Benchtop Power Amplifier

VENDORVIEW

The 350S1G6 provides wideband high linear output power over a frequency band of 0.7 to 6 GHz. Over 350 W of output power is achieved with only 1 milliwatt of input power. This amplifier is designed using "Hybrid Microelectronics Technology" resulting with an amplifier with greater power density, lower size and lower production cost than previously possible.

AR RF/Microwave Instrumentation

www.arworld.us

Solid-State Pulsed Power Amplifier

COMTECH PST introduced a gallium nitride (GaN) amplifier for applications in the S-Band radar market. The AB linear design operates over the 3.1 to 3.5 GHz frequency band and is easily modified to also support 2.9 to 3.1 GHz radar applications. The amplifier design features include options for control of phase and amplitude to allow for integration into high power systems utilizing conventional binary or phased array combining approaches for power levels of up to 10 kW.

COMTECH PST

www.comtechpst.com

RF Amplifier

VENDORVIEW

Empower RF announced it is shipping a new, RF amplifier system that complements the frequency coverage and power level "footprint" of its next generation, high power PA product family. Model 2180, covering 1 to 2.5 GHz and delivering an unprecedented 2 kW CW of broadband output power in a 8U, air cooled chassis is its latest market release. Offering unrivaled size, weight, and power advantages and building on a design architecture that has been a catalyst for technology upgrades from customers with diverse requirements from multiple markets, Model 2180 provides excellent performance for end applications.

Empower RF Systems

www.empowerrf.com

New**Products**

Pulsed Transistor

IGT2731M150 operates over the instantaneous bandwidth of 2.7 to 3.1 GHz. With 300 s pulse width and 10% duty cycle pulsing conditions it supplies a minimum of 150 W of peak output power. Typical performance is 165 W peak output power, 15 dB gain and 60% efficiency from a 50 V supply voltage. Available in either bolt-down or earless "S" package.

Integra Technologies Inc.
www.integratech.com

30 dB Gain, Portable Amplifier

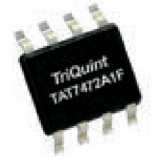
VENDORVIEW

PMI Model No. PTB-30-2040-5R0-10-115VAC-292FF is a portable amplifier that operates over the 20 to 40 GHz frequency range. This model provides 30 dB of typical gain with an OP1dB of +10 dBm minimum. This amplifier features an on/off switch that is located on the front panel and operates on 120 VAC.

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

75 Ω PHEMT Dual RF Amplifier

VENDORVIEW



Richardson RFPD Inc. announced the availability and full design support capabilities for a new PHEMT dual RF amplifier from Qorvo. The TAT7472A1F is a 75 Ω RF amplifier designed for CATV use but capable of operation up to 1218 MHz, making it suitable for DOCSIS 3.1. It contains two separate amplifiers for push-pull applications and is fabricated using 6-inch GaAs PHEMT technology to optimize performance and cost. Each amplifier contains on-chip active biasing, with bias current set points that are adjustable with a single resistor from the input to ground.

Richardson RFPD
www.richardsonrfpd.com

Benchtop Broadband PA

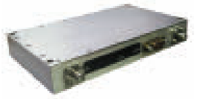
VENDORVIEW

Model SBB-0132732526-KFKF-SB is a benchtop broadband power amplifier operating from 1 to 26.5 GHz. The amplifier provides 25 dB small signal gain and a minimum +25 dBm output power over the entire frequency range. The benchtop amplifier is designed to use 100 to 240 V AC power directly from power line for laboratory use. The benchtop amplifier is equipped with K connectors for RF path and measures 3.75" (W) × 4.15" (L) and 1.75" (H).

SAGE Millimeter Inc.
www.sagemillimeter.com

400 to 450 MHz Bidirectional Power Amplifier

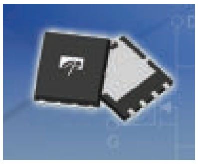
The TTRM1076 is a high linearity bidirectional SSPA suitable for use with any modulation and signal type. It is currently utilized in UAV data links and long range point-point COFDM video links. High speed T/R switching and sequencing of the PA, LNA and switch driver circuitry is performed by an on-board CPLD, where switching timing can be adjusted in firmware based on system requirements. The transmit section produces over 25 W of BPSK power, and over 6 W of 64 QAM. The unit also features a three color status LED on the front panel that shows if the SSPA is in transmit or receive mode, or if an alarm condition exists. The amplifier housing is weatherproofed per the guidelines of IP66.



Triad RF Systems Inc.
www.triadrf.com

Semiconductors

45 V MOSFET



Alpha and Omega Semiconductor Ltd. introduced a single n-channel 45 V MOSFET with an ultra-low on-resistance of 1.15 mOhms at 10 V. The AON6152 provides the best combination of maximum

NewProducts

power conversion efficiency and higher driver capability to minimize switching power loss. This latest addition to AOS's medium voltage product portfolio is designed to address a wide range of applications including secondary-side synchronous rectification in AC/DC and DC/DC converters, as well as industrial and motor drive applications.

Alpha and Omega Semiconductor Ltd.
www.aosmd.com

K-Band Silicon SATCOM Rx Quad Core IC

The AWS-0102 K-Band silicon SATCOM Rx quad core IC supports 4 dual polarization radiating elements with full programmable polarization flexibility. The device provides 22 dB of gain with a noise figure of 3.4 dB at 20 GHz.

Additional features include system controlled gain compensation over temperature and temperature reporting via the serial control bus. Silicon technology enables very high integration of functionality thus enabling planar antenna design at K-Band with reduced system size, weight and cost.

Anokiwave
www.anokiwave.com

Systems

Direct Conversion Receiver ICs

The CMX994A and CMX994E are RF receiver ICs featuring I/Q demodulators with low power consumption and high performance features.

They are targeted at the next generation of narrowband and wideband Software Defined Radios (SDR) for wireless data and two-way radio applications. They are suitable for modulation schemes including: QAM, 4FSK, GMSK and pi/4-DQPSK. Key features include on-chip VCO for VHF applications, on-chip LNA, precision baseband filtering with selectable bandwidths and a small PCB area, typically less than 50% of a dual superhet, it is claimed.

CML Microcircuits
www.cmlmicro.com

Millimeter Wave System

MI Technologies' millimeter wave system features a combination of MI Standard Products to include a MI-350 advanced microwave measurement system w/local control unit, MI-757 mixer, MI-758 multiplier and MI-3000 arena software w/3046 SNF analysis.

MI Technologies
www.mitechnologies.com

Remote Collection System

Surveyor 500 combines the scanning receiver and the computer into a single device. Surveyor 500 is a closed box survey tool. The user simply turns the unit on and Surveyor 500 will prepare itself and begin collecting data. Communication to the Surveyor 500 can be established with any device capable of using an Internet connection or a remote desktop connection. For advanced users, a connection can be made to the device using ethernet. This feature makes Surveyor 500 able to become a remote probe.

QRC Technologies
www.qrctech.com

Sources

RF Signal Generator

VENDORVIEW

This small intelligent RF signal generator operates up to 6 GHz remote controllable via USB or stand-alone (internal battery) batch program operation. Aaronia's new BPSG RF generator series offers up to +18 dBm, 65 dB dynamic range and internal TCXO (or external reference). It fits to every Aaronia antenna to get an active field-strength generator. Intelligent batch programs (sweep, ramp, modulation and frequency lists) start automatically after every power on. The BPSG starts at €499,95 and is made in Germany and includes a 10 year warranty.

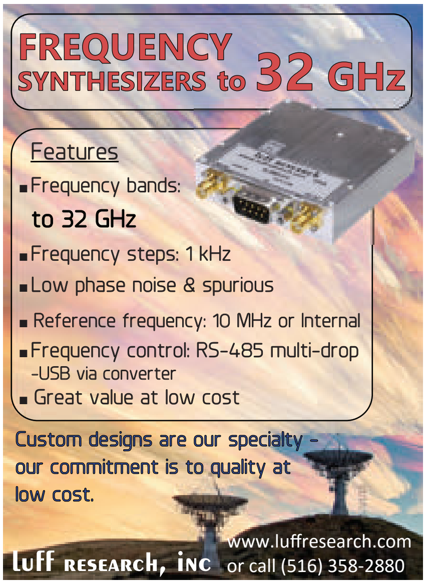
Aaronia AG
www.aaronia.de

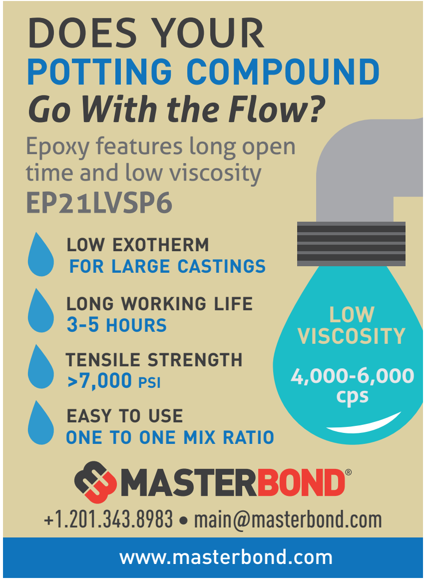
Customizable RF/Microwave Signal Generator Solutions

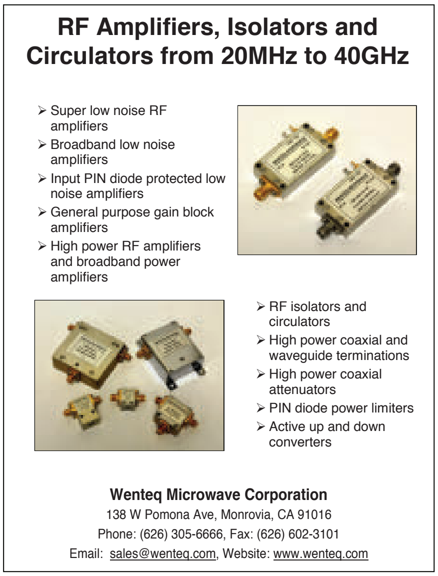
Berkeley Nucleonics released new high performance, robust and extremely cost effective RF/microwave generators. BNC now offers 12, 20 and 26.6 GHz frequencies. Each base frequency can now be customized with high output power (HP), no modulation (CW only), as well as rack mountable (R) 1U configurations for system integrations. BNC continues to offer the best low phase noise, fast switching speeds, extensive modulation capabilities in a portable lightweight benchtop, card level or rack mounted package.

Berkeley Nucleonics
www.BerkeleyNucleonics.com

MICRO-ADS







NewProducts

6 GHz RF USB Signal Generator

DS Instruments introduced the SG6000M ultra-compact RF signal generator. This sturdy all-aluminum device is USB powered and measures in at only 2.7" × 2.0" × 1.1" making it the size of a deck of cards. The SG6000M is a PC compatible instrument controllable via free PC GUI or as a COM port device supporting industry standard SCPI commands for automated functionality.

DS Instruments
www.dsinstruments.com

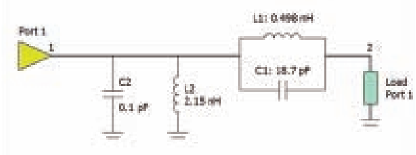
RF Receiver

IZT GmbH expands its industry leading RF receiver family, introducing the IZT R3500. The new RF receiver provides a high performance solution for the interception of RF signals. Instead of standard solutions with fixed filters, the R3500 offers a highly linear, flexible preselector with electronically configurable start and stop frequencies. Modern, automatic signal classifiers are able to simultaneously analyze several megahertz of spectrum for any signals of interest. The interception of the high frequency (RF) signals poses an exceptional challenge for the dynamic range of any receiver, especially when large and sensitive antenna systems are used.

IZT GmbH
www.izt-labs.de

Software

XFdtd and Optenni Integration



Remcom announced the integration of XFdtd® electromagnetic simulation software and Optenni Lab™ matching circuit optimization software. The Optenni addition enables XFdtd users to more easily generate a matching network topology and initial component values for their device. Once the topology is chosen and physically laid out on the PCB, XFdtd's circuit element optimizer completes the matching network design process by determining the optimal component values using full wave FDTD simulation, taking electromagnetic phenomena, such as coupling, into account.

Remcom
www.remcom.com

DUAL or SINGLE LOOP
SYNTHESIZER & PLO MODULES

Up to 30 GHz*

Features:

- Proprietary digital Integer and Fractional PLL technology
- Lowest digital noise floor available -237 dBc/Hz figure of merit
- Output frequencies from 100 MHz locked crystal to 30 GHz
- Available with reference clean up dual loop, or single loop for very low noise reference
- Parallel fixed band stepping or SPI interface synthesized up to octave bandwidths
- Reference input range 1 MHz to 1.5 GHz
- Dual RF output or reference sample output available
- +12 dBm standard output power +16 dBm available
- Standard module size 2.25 X 2.25 X 0.5 Inches (LxWxH)
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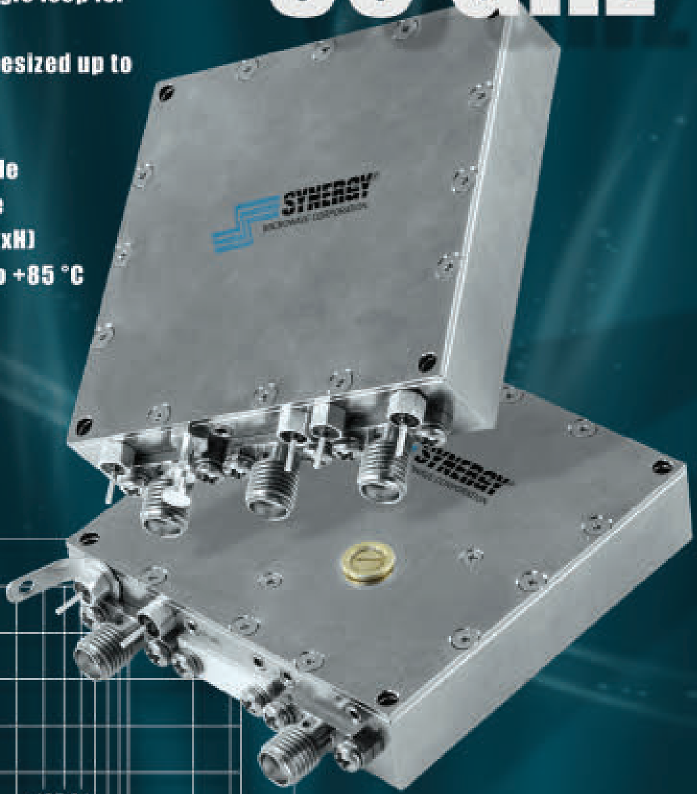

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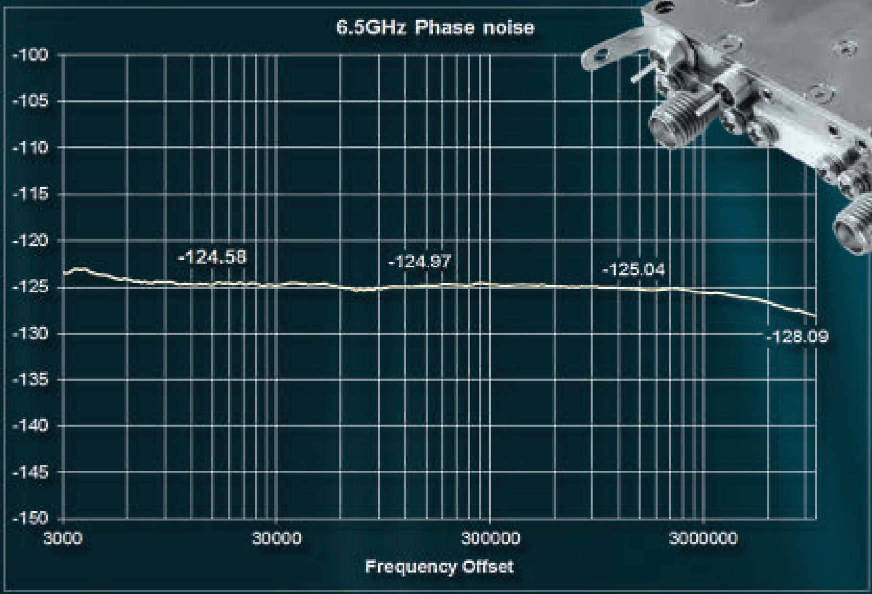

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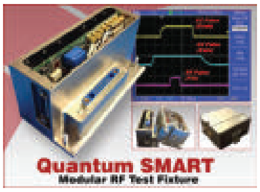

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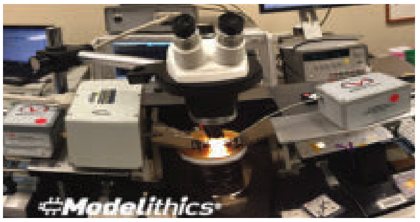

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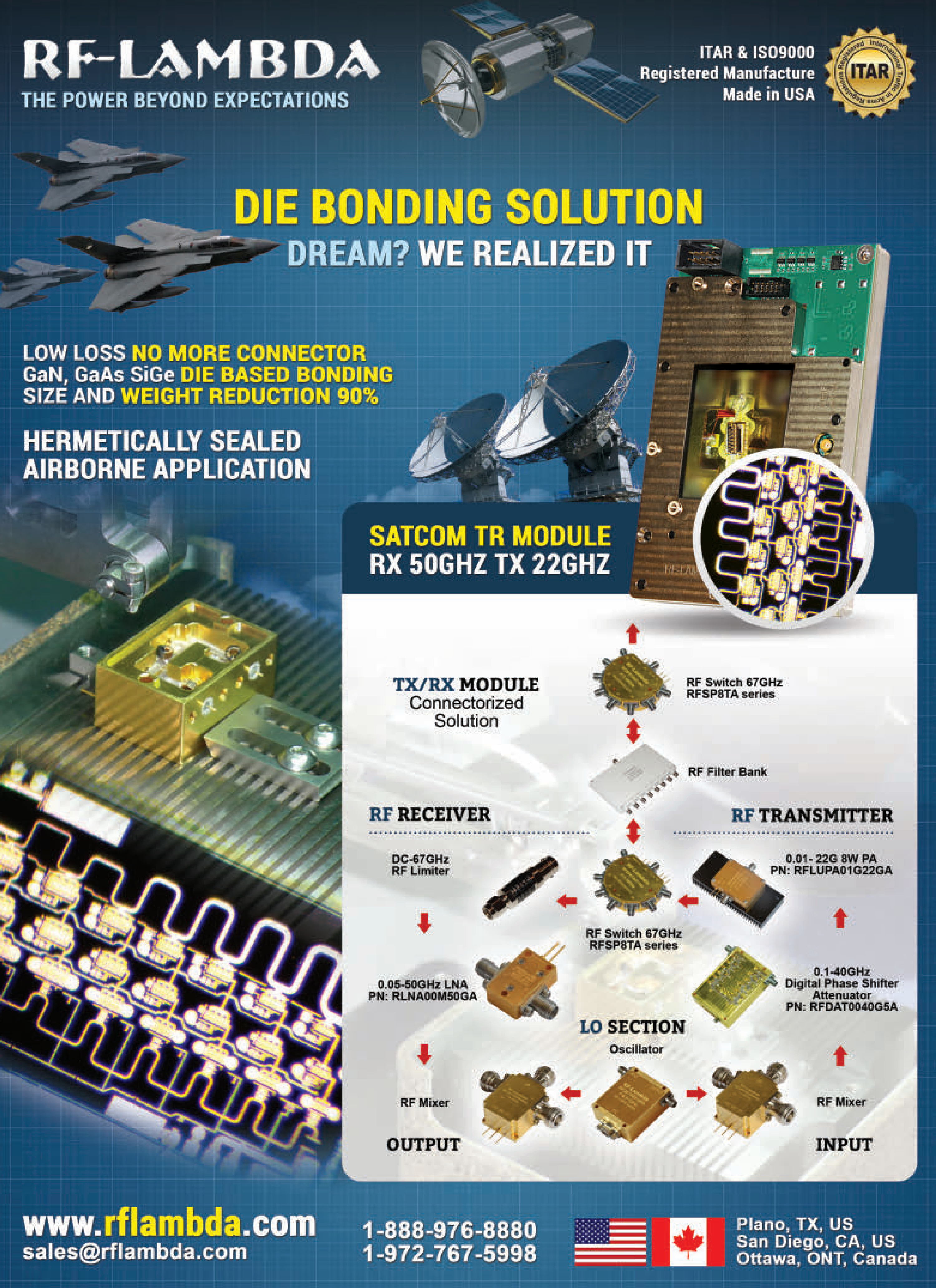

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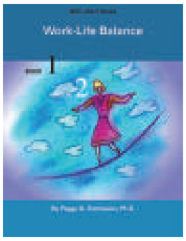

Work-Life Balance

Peggy Hutcheson, Ph.D.

Reviewed by: Gary Lerude

The ideal of work-life balance has been a conundrum and tension throughout my career. Naïve dream or achievable goal? Wikipedia says the term was first used in the U.K. in the late 1970s and appeared in the U.S. in 1986. Although work-life balance has been widely discussed, corporate endorsement and adoption have been slow. Work as life's top priority, reflected by long hours, seems the norm at many companies, particularly in the tech sector. Birthing a new technology is fraught with schedule slips and budget overruns. Adding Andy Grove's well-known paranoia that the competition will reach the goal line first, it's not surprising that company culture belies the framed value statements on the walls of the conference rooms.

Thirty years after the term first appeared in the U.S., work-life balance clearly remains an issue, perhaps more so because of communications technology that keeps us constantly connected. Perhaps this motivated the IEEE to address the topic by publishing two small volumes: "Work-Life Balance," Books 1 and 2. The two "books" – perhaps they should be called white papers, as they are under 20 pages each and can be read in a single sitting – address those of us who are seeking balance, rather than advocating that corporations change their cultures.

Like all self-help books, if these are to have an impact, it will be from the reflection and actions that follow the reading. After providing a working definition of work-life balance ("the state of control, achievement, and satisfaction in your life"), author Peggy Hutcheson writes that the "right" balance is personal, unique to each of us and one that changes over the course of a career. Our sense of balance ebbs and flows from week to week, reflecting the dynamic demands of our work and personal responsibilities. Reaching a sense of balance requires that we discern what's important to us, then have the courage to follow that path.

To assist with that discernment, Hutcheson poses 10 questions that explore various psychological dimensions, such as the tension you feel from the competing priorities that tug on you, your perception of the expectations of your colleagues and management, whether you feel you have the power to choose how you spend your time and how much energy it takes to manage the negative emotions that arise from feeling out of balance.

The second book tells how the fulcrum of work-life balance changes over the course of a career. A recent graduate beginning a career may be inspired by her work, the opportunity to convert theory to practice, to contribute to the industry, to prove herself. She doesn't mind the long hours. Approaching retirement, the seasoned veteran who has lived through multiple corporate initiatives, reorganizations and mergers, survived a few layoffs and accumulated hundreds of thousands of airline miles visiting customers may wish for a more measured pace, away from the organizational bureaucracy and paradox, yet still wanting to leave a legacy for the many years of service to the industry.

If you're looking for five simple steps to nirvana, you'll be disappointed. Hutcheson provides gentle guidance that can help you discern your priorities and identify the activities that give you the most satisfaction. Then it's up to you to focus on those and accept the trade-offs.

To order this book, contact:

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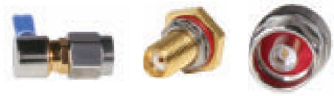

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Zentech Models Resurgence in US Manufacturing

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In a world that is flat, where so much manufacturing has moved offshore and is dominated by massive firms, why would anyone want to be a contract electronics manufacturer based in the U.S.? Zentech CEO Matt Turpin, shown above, smiles when asked the question. He sees the company's mission as more than "putting parts on boards," although doing that well is the foundation of Zentech's business. Since its start in 1998, the Baltimore firm has honed a competency manufacturing highly complex designs for high reliability applications, whether small lots or runs of 100,000. On that base, Zentech has built a suite of value-added services, including inventory purchasing and management, board design and layout, test system development, final assembly, failure analysis, quick-turn prototyping and RF manufacturing and test.

To ensure the highest quality, Zentech invests in advanced surface-mount technology and process capability and employs best manufacturing practices. This includes automated optical inspection of solder paste components and completed assemblies, 3D X-ray technology and lean manufacturing. Their many certifications testify to this philosophy of ongoing improvement: ISO 9001:2008, AS9100:2009, ISO 13485:2003, JCP DD2345, IPC Class 3 Trusted Source QML certified, IPC J-STD 001 Space certified and ITAR registration. The company's name even reflects this commitment: Zentech is an amalgam of "tech" for technology and "zen" from the Japanese word Kaizen, meaning improvement.

Almost half of Zentech's business comes from defense and aerospace customers. These are familiar names: ARDEC (the U.S. Army's Armament Research Development Engineering Center) , L3 Communications, NAVSEA (Naval Sea Systems Command), Northrop Grumman and Raytheon. From a start in C5ISR (Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance), Zentech has expanded to serving radar and electronic warfare. Its assemblies fly on the F-16, F-22 and F-35, and the company is one of only two contract electronics manufacturer certified by the IPC Validation Service for space assemblies. The remainder of Zentech's business comes from medical, communications and industrial controls applications, where performance and reliability are demanded.

While the global electronics manufacturing services market is growing between 5 and 6 percent annually, Zentech will grow 30 percent this year, doubling the number of customers they serve. The growing customer base reflects the truism that new customers tend to become long-term customers when they experience how easy it is to do business with Zentech. To accelerate their growth, earlier this year Zentech acquired Colonial Assembly & Design (CA&D). CA&D brings a 30-year heritage as a prime contractor for electronics systems design and manufacturing, serving the Department of Defense and both military and commercial aviation. They strengthen Zentech's capabilities in engineering, product design, circuit design, machining, cable assembly and wire harnessing.

So why does Matt Turpin believe so strongly in Zentech, in a world that is flat and with such tough competition? He says, "The world has always been changing. The economic landscape has changed with it, as the world becomes increasingly 'flat' and those with competitive advantage emerge and become noticed. But, increasingly, businesses are finding that competitive advantage doesn't necessarily mean least expensive. Apple doesn't have the cheapest phones, Tesla doesn't have the cheapest cars and Zappos doesn't have the cheapest shoes – yet all of them continue to win and compete. Zentech loves to compete by ensuring that organizations are successful in bringing their products to market quickly, reliably, competitively and focused on lowest total cost. We are proud of the fact that thousands of people continue to have jobs because of our ability to help make their companies successful."

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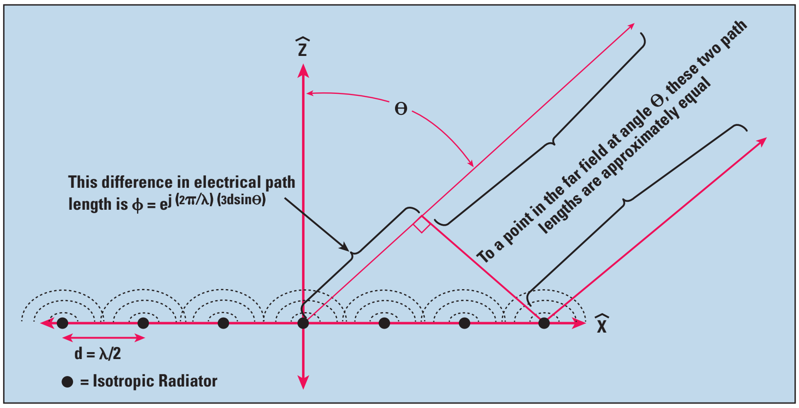
COVER FEATURE
INVITED PAPER

Highly Integrated Silicon ASICs: a Disruptive Technology for AESAs

Ian Gresham, Rob McMorrow, David Corman and Nitin Jain
Anokiwave Inc., San Diego, Calif.

Active electronically scanned array (AESA) antennas have been employed for military phased array radar systems for over five decades. Their popularity has dramatically increased recently as advances in technology enable compact, low cost arrays for commercial applications.[1] As they are adopted for markets as disparate as weather radar, sense-and-avoid radar for commercial and private drones, global ground-satellite communication for Internet access as well as 5G infrastructure, they are poised to become even more prevalent.[2] Indeed, the use of phased array techniques to provide advanced antenna aperture capabilities is seen as fundamental to the rollout of 5G infrastructure.[3,4]

One of the driving technologies for this path to growing adoption is the increasing use of silicon-based (Si) technologies (SiGe BiCMOS and RF CMOS) to provide increased functional density and capability within a single die/package.[5] This article reviews some of the technical challenges of building high density planar phased arrays and suggests that solutions to these problems can be found by greatly increasing the level of integration in the IC solutions, thus enabling large-scale planar AESA arrays. By taking advantage of the integration capability of silicon, additional system level functionality such as on-chip diagnostics, built-in self-test (BIST) and built-in calibration (BICAL) can be utilized to give the end user far more visibility and control over the operation of the array. Examples of the performance features that can be embedded into highly integrated application specific integrated circuits (ASIC) used in silicon-based AESA arrays will be discussed.

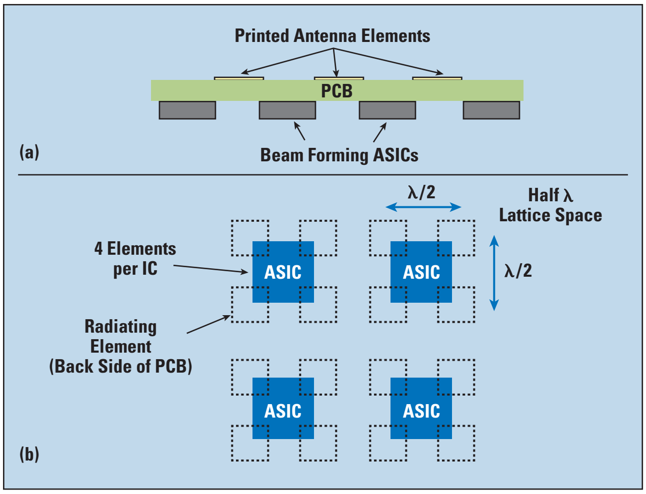


▲ *Fig. 1 Simplified one-dimensional planar array antenna consisting of a row of isotropic radiators. The far field antenna pattern is a composite of the excitations at each element.*

Figure 1 shows a simplified one-dimensional illustration of a phased array antenna, consisting of a row of isotropic radiators. The composite response of the antenna pattern in the far-field is a function of the amplitude and phase excitation at each element. Simplistically, the careful control of each amplitude and phase response determines the magnitude and scan angle of a single- or multi-beam antenna pattern. One of the constraints for a wide scan angle antenna pattern is the restriction that each of the antenna elements is spaced by no more than a free space half wavelength ($\lambda 0$) to

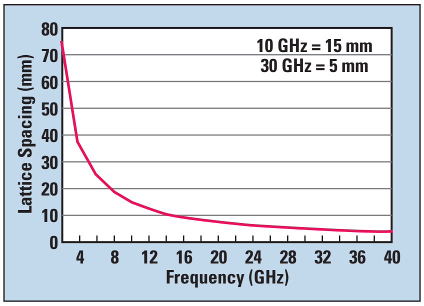
avoid the generation of grating lobes, where waves from each element are summed in phase producing beams in undesired directions.[6,7] Beamforming can be performed in either the analog or the digital domain (or both) with trade-offs in system performance for complexity, linearity and power dissipation.

Planar phased array antenna solutions are attractive in providing a compact, and potentially low-profile form, thus enabling their use in a broader range of applications.[2] The primary enabler for a planar-form solution is for the analog beamforming circuitry – transmit (Tx), receive (Rx) or transceiver (Xcvr) – to fit physically between the elements of the antenna lattice. ***Figure 2*** shows an illustration of how this may be realized, where the beamforming ASICs are surface mounted to a PCB with the antenna radiating surface on the opposite side. Note that in this highly idealized drawing, signal routing and heat sinks for thermal power management are not shown.



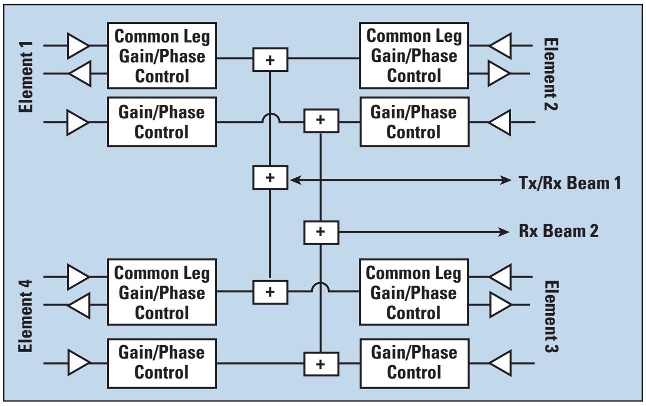
▲ *Fig. 2 Side (a) and plan (b) views, showing beam forming ASICs mounted on the backside of the planar antenna array.*

So far, so good. But the challenge of this approach can be appreciated by considering how the available physical dimensions rapidly shrink as a function of frequency. To a first order, the lattice spacing between antenna elements is constrained to a half wavelength to avoid the presence of grating lobes, which is plotted in ***Figure 3*** as a function of the operating frequency. (In reality, the maximum spacing is also a function of the maximum required scan angle). The physical constraints governing the available area for component integration falls dramatically from 37.5 mm at 4 GHz (S-Band) to 15 mm at 10 GHz (X-Band) and only 5 mm at 30 GHz (Ka-Band).



▲ *Fig. 3 Half wavelength lattice spacing vs. frequency.*

Unfortunately, discrete based solutions in commercially available surface mount device (SMD) packages can easily exceed these limitations, as their combined area and allowance for interconnects and support componentry occupy a large footprint. At X-Band and above, increased integration becomes the only way to make such a planar system a viable option. Solutions have become available in recent years that integrate single element beam formers with Tx/Rx functionality in a single package.[8] GaAs technologies that are commonly used for these functions due to their high electron mobility and associated performance metrics are expensive and limited in their integration capability. By comparison, high performance SiGe BiCMOS and RF CMOS have demonstrated the required performance at microwave and millimeter wave frequencies in multiple applications.[5] In addition, their ability to integrate dense functionality results in the potential for combining product solutions that can support multiple radiating elements within a single package. ***Figure 4*** is a functional block diagram of a single component that simultaneously supports dual polarization and four radiating elements.

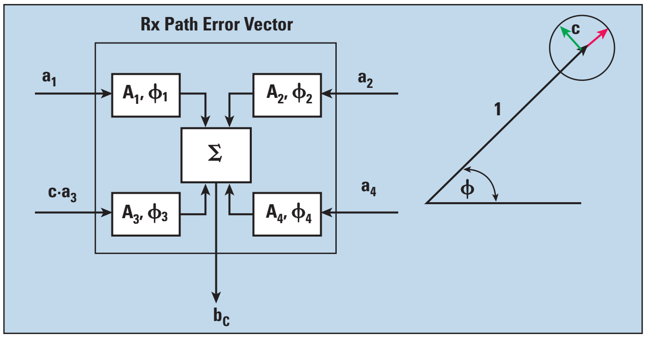


▲ *Fig. 4 Functional block diagram of the integrated TDD T/R chip.*

HIGHLY INTEGRATED SOLUTION

This section reviews an example of how a highly integrated TDD (time-domain duplex) transmit-receive chip supporting four discrete antenna elements may be configured to meet the objective requirements of cost, size and functionality. It is packaged within a standard commercial QFN-style plastic package measuring 7 × 7 × 0.9 mm, and easily fits within the 15 mm lattice spacing at 10 GHz for X-Band applications. The IC consists of four distinct quadrants that can each be operated and controlled discretely, with the ability to simultaneously drive four antenna elements in transmit mode. In addition, there are eight independent receive ports – two per quadrant – that allow for dual polarization on each antenna element when operating in receive mode. Transmit and receive waveforms can be weighted independently with 12-bit complex vector modulators consisting of 6-bit phase control, where the least significant bit (LSB) is 5.625 degrees, and 6-bit amplitude control, providing 31.5 dB dynamic range and LSB of 0.5 dB.

Figure 4 shows this partitioning in more detail. Each quadrant consists of a Tx/Rx arm sharing a common path vector modulator (complex amplitude and phase) as well as a second receive-only arm which shadows the Tx/Rx function. Central to the quadrant based operation is a chip-core where the modulated received signals are coherently combined and feed a common RF port. The TDD based operation of the die allows the combiner network of the Tx/Rx arm to be used for coherent power splitting when operating in the transmit mode. Over 31 dB of dynamic range is therefore available in each discrete antenna element path through varying the discrete vector modulators. This dynamic range can be used for array taper or other gain control functions. The settings of each of the vector modulators, as well as the other functions on the chip, are controlled using a serial peripheral interface (SPI) for data transfer and control signal management.



▲ *Fig. 5 Unwanted signal coupling degrades modulated waveform accuracy, inducing AM-AM and AM-PM errors.*

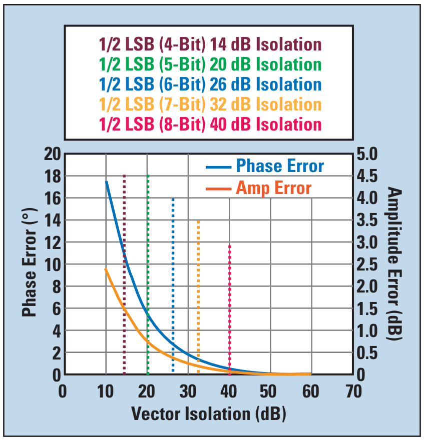
Temperature compensation of the entire chip can be enabled through additional digital variable attenuators (DVA), allied with active gain stages in each of the common combiner ports to extend the controllable dynamic range of the IC to over 50 dB. This can be used in conjunction with an on-chip temperature sensor to account for temperature changes within the IC and also compensate other temperature sensitive components elsewhere in the system. Real-time, closed loop temperature compensation can be implemented by reading data from the IC temperature sensor, updating the appropriate settings and using available data for external components. Maximum system flexibility results from the gain control partitioning provided by the chip.

PHASE AND AMPLITUDE ACCURACY

Although an increase in the number of antenna elements that can be supported by a single component, by utilizing the benefits of the functional integration density of Si, has several advantages (i.e., reduced bill-of-materials, reduced inventory, smaller PCB integration form-factor), it is not an approach that can be followed with impunity. Other functional and performance considerations include the ease of routing low-loss and controlled impedance transitions between the various RF ports and the antenna elements, thermal dissipation paths, the number of external components, signal and supply path constraints and unwanted signal coupling.

Figure 5 shows how signal coupling and appropriate isolation between signal paths needs to be considered and the potential limitations they may impose on system performance. In this example, four discrete Rx paths – a_1, a_2, a_3, and a_4 – are input to a common beamformer IC and coherently combined with a summed output signal of bc. Ideally, each of the four signal paths would remain isolated up to the input of the summing network, and the complex beam weight (Ai, ϕi) applied to each signal would have zero associated amplitude and phase error. In reality, non-idealities in each of the vector modulators and other components in each signal path will impose some level of AM-AM, PM-AM and AM-PM distortion, resulting in an associated error in the signal vector. In theory, any of these corrupting influences are well known and modeled during the design phase; as long as they are maintained below the magnitude of ½ LSB, they should not degrade performance.

More difficult to deal with is coupling between signal paths that may be less predictable, arising from several sources including signal transmission lines between the antenna elements and the component RF ports, signal coupling within the package through the unwanted radiation of bondwire transitions, dielectric material loading of the package over-mold and parasitic and leakage path coupling through other on-chip networks that are more difficult to account for at high frequencies.[9] These may include such disparate paths as bias distribution networks, pad-rings and ESD domain coupling. Regardless of the source, the effect illustrated in Figure 5 produces the same result: distortion of the desired vector by a parasitic phasor that causes amplitude or phase distortion or both. In the simplest case, maximum amplitude error occurs when the coupled phasor is in phase with or exactly out of phase with the desired vector. Here, the magnitude of the error vector is



▲ *Fig. 6 Phase and amplitude error vs. coupled path isolation.*

$$\Delta A_{error}(dB) = 20\log_{10}(1 \pm |c|) \quad (1)$$

Similarly, the maximum phase error occurs when the coupled phasor is orthogonal to the phase of the desired vector, resulting in a maximum phase error of

$$\Delta\varphi_{error}(deg) = \tan^{-1}|c| \quad (2)$$

The magnitude of the total amplitude and phase error of the desired vector needs to be maintained below ½ LSB, leading to a relationship between the number of available bits of amplitude and phase resolution and the allowable level of coupling between signal paths. ***Figure 6*** shows how this relationship varies for several combinations of vector modulator resolution. For example, to maintain the required accuracy for 6-bit amplitude and phase control, the magnitude of the worst case error vector needs to be less than 26 dB when normalized to a vector magnitude of 1. This figure, though, does not account for the effect of channel gain on the magnitude of the coupled signal. ***Figure 7*** shows how the level of coherent gain imposes more stringent requirements on the allowable coupling and drives increased channel-channel isolation. As the desired channel gain increases, the required coupling must decrease

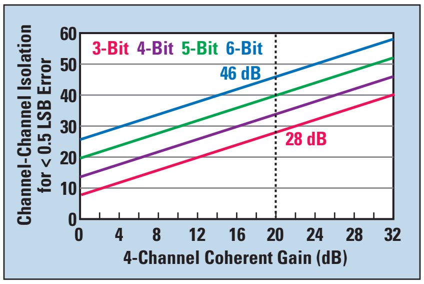


Fig. 7 Required minimum channel-channel isolation increases with coherent gain.

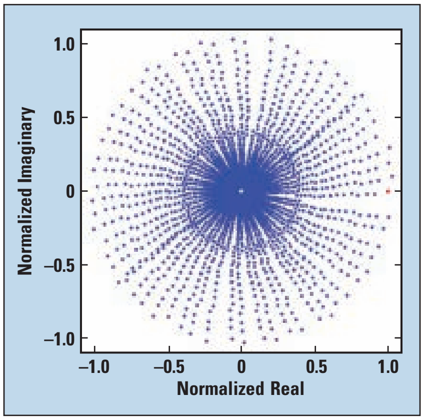


Fig. 10 Measured 12-bit vector modulator (6-bit amplitude and 6-bit phase) state map at 9.4 GHz.

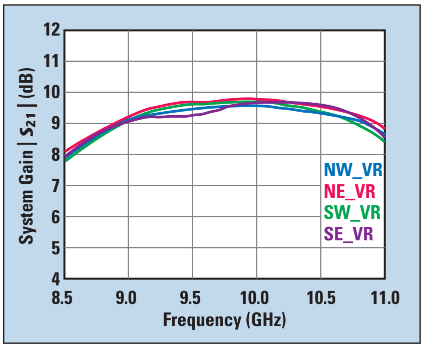


Fig. 8 Measured coherent receiver gain, showing < 1 dB imbalance across four channels.

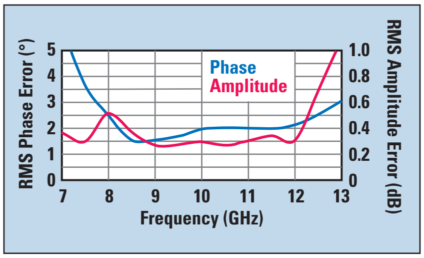


Fig. 11 Measured RMS amplitude and phase error across X-Band.

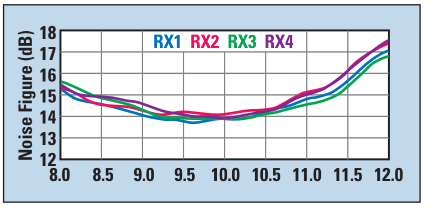


Fig. 9 Measured receiver noise figure. The four channels are assumed to be driven by non-coherent noise sources.

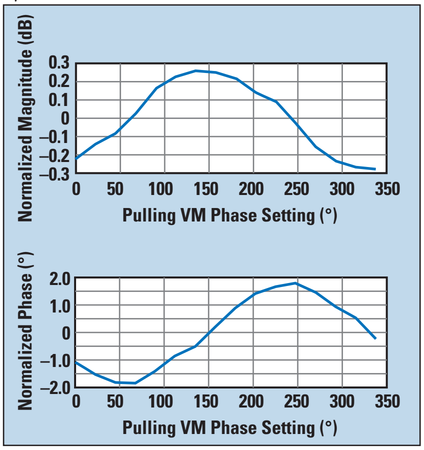


Fig. 12 Signal magnitude and phase error from unwanted signal coupling to adjacent ports.

dB for dB to keep the same ½ LSB error. For example, if the channel gain is 20 dB and the vector modulator provides 6-bit complex modulation, the absolute isolation required becomes 26 dB + 20 dB or 46 dB.

ACTUAL PERFORMANCE METRICS

This section presents measured data for a commercially available 4-element beam former IC, to indicate the available performance for a highly integrated, multi-element solution. ***Figure 8*** shows the measured coherent receiver gain, which is defined as the combined (superimposed) signal gain between each of the four receiver ports and the output of the coherent combiner. The vector modulator for each signal path is set to a common complex beam weight for this measurement, resulting in a coherent gain that is approximately 7 dB across the band. The amplitude imbalance between the ports is < 1 dB, including mismatch. Noise figure (NF) versus frequency is shown in ***Figure 9***. This has been adjusted to reflect the NF seen when each port is driven from non-coherent noise sources. The NF at the center of the band is 14 dB. If only a single channel were measured, the resulting NF would be 4.1 dB higher. The input 1 dB compression point for the receiver is approximately -2 dBm at the center of the band. This is measured on a single channel.

The performance of the vector modulator is shown in ***Figure 10***. All 12 bits of amplitude and phase states (4,096 states) were measured and graphed on a polar plot. The concentric circles and linear spokes of the figure are indicative of the low PM-AM and AM-PM distortion of the vector modulator. ***Figure 11*** shows the explicit RMS phase and amplitude error across the band. The amplitude error is less than 0.5 dB, while the phase error is less than 3 degrees, or about 2/3 LSB. The channel-channel isolation can be inferred from a combination of measured S-parameters and beam rotation. A signal coupled to the common output port and superimposed upon the desired signal vector will cause AM-AM and AM-PM errors in the signal vector, as previously described. By measuring the signal path from any Rx input to the common output beam former port and adjusting the beam weight settings of the non-signal path vector modulators, the magnitude of the signal coupling into the main signal path can be estimated, as shown figuratively in Figure 5. The measured error in the phase response is approximately ±1.5 degrees as shown in ***Figure 12***, corresponding to a port-port isolation of approximately -38 dB, accounting for the coherent receiver gain.

ADVANCED FEATURES WITH INTEGRATION

The core technology enabler of dense functional integration is the ability to integrate multiple controllable circuit blocks within a single die using Si-based processes and control the operation using the SPI ports. It is then only a small additional step to use the access to the die provided by the SPI to embed supplementary functions and controls that can be controlled digitally by the customer to increase operational flexibility. In this example, a proprietary 5-wire, 50 MHz SPI has been used. This has been designed to minimize coupling between digital and RF signals. With the proprietary SPI bus, multiple ICs in a row or column or any other subset of an array can be daisy chained and driven by a single bus and latched in tandem.

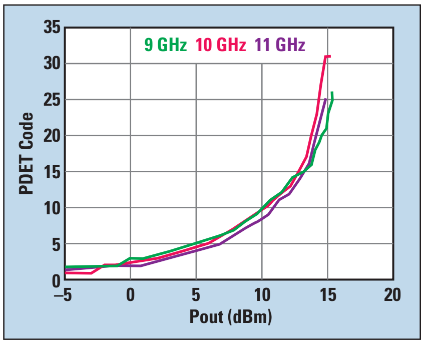
In addition to the ability to write vectors to multiple registers, the SPI also allows read-back from functional blocks on the IC. This capability gives the array system integrator insight into real-time operation through the addition of on-chip telemetry. Each transmit arm includes an on-chip

power detector that samples the output signal with 5-bit resolution and provides the power measurement as a digital word to the SPI. In addition, the time at which the transmit power is measured can be determined by the user. This accommodates radar systems with varying pulse widths and also provides information on transmit pulse droop, if the measurement interval is varied pulse to pulse. ***Figure 13*** shows the detector output vs. power level and frequency. Similarly, on-chip temperature sensing provides real-time information and insight into the reliability of the IC.

Separate pins are provided to enable either transmit or receive mode, providing the flexibility to select the desired set-up time between activating transmit or receive DC power and when the RF waveform is applied. To minimize power dissipation, all transmit functions are powered down when the IC is in receive mode and vice-versa during transmit. The DC power consumption is 1.8 W in transmit, 1.7 W in receive if both receive beams (4-elements, dual polarization) are active and 1.3 W in receive if only one receive beam (4-elements, single polarization) is active. The chip is biased with a 1.8 V supply.

Another feature is the ability to set the chip in a calibration mode, where only one quadrant at a time is enabled. Separate pins are provided to communicate with an external front-end chip so that a complete channel-by-channel calibration can be performed. A further programming feature is the delay time between data latch and beam weight adjustment. The simultaneous change to all of the transmitters in a large array can create spurious lobes and system level problems. Dithering the time between latch and change for each IC can avoid this.

Lastly, programming the vector modulator for a single IC only takes 4.5 µs at 50 MHz. If a large number of ICs are daisy-chained for row-column addressing operations, the entire process can take substantially longer. One solution to this is to allow fast beam steering (FBS) by incorporating a programmable register stack with each vector modulator that can be pre-programmed with 12 bits of phase and amplitude information. Each vector modulator has a stack of eight registers that can be pre-loaded



▲ *Fig. 13 Transmit path output power code vs. input power at 9, 10 and 11 GHz.*

using the SPI bus and then directly addressed via a 3-bit direct addressing parallel interface, eliminating the wait for a serial load via the SPI bus. This means that the beams can be switched in as fast as 50 ns. These two modes, programming on the fly and fast beam steering, provide flexibility for any radar application.

CONCLUSION

Planar AESAs require increased compaction of circuit functionality to maintain the required form factors at high frequencies. This is driven by the minimum lattice spacing requirements of antenna elements, to avoid the introduction of grating lobes in the radiation patterns of the antenna. One of the consequences of increased functional density is reducing the number of required components and reducing the cost for the entire bill-of-materials. A proven method for achieving this compaction is realizing the circuitry in a highly integrated Si IC. Additional benefits of this technology are the ability to integrate control and tuning elements to trim the optimal performance of the IC, using a serial interface, and providing telemetry for system monitoring, such as temperature and output power. Reducing the physical dimensions requires careful design to avoid limiting the accuracy of the available beam weight resolution through unwanted signal coupling paths; however, this has been shown to be possible. Other performance metrics possible with a 12-port IC supporting dual-polarization Tx/Rx receive functionality for a 4-element antenna solution have also been presented. ■

ACKNOWLEDGMENT

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INVITED PAPER

Flexible Testbed for 5G Waveform Generation and Analysis

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While LTE and LTE-Advanced are still being deployed, research into next generation wireless networks is already in high gear. That next generation – 5G – will likely comprise a dense, highly integrated network of small cells supporting peak data rates of up to 10 Gbps and 1 ms or less roundtrip latencies, while utilizing a number of different air interfaces at both microwave and millimeter wave frequencies. The combined network may be able to support everything from simple machine-to-machine (M2M) devices to immersive virtual reality streaming. While that bodes well for an end user experience, it presents some interesting challenges for those engineers developing 5G systems.

Making the leap from prediction to practical implementation starts with the creation, generation and analysis of prototype signals. As there is no 5G standard at this time, no physical layer waveforms have yet been defined. Although there is a lack of consensus on 5G waveforms, filter bank multi-carrier (FBMC), universal filtered multi-carrier (UFMC) and orthogonal frequency-division multiplexing (OFDM) waveforms are being considered. Other potential candidates include waveforms at sub-6 GHz frequencies and those at microwave and millimeter wave (mmWave), which may involve wide bandwidths of up to 2 GHz. The number and variety of waveforms, frequencies and bandwidths being researched introduce new test challenges for 5G signal generation and analysis.

Key to overcoming these challenges is flexibility during 5G research and early testing. Engineers must have the ability to perform "what-if" analyses while they are evaluating early concepts and new candidate 5G waveforms. Without this ability, the risk of choosing the wrong path and not discovering issues until much later in the development cycle – when it is much more costly and time consuming to change – can increase. Flexibility, especially with signal creation and signal analysis tools, can be especially important, as they enable rapid changes in direction as strong 5G waveform candidates emerge. Engineers also need the flexibility to use a wide range of modulation bandwidths (from several megahertz to a few gigahertz) and frequency bands (from RF to microwave to mmWave).

To address these challenges, engineers would ideally like to combine off-the-shelf hardware and software to create a flexible 5G waveform generation and analysis test platform, such as Keysight's 5G waveform generation and analysis testbed reference solution (see ***Figure 1***). The testbed reference solution provides flexibility through its software and hardware elements. In the software, flexibility ensures that engineers can generate and analyze various types of 5G candidate and custom waveforms. With the hardware, both flexibility and scalability work together to give engineers the ability to generate and analyze signals from RF to mmWave frequencies with up to 2 GHz bandwidth.

To generate wideband test signals with up to 2 GHz of modulation bandwidth at frequencies up to 44 GHz, the solution employs a precision arbitrary waveform generator (ARB) and vector signal generator, with wideband I/Q inputs, running signal creation software. Higher frequencies can be achieved through the use of an up-converter. This combination of hardware and software enables 5G candidate waveforms such as custom FBMC, OFDM and single-carrier to be generated. Integration of system-level design software with hardware further enables custom or proprietary algorithms and "what-if" scenarios to be evaluated, such as the coexistence of an LTE signal in the presence of an FBMC signal.

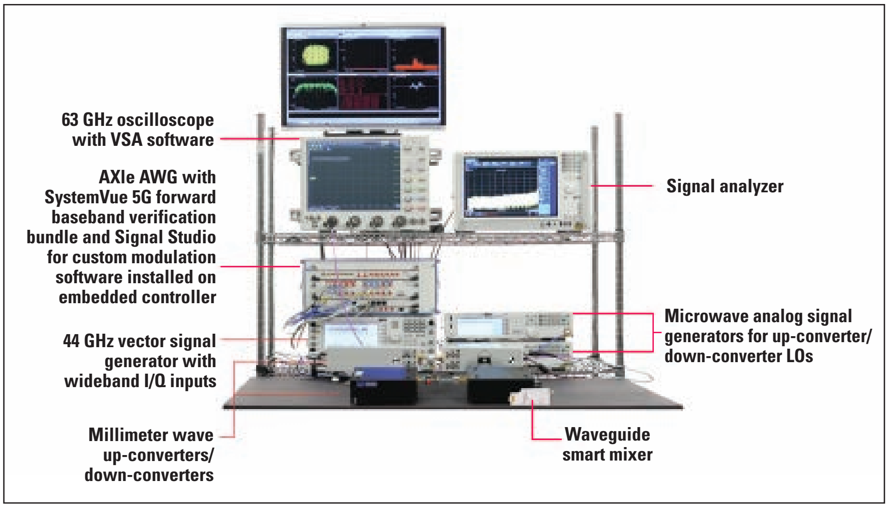
The testbed reference solution can also be used to demodulate and analyze test signals. In this case, 89600 VSA software is typically employed with the simulation software or on a number of different hardware options, including a signal analyzer, oscilloscope or PC that controls a variety of instruments or digitizers.

To illustrate the viability of this type of testbed reference solution, two test cases will be examined: a ~1 GHz wide custom OFDM signal at 28 GHz and a 2 GHz single-carrier signal at 73 GHz.

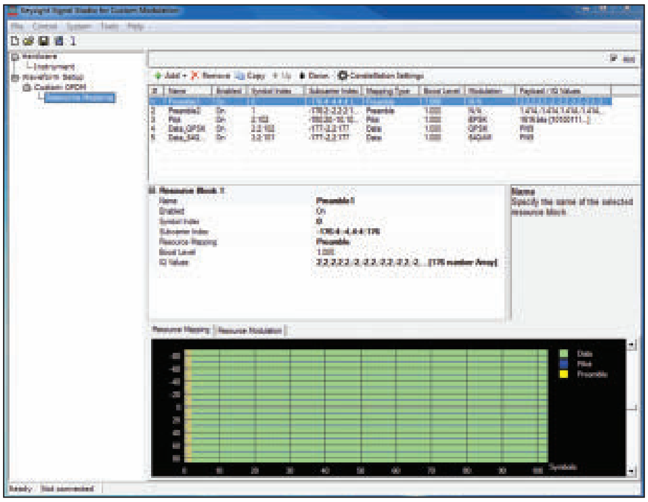
28 GHz WIDEBAND OFDM SIGNAL

For this case, the testbed reference solution combines a precision AWG with a vector signal generator with wideband I/Q inputs to produce wideband microwave test signals up to 44 GHz. Signal creation software enables the custom OFDM waveform to be created with approximately 1 GHz modulation bandwidth at 28 GHz (see ***Figure 2***). Resource-mapping parameters were set for the preamble, pilot and data subcarriers, including the location and boosting of each resource block. I/Q values were set for the preamble, modulation and payload for pilot and data. The waveform is generated, then read into the AWG and played out using the AWG's front panel software. The I/Q outputs of the AWG are fed into the wideband I/Q inputs on the vector PSG, and the PSG modulates the I/Q waveforms on a 28 GHz carrier. The test signal from the PSG RF output is analyzed using a 63 GHz high-performance oscilloscope with 89600 VSA software.

The resulting test signal measurement with the 89600 VSA software (see ***Figure 3***) comprises a six-trace display that shows (clockwise from upper left) the constellation, error vector magnitude (EVM) versus subcarrier, search time, OFDM equalizer channel frequency response, error summary and the ~1 GHz spectrum at the 28 GHz center frequency.



▲ *Fig. 1 Flexible 5G waveform generation and analysis testbed.*



▲ *Fig. 2 Signal creation software for creating custom, wide bandwidth OFDM signals.*

▲ *Fig. 3 Custom OFDM signal with ~1 GHz bandwidth at 28 GHz.*

SINGLE CARRIER SIGNAL AT 73 GHz

For this case, the testbed reference solution configuration is extended to 73 GHz using a mmWave up-converter for signal generation and either a mmWave down-converter or waveguide smart mixer for signal analysis. The configuration shown in ***Figure 4*** uses a microwave signal generator to provide the LO for the mmWave up-converter. A mmWave amplifier and filter at the up-converter output may be added to boost power and filter the spectrum. A waveguide smart mixer is used for signal analysis from 60 to 90 GHz, combined with a signal analyzer and oscilloscope. The waveguide smart mixer is connected to the output of the mmWave up-converter, and the IF output is fed into the signal analyzer for spectrum analysis. The auxiliary IF output is fed into the oscilloscope for wide bandwidth demodulation analysis with the VSA software.

At these frequencies and bandwidths, linear amplitude and phase er-

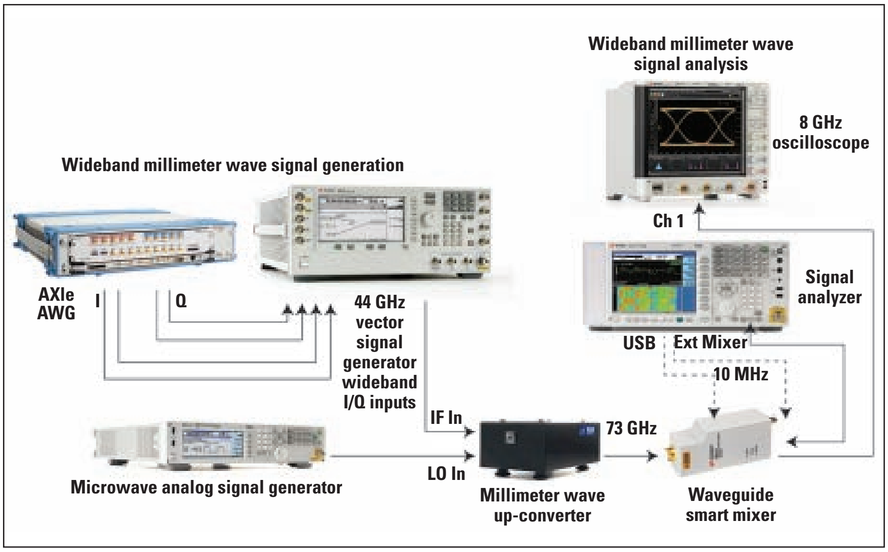


Fig. 4 Example hardware setup for waveform generation and analysis at 73 GHz (mmWave amplifier and filter not shown).

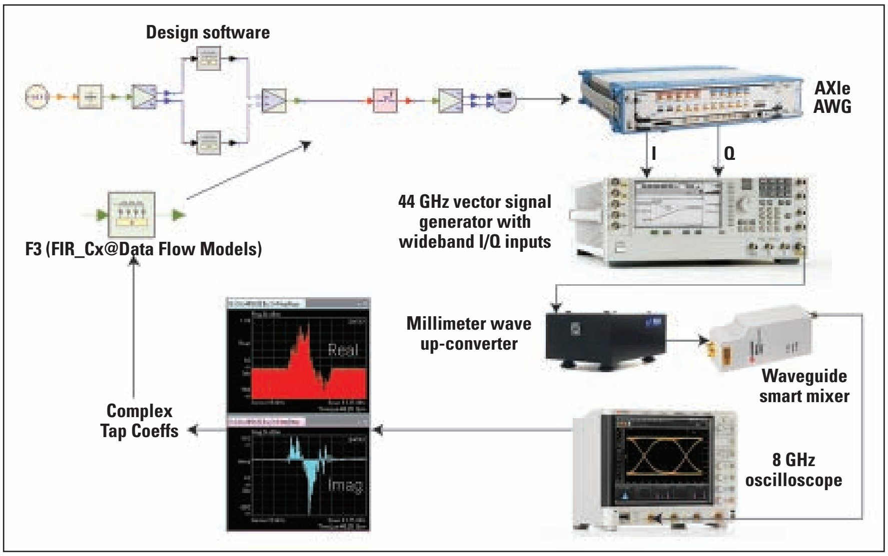


Fig. 5 Integrating design software and test equipment to correct for linear amplitude and phase errors in the test signal (mmWave amplifier and filter not shown).

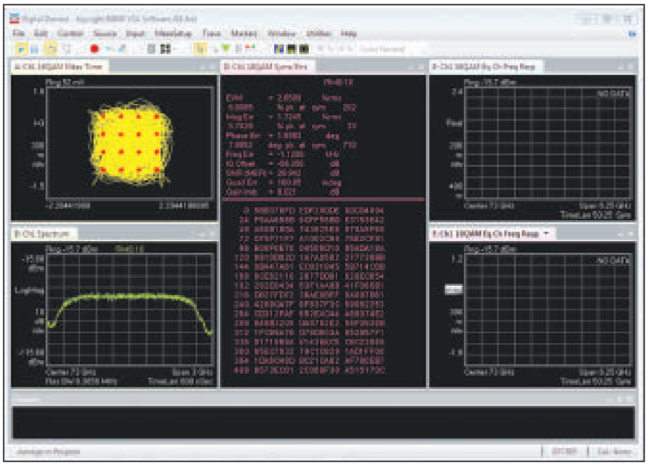


Fig. 6 Demodulating a 73 GHz waveform with 2 GHz of modulation bandwidth. Constellation maximum used as the EVM normalization reference.

rors may be caused within the signal chain by the AWG, vector signal generator, up-converter, waveguide smart mixer, cables/interconnects and signal analyzer. These were reduced by deriving the necessary vector corrections using the adaptive equalizer in the VSA software. The equalizer produces a complex-valued frequency response that can be used to minimize amplitude and phase errors. This is done by reading the frequency response into the system-level design software used to generate the wideband waveform, and then using it to pre-correct the waveform response (see ***Figure 5***).

Figure 6 shows the demodulation analysis of the vector-corrected waveform at 73 GHz, with 2 GHz modulation bandwidth. Demodulating a 2 GHz wideband signal is typically quite difficult without adaptive equalization, due to hardware impairments across the wide bandwidth. However, in this example the linear amplitude and phase errors were corrected in simulation to generate a waveform that produced a low EVM without adaptive equalization.

CONCLUSION

The development of 5G includes an aggressive set of characteristics that will be difficult to achieve. A high degree of flexibility is needed to help researchers and engineers address these challenges and quickly respond to changes in direction as 5G evolves.

Test systems such as the 5G waveform generation and analysis reference solution combine hardware and software to create a flexible 5G waveform generation and analysis platform. This enables engineers and researchers to generate and analyze emerging 5G candidate waveforms. The software elements for the testbed provide flexibility in the types of 5G candidate waveforms being generated and analyzed. The hardware elements for the testbed provide flexibility and scalability from RF to microwave to mmWave and modulation bandwidths up to 2 GHz. ■

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INVITED PAPER

Expanding Mobile Capacity: The Evolution to LTE-U and LAA

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As mobile operators seek additional spectrum to handle the exponential growth in data traffic, the unlicensed 5 GHz bands offer additional spectrum to increase system capacity at literally no cost. Standards development to share the spectrum is well underway, known in the industry as LTE-U and LAA. This article explores the basic principles behind LTE-U and LAA, the approach to ensure coexistence and fair sharing, and implementation challenges.

Due to the ongoing transition from voice-centric mobile phones to smartphones and tablets – greatly accelerated by the launch of LTE networks beginning in 2009 – mobile broadband data consumption has increased exponentially over the past five years. Global mobile data traffic grew 69 percent in 2014 alone and reached 2.5 exabytes per month, up from 1.5 exabytes per month in 2013. Additional growth of 59 percent is forecast for 2015, reaching 4.2 exabytes per month. Video streaming is the dominant traffic type and accounted for more than 55 percent of all mobile data traffic in 2014. Such ongoing exponential growth represents quite a challenge for mobile network operators worldwide.

Service providers must efficiently use the spectrum available to them to deliver an excellent user experience while offering high data rates on an average basis to every subscriber. LTE is the technology of choice; however, spectrum is not an infinite resource. Over recent years, service providers have invested billions of dollars on a global scale to increase their spectrum holdings and, thus, their system capacity. However, only a limited amount of frequencies are available that local regulators can auction off to service providers, leading to tough competition as well as bidding wars in extreme cases to acquire additional licenses.

Due to this shortage, alternatives are required. One very promising alternative is to take advantage of unlicensed spectrum, such as the industrial, scientific and medical (ISM) frequency bands – especially the underutilized 5 GHz frequency band. Opportunistic usage of the spectrum, while deploying LTE component carriers in this frequency band, allows network operators to increase their system capacity while adding additional spectrum

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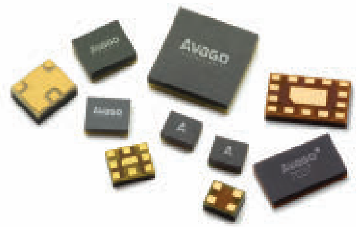

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resources at literally no cost. This alternative is known across the industry as LTE in unlicensed spectrum, or LTE-U. This approach has gained significant momentum, especially in the United States.

Accordingly, the 3GPP, the standardization body behind LTE, took up the challenge of enhancing the technology while adding the required functionality to support LTE-U. The feature is currently being standardized as licensed assisted access (LAA) using LTE. It will be added with Release 13, which should be finalized in March 2016. Of course, there is no free lunch, and everything has its price. Coexistence and fair sharing of the spectrum resource among LTE-U operators and, more importantly, with existing technologies such as Wi-Fi are important prerequisites to the success of LTE-U/LAA.

5 GHz SPECTRUM REGULATION

The 5 GHz spectrum is regulated in a similar manner throughout the world, but additional rules do apply in the different regions. Frequency regulation from a global perspective is administered by the International Telecommunication Union (ITU) on a regional basis. There are three regions defined. ITU Region 1 is primarily Europe; ITU Region 2 is America, including the United States, Canada and Brazil, for example; and ITU Region 3 is Asia with China, Japan and South Korea. Countries belonging to any of these regions typically adhere to the overall concept for that region; however, there can be additional regulations in place locally that apply to certain parts of the spectrum. The regulatory aspects for the 5 GHz spectrum in the U.S. are considered in this article, since there is a very strong interest in LTE-U and LAA that is driven by local tier one operators.

Figure 1 shows the spectrum allocation in the U.S. The spectrum between 5150 and 5925 MHz is divided into four domains that are designated UNII-1 to UNII-4, where UNII stands for unlicensed national information infrastructure. For the four domains, different regulatory rules apply, for example, the allowed maximum conducted output power, the peak power spectral density (PSD) and out-of-band (OoB) emissions. ***Table 1*** shows the requirements set by the Federal Communications Commission (FCC), the regulatory authority in the U.S.[1]

As can be gathered from Table 1, UNII-2 devices need to support transmit power control (TPC) as well as dynamic frequency selection (DFS); (see Figure 1). In contrast, UNII-1

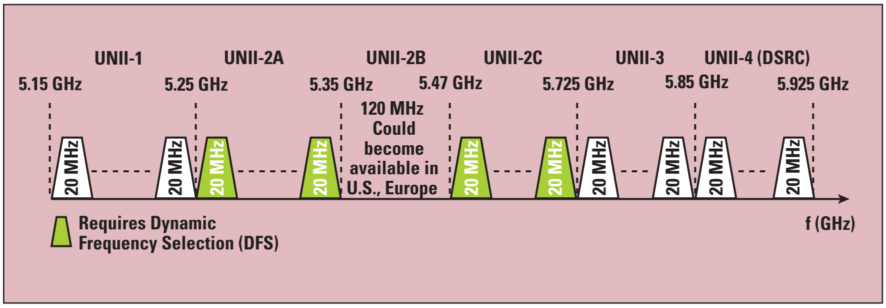


Fig. 1 5 GHz spectrum allocation.

TABLE 1

TRANSMIT POWER REQUIREMENTS FOR UNII DEVICES OPERATING IN THE U.S.[1]

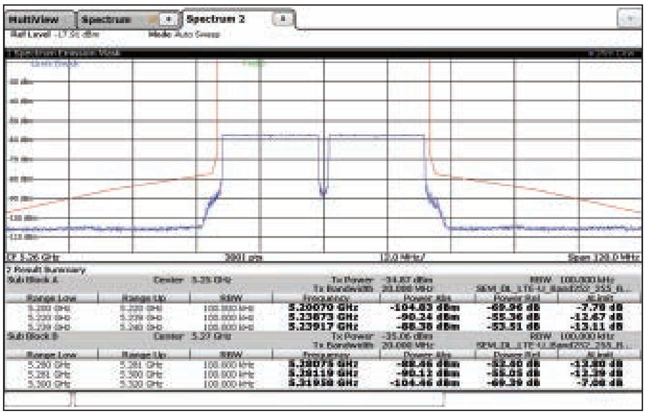
Frequency Band		UNII-1 5.15 – 5.25 GHz	UNII-2A 5.25 – 5.35 GHz	UNII-2C 5.47 – 5.725 GHz	UNII-3 5.725 – 5.85 GHz	Comments
Maximum Conducted Output Power (dBm) <min (a,b)	a	eNB: 30 UE: 24	24	24	30	
	b		11+10log(B)	11+10log(B)		B is the 26 dB emission bandwidth
Peak Power Spectral Density (dBm/MHz)		eNB: 17 UE: 11	11	11	30 dBm in 500 kHz	
Assumed Antenna Gain (dBi)		6	6	6	6	Peak power is reduced by G–6 dB for directional antennas with gain > 6 dBi
Out-of-Band (OoB) Emissions	Frequency Support (GHz)	Outside 5.15 – 5.35	Outside 5.15 – 5.35	Outside 5.47 – 5.725	Outside 5.715 – 5.865	
	EIRP (dBm/MHz)	-27	-27	-27	-27	Resolution bandwidth = 1 MHz
	Frequency Support (GHz)				5.715-5.725 5.85 – 5.86	
	EIRP (dBm/MHz)				-17	
Transmit Power Control (TPC)		N/A	TPC to 6 dB below a mean EIRP of 30 dBm. No TPC for mean EIRP < 27 dBm		N/A	

and UNII-3 do not require this additional mechanism to ensure coexistence with other systems, thereby making the lower and upper portion of the spectrum the first targeted frequencies that will be used by LTE-U and LAA. Consequently, two new frequency bands were defined by the 3GPP as Band 252 and Band 255, which correspond to UNII-1 and UNII-3, respectively. Note that the channel raster definition for these two bands follows the Wi-Fi channel assignment to avoid in-channel interference.

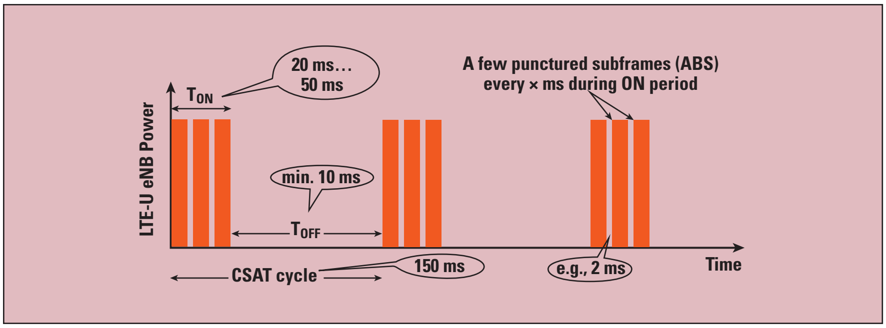
With the band definition, the 3GPP is acknowledging the initial work that has been done within an industry alliance, called the LTE-U Forum, which was forged to accelerate the time to market for LTE-U. The founding members of the LTE-U Forum were Verizon Wireless, Qualcomm, Ericsson, Alcatel-Lucent and Samsung. These key players in the wireless industry have agreed on coexistence aspects to allow fair sharing of the spectrum resource with other LTE-U operators and technologies such as Wi-Fi. Furthermore, they agreed on a set of specifications to define the minimum requirements for handsets and base stations supporting LTE-U.

For example, the minimum requirements for an eNB (LTE base station) are based on the 3GPP's technical specification (TS) 36.104. This document takes the limits and tolerances that are provided within TS 36.104 for RF measurements, such as adjacent channel leakage power ratio (ACLR) or spectrum emission mask (SEM), and adapts them for base stations that support LTE-U in terms of the regulatory aspects. ***Figure 2*** shows an adapted spectrum emission mask (SEM) measurement on an LTE-U capable base station operating in frequency band 255 (UNII-3). The measurement is in line with the LTE-U eNB minimum requirements specification.[2]

To distinguish the work done by the LTE-U Forum from that of the 3GPP, from a forum perspective, LTE-U is defined to use bands 252 and 255 as a supplemental downlink only. The LAA work item also defines the anchor carrier or primary component carrier (PCC) for the communications link to reside in a licensed frequency band but does not exclude the use of the 5 GHz spectrum for uplink carrier aggregation at a later stage. For the moment, the 3GPP is also considering the (secondary) component carrier placed in the 5 GHz bands solely as a transmission resource.[3]



▲ *Fig. 2 SEM measurement using the R&S®FSW signal and spectrum analyzer in line with the LTE-U eNB minimum requirements specification.*



▲ *Fig. 3 LTE-U base stations use CSAT to ensure fair spectrum sharing with other LTE-U operators and Wi-Fi.*

ENSURING COEXISTENCE

The LTE-U Forum members have agreed on a two-step approach to ensure coexistence with other technologies and LTE-U operators, along with fair sharing of the spectrum resource with existing technologies. First, this is based on smart channel selection during the initial boot-up phase, which is then continued dynamically during operation. In other words, an LTE-U capable base station (similar to a Wi-Fi access point) periodically monitors the frequency band and selects its channel based on channel quality measurements and input parameters such as traffic load. A 'channel penalty' function has been proposed that has multiple input parameters with variable weighting factors. Based on the measurements and weighting factors, a penalty for each potential channel is determined. The channel with the lowest penalty is selected and a 20 MHz LTE component carrier is transmitted on this frequency channel. A terminal that supports LTE-U is informed about the exact carrier frequency via the defined signaling methods for carrier aggregation and can thus access that component carrier.

As of now, aggregation of up to three component carriers is foreseen. One is in a licensed frequency band that could have any bandwidth depending on the spectrum of the respective operator. In addition, there can be up to two 20 MHz component carriers in the unlicensed frequency band. Such carriers are always 20 MHz wide – no more and no less due to the Wi-Fi channel definition, where the minimum bandwidth is 20 MHz. In total, there could be an aggregated transmission bandwidth of up to 60 MHz, including 2 × 2 MIMO operation per component carrier, and a maximum peak data rate of 450 Mbps.

After initial channel selection, the LTE-U capable base station must use carrier sensitive adaptive transmission (CSAT) to ensure fair sharing with other LTE-U operators using the spectrum and Wi-Fi. The basic principle behind CSAT is to define a cycle with a duration of some milliseconds that is divided into an "on" period and an "off" period. The length of the cycle and thus the duration of the on and off periods are dynamically adaptable based on the traffic situation (see ***Figure 3***). If there is a heavy load on the selected channel, when many Wi-Fi access points and other LTE-U base stations are active, then the CSAT cycle might be long, up to 150 ms, and the on period short, for example only 20 ms. If the channel is not heavily occupied, a shorter CSAT cycle might be appropriate with a longer on period and therefore a shorter off period. Note that the values shown in Figure 3 were suggestions by LTE-U Forum members, presented at a workshop in May 2015.

During the on period of the CSAT cycle, a few subframes are periodically punctured and configured as almost blank subframes (ABS). The actual quantity depends on the duration of the on period and, thus, on the traffic load. The puncturing of subframes is intended to ensure that latency-sensitive applications that run over Wi-Fi, such as voice over Wi-Fi (VoWi-Fi), can still function once LTE-U is operational.

Besides testing the RF conformance of LTE-U capable base stations by measuring the transmission power, SEM and ACLR, it is important to test handset performance and coexistence. To demonstrate LTE-U performance, a setup that was featured at Mobile World Congress 2015 was used to emulate and aggregate three LTE component carriers with a bandwidth of 20 MHz each and 2×2 MIMO. Two of the component carriers were placed in a licensed frequency band, and the other component carrier was placed in the UNII-3 domain of the 5 GHz spectrum. Aggregating these three carriers achieved a maximum data rate of 450 Mbps. The demonstration involved a maximum throughput test to verify that the device under test was capable of handling this high data rate.[4] To ensure coexistence, it was also important to verify that the device was able to support CSAT.

OUTLOOK

The 3GPP is standardizing LTE-U functionality known as LAA. Part of the standardization involves integrating listen before talk (LBT) functionality, which is required in Europe and Japan to use the 5 GHz spectrum. A device that wants to utilize the spectrum must always sense the channel first before starting to transmit. At this time, the standardized LBT functionality is based solely on energy detection.

LTE-U is currently a hot topic in the wireless industry. The feature provides an attractive alternative for network operators who want additional spectrum to increase their system capacity. Fair sharing of the resource among operators and existing technologies such as Wi-Fi is key to the success of LTE-U. ■

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60 GHz Backhaul Links Ready to Boost Cellular Capacity

INVITED PAPER

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The ever-increasing demand for data on the world's cellular networks has operators searching for ways to increase capacity 5000× by 2030.[1] Getting there will require a 5× increase in channel performance, a 20× increase in allocated spectrum and a 50× increase in the number of cell sites. Many of these new cells will be placed indoors, where the majority of traffic originates, and fiber is the top choice to funnel the traffic back into the network. Yet there are many outdoor locations where fiber is not available or is too expensive to connect; for these situations, wireless backhaul is the most viable alternative.

Unlicensed spectrum at 5 GHz is available and does not require a line-of-sight (LOS) path. However, bandwidth is limited and interference from other users of this spectrum is almost guaranteed, due to heavy traffic and wide antenna patterns. 60 GHz is emerging as a leading contender to provide these backhaul links for the thousands of outdoor cells that will be required to meet capacity demands. This spectrum is also unlicensed. Unlike frequencies below 6 GHz, it contains up to 9 GHz of available bandwidth. Moreover, the high frequency allows for very narrow and focused antenna patterns that are somewhat immune to interference; however, they do require LOS paths.

Modems based on FPGAs and systems on a chip (SoC) are increasingly used in wireless backhaul solutions, since platforms using them can be modular and customizable, reducing the total cost of ownership for OEMs. For the radio portion of these links, transceivers have been integrated into silicon ICs and assembled in low cost, surface-mount packages. Commercial parts are now available to build a complete two-way data link at 60 GHz, filling each of the functional blocks in ***Figure 1***. Developed by Xilinx and Hittite Microwave (now Analog Devices), the design includes a Xilinx modem and Analog Devices millimeter wave radio. This link meets the performance and flexibility requirements of the small cell backhaul market.

As shown in Figure 1, two nodes are required to create the link. Each node contains a transmitter with a modulator and its associated analog chain and a receiver with a demodulator and its associated analog chain. The modem card is integrated with analog and discrete devices. It contains oscillators to ensure the accuracy of frequency synthesis, and all the digital functions are executed in an FPGA or SoC. This single-carrier modem core supports modulations from QPSK to 256 QAM in channel bandwidths up to 500 MHz, achieving data rates as high as 3.5 Gbps. The modem supports both frequency-division duplex (FDD) and time-division duplex (TDD) transmission. Robust modem design techniques reduce the phase noise implications of the local oscillators. Powerful low-density parity check (LDPC) coding is included for improved performance and link budget.

MILLIMETER WAVE MODEM

The millimeter wave modem enables infrastructure suppliers to develop flexible, cost-optimized and customizable links for their wireless backhaul networks. The modem is fully adaptive, low power and small, and can be used to deploy indoor and full outdoor point-to-point links, as well as point-to-multipoint links. The solution allows operators to build scalable and field-upgradable systems.

Figure 2 shows a functional block diagram of the digital modem, which is implemented as an SoC. Besides the programmable logic (PL), the platform's scalable processing system (PS) contains dual ARM Cortex-A9 cores with integrated memory controllers and multistandard I/Os for peripherals. The SoC platform is used to perform various data and control functions and to enable hardware acceleration. An integrated millimeter wave modem complete with PHY, controller, system interfaces and packet processor is included.

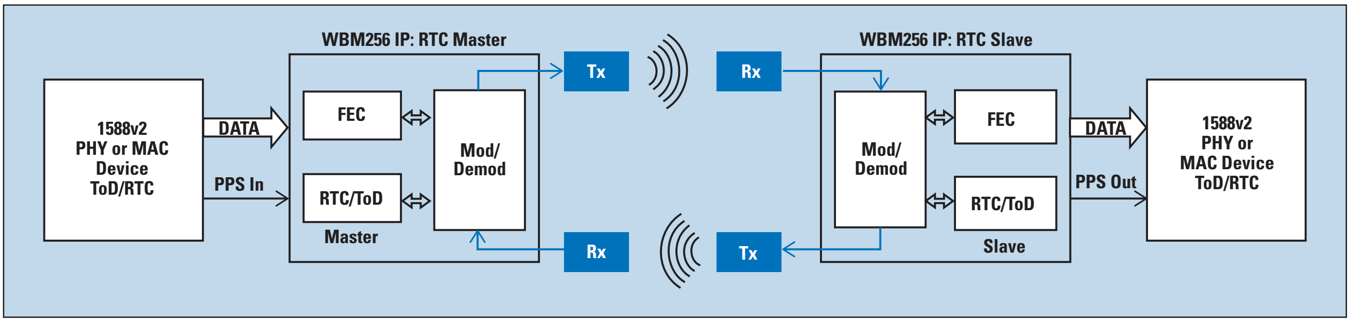
Based on the required architecture, different modules can be inserted, updated or removed. For example, an XPIC combiner could be implemented to enable the modem to be used in a cross-polarization mode with another modem. The solution is implemented in the PL, where serializer/deserializer (SerDes) and I/Os are used for various data path interfaces, such as between the modem and packet processor, the packet processor and memory, inter-modem or DAC/ADC.

Other important features of the modem IP include:

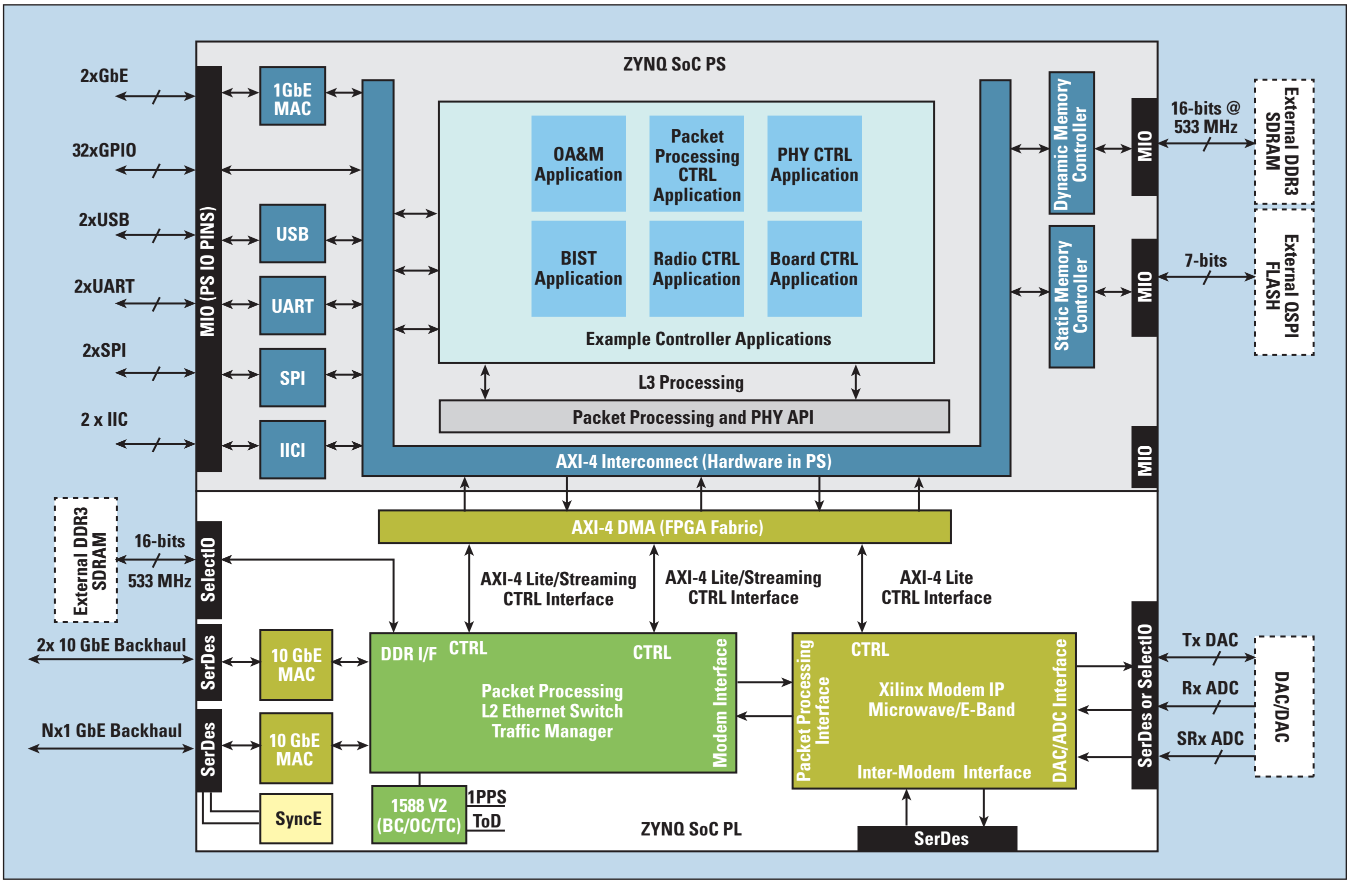
- Automatic hitless and errorless state switching through adaptive coding and modulation (ACM) to keep the link operational
- Adaptive digital closed-loop predistortion (DPD), to improve RF power amplifier efficiency and linearity
- Synchronous Ethernet (SyncE), to maintain clock synchronization and
- Reed Solomon or LDPC forward error correction (FEC), based on the design requirements.

LDPC FEC is the default choice for wireless backhaul applications, while Reed Solomon is preferred for low-latency applications such as front-haul. LDPC implementation is highly optimized and exploits FPGA parallelism for computations done by the encoders and decoders. The result is noticeable SNR gains. Different levels of parallelism are applied by varying the number of iterations of the LDPC core, which optimizes the size and power of the decoder. The design can also be modeled based on channel bandwidth and throughput constraints.

This modem solution comes with a graphical user interface (GUI) for both display and debug. It is capable of high level functions such as channel bandwidth and modulation selection as well as low level ones such as setting hardware registers. To achieve 3.5 Gbps throughput, the modem IP runs at a 440 MHz clock rate. It uses five gigabit transceivers (GT) for connectivity interfaces to support the ADCs and DACs and a



▲ *Fig. 1 Functional block diagram of the two-way 60 GHz link.*



▲ *Fig. 2 The wireless digital modem is implemented with a programmable SoC.*

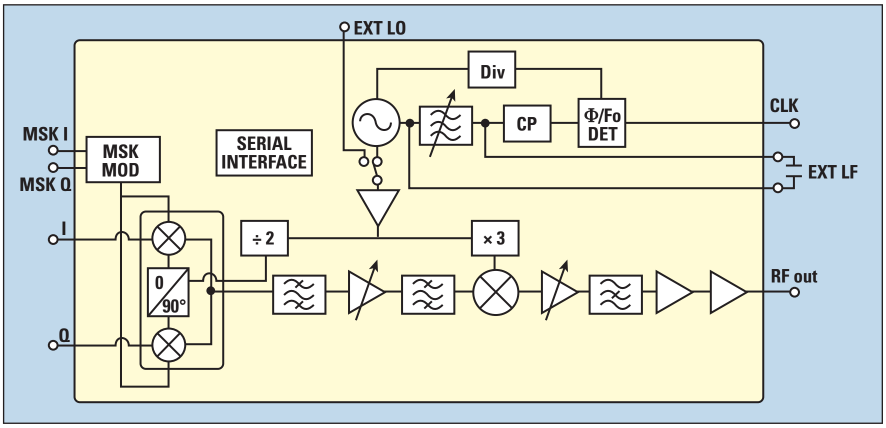
few more GTs for 10 GbE payloads and CPRI interfaces.

MILLIMETER WAVE TRANSCEIVER

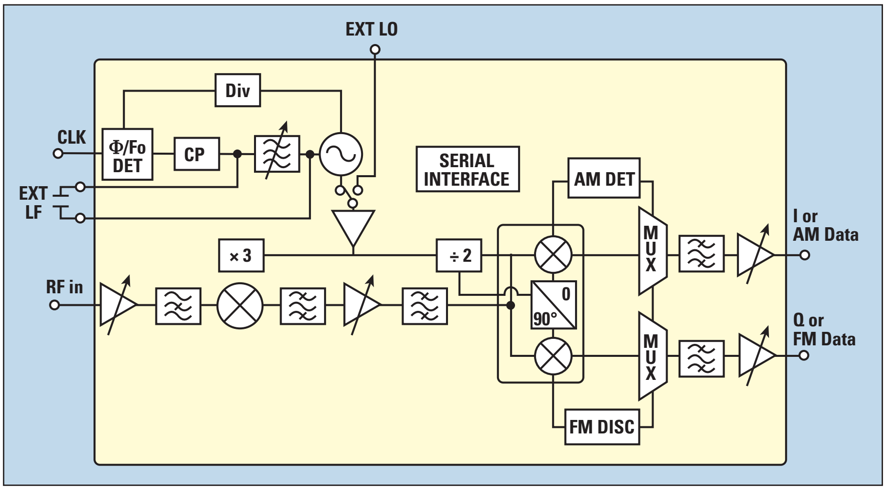
A second-generation SiGe chipset was optimized for 60 GHz small cell backhaul applications. The transmitter chip is a complete analog baseband to millimeter wave up-converter. An improved frequency synthesizer covers 57 to 66 GHz in 250 MHz steps, with low phase noise that can support modulations up to at least 64 QAM. The output power was increased to roughly 16 dBm linear, and an integrated power detector monitors the output power to maintain the output within regulatory limits. The transmitter chip offers either analog or digital control of the IF and RF gains. Analog gain control is sometimes needed when using higher-order modulation, since discrete gain changes can be mistaken for amplitude modulation, leading to bit errors. A built-in serial peripheral interface (SPI) supports digital gain control.

For applications requiring even higher-order modulation in narrow channels, an external PLL/VCO with lower phase noise can be injected into the transmitter, bypassing the internal synthesizer. ***Figure 3*** shows a block diagram of the transmitter chip, which supports up to 1.8 GHz of bandwidth. An MSK modulator option enables low cost data transmissions up to 1.8 Gbps without the need for expensive and power-hungry DACs.

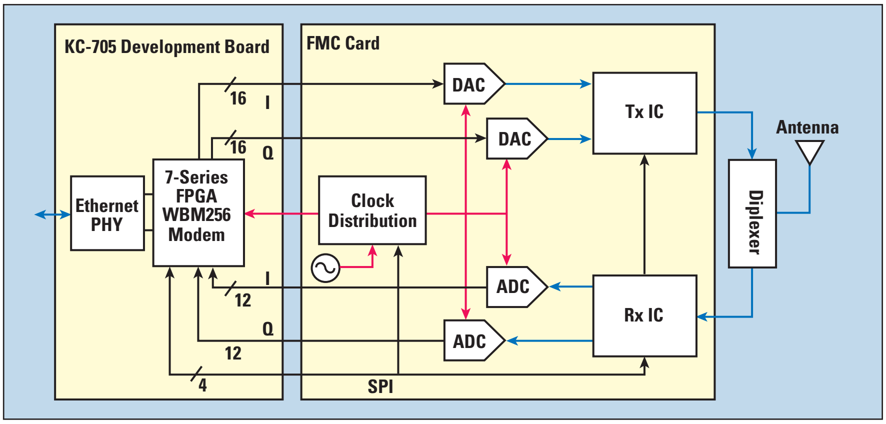
A receiver chip complements the transmitter IC (see ***Figure 4***) and is, likewise, optimized to meet the demanding requirements of small cell backhaul applications. The receiver features a significant increase in the input P_{1dB} to -20 dBm and IIP3 to -9 dBm to handle short-range links, where the high gain of the dish antennas leads to high signal levels at the receiver input. Other key features include a low 6 dB noise figure at maximum gain, adjustable lowpass and highpass baseband filters, either analog or digital control of the IF and RF gains and the same new synthesizer design found in the transmitter chip, to support 64 QAM modulation over 57 to 66 GHz. The receiver also contains an AM detector to demodulate amplitude modulation such as on/off keying (OOK) and an FM discriminator to demodulate simple FM or MSK modulation. This



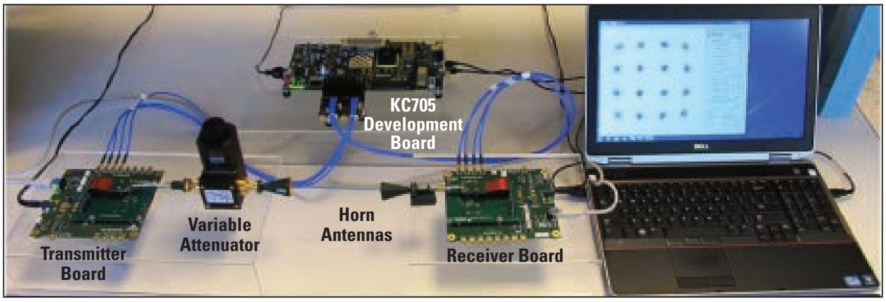
▲ *Fig. 3 Functional block diagram of the 60 GHz transmitter IC.*



▲ *Fig. 4 Functional block diagram of the 60 GHz receiver IC.*



▲ *Fig. 5 A reference design for the 60 GHz link based on Xilinx and Analog Devices ICs.*



▲ *Fig. 6 60 GHz link demonstration platform.*

is in addition to the I/Q demodulator that is used to recover the quadrature baseband outputs for QPSK and more complex QAM modulation.

Both transmitter and receiver ICs come in a 4 × 6 mm wafer-level BGA package. Surface-mount packaging supports low cost manufacturing of radio boards for backhaul applications.

Figure 5 shows a block diagram of an the millimeter wave modem and radio system. In addition to the FPGA, modem software and millimeter wave chipset, the design contains a dual-channel, 12-bit 1 GSPS ADC; a quad-channel, 16-bit, up to 2.8 GSPS Tx DAC; and an ultra-low jitter clock synthesizer, with support for the JESD204B serial data interface employed on both the ADC and DAC ICs. A demonstration platform (see ***Figure 6***) was jointly created by Xilinx and Analog Devices. It includes the FPGA-based modem on a Xilinx development board, a standard FMC board containing ADCs, DACs and clock and two radio module evaluation boards. The platform includes a laptop for modem control and visual display and a variable RF attenuator to replicate the path loss of a typical millimeter wave link. The FPGA on the development board executes the WBM256 modem firmware IP. A standard FMC mezzanine connector on the development board connects to the baseband and millimeter wave radio boards. The millimeter wave modules snap onto the baseband board. The modules have MMPX connectors for the 60 GHz interfaces and SMA connectors for optional use of an external local oscillator. This platform contains all the hardware and software needed to demonstrate point-to-point backhaul connections of up to 1.1 Gbps in 250 MHz channels for each direction of an FDD link.

DESIGN CONSIDERATIONS

The experience developing the modem, transceivers and demonstration platform yielded the following considerations for designers:

Since they're highly modular and customizable, FPGAs can reduce the cost to build platforms for wireless backhaul. When choosing commercial parts for a millimeter wave modem solution for small cell, select power-efficient FPGAs/SoCs and high performing wideband IP cores. High speed is also a factor to consider when selecting GTs for wideband communications and switching functions. Look for a solution that can scale to support multiple product variations on the same hardware platform, from lower end, small cell backhaul radios that operate at a few hundred megabits per second to high performance systems carrying 3.5 Gbps.

For the radio, transceiver ICs in surface mount packages will lower the cost of manufacturing. Parts currently on the market will meet the power, size, flexibility and functionality requirements for small cell wireless backhaul. The high-performing data converters and clock-management ICs that are required to complete a wireless backhaul link are also commercially available.■

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INVITED PAPER

Multiplexers in Mobile Handsets with LTE-Advanced Carrier Aggregation

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In many parts of the world, smartphones have become an integral part of everyday life, and many users rely on their handsets as an easy way for going online. In the U.S., it is reported that in early 2011, one in three Americans owned a smartphone. As of 2015, that number has almost doubled.[1] Projections indicate that in 2016 smartphone penetration will exceed 80 percent in the U.S.[2] This continuous growth of smartphone popularity, and the expansion of its user base feeds the need for increased wireless data traffic, which has to be met with an increase in available bandwidth. The 3GPP standards body for mobile broadband specifies the spectrum of bands that can be used in wireless communications. Since the wireless spectrum is already crowded, and new chunks of wireless spectrum are hard to come by, 3GPP's LTE-Advanced specifications identify carrier aggregation (CA) as one means to increase bandwidth over existing LTE frequency bands.[3]

With LTE, data traffic is aggregated in component carriers (CC) which are blocks of frequency spectrum 1.4, 5, 10 or 20 MHz wide. To increase the bit rate, CA means that up to five CCs can be aggregated, either within the same band or across different frequency bands. The number of downlink CCs must always equal or be greater than the number of uplink CCs. Since most of the wireless traffic demand is presently in the downlink (DL) direction, only one uplink (UL) CC is used, limiting carrier aggregation to the DL direction.

All smartphones on the market today already include the capability to transmit and receive on different frequency bands, for roaming purposes. However, enabling simultaneous operation of two separate LTE bands for CA puts additional constraints on the phone's hardware components and data traffic management. In particular, inter-band CA with two frequency division duplex (FDD) LTE bands means that each transmit band now has two equally valid receive bands associated with it.

MULTIPLEXERS

Smartphones combine a lot of functionality into a relatively small package, and the size of any component inside the phone is limited. The RF front-end in a handset comprises all components between the antenna and the baseband/transceiver chips, such as frequency filtering devices, switches, power amplifiers, LNAs and a number of matching and routing elements. For any FDD band, a duplexer comprises two RF filters which ensure that the uplink transmit signal (Tx) does not interfere with the downlink reception (Rx). Integrating multiple non-overlapping filter bands into a single module (multiplexer) can reduce component count and the size of the phone's RF

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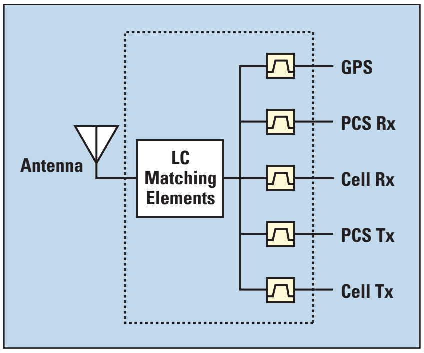
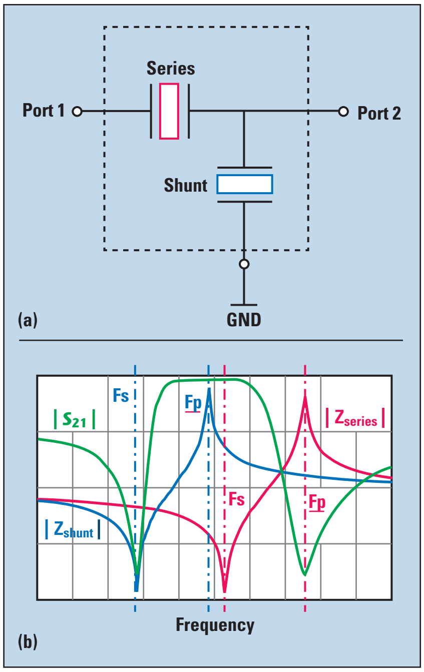


▲ *Fig. 1 Quintuplexer comprising five filters with dissimilar passband frequencies.*

front-end, as well as simplify and accelerate the integration into the phone. Introduced several years ago, multiplexers have become a standard way to optimize, miniaturize and simplify the filtering needs of multi-band phones, requiring only a single antenna to cover multiple bands without a switch between the antenna and the frequency filters.[4] As an example, the functional block diagram of a quintuplexer is shown in ***Figure 1***. Since CA requires different bands to be on at the same time (i.e., no switching between bands), a multiplexer is a convenient implementation to meet CA filtering needs.

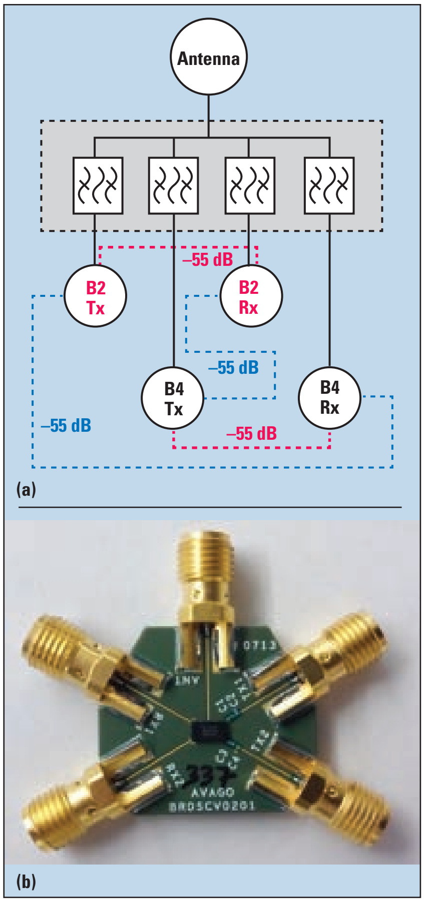
Although common in earlier wireless generations, the RF front-end architecture of LTE phones no longer incorporates inter-stage filters between the transceiver and the PA in the transmit path. All FDD frequency filtering is now done by the duplexer or multiplexer, which puts stringent performance requirements on the filters. Any spurious signal from the PA toward the antenna needs to be rejected in the Rx path to not degrade phone sensitivity. This Tx/Rx isolation requirement in the duplexer specification is typically pegged at 55 dB minimum at the Tx and Rx frequencies. The filters inside the CA multiplexer must provide high Tx/Rx isolation, not only within a single FDD band but also across the different FDD LTE bands used in CA.

Driven by size and performance requirements, essentially all RF filtering devices in the handset incorporate surface acoustic wave (SAW) or bulk acoustic wave (BAW) resonator filter technologies. Both SAW and BAW technologies utilize piezoelectric resonators as the basic building block and are well established, mature technologies for RF filtering. For the filter designer, noteworthy SAW or BAW resonator properties are acoustic coupling (kt^2) and Q-factor. Combining resonators to create a filter, ***Figure 2a*** illustrates a 1-stage half-ladder filter topology, a basic element for many filters. This configuration forms a passband when the series resonator has a higher resonance frequency than the shunt resonator (see ***Figure 2b***). Based on this basic topology, any practical filter cascades multiple half-ladder stages to provide sufficient degrees of freedom to meet any realistic in-band and out-of-band filtering requirements. By doing so, the multi-stage filter arranges its poles within the passband, and the zeros outside its passband.

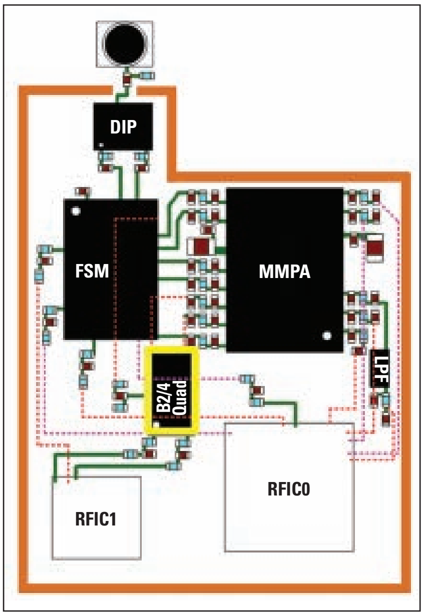


▲ *Fig. 2 One stage half-ladder filter topology (a) with corresponding resonator impedances (Zseries, Zshunt) and filter response (b). Practical implementations of this basic filter topology use multiple stages.*

Combining two filters into a duplexer is the simplest form of a multiplexer. When combining RF filters into a CA-compatible multiplexer, there are two essential design constraints. First, all filters in the multiplexer must be matched at the common antenna node. For any of the passband frequencies, only the respective filter is terminated at the antenna port's impedance Z_{ant}, to minimize RF reflections between the antenna and the multiplexer in the phone; all other filters must appear as open circuits, such that there is no signal leakage into any other filter path. Secondly, high Tx/Rx isolation, both in band and cross-band, is needed for CA use of the multiplexer.



▲ *Fig. 3 Band 2/4 quadplexer block diagram (a) and evaluation board (b). The dotted lines show high Tx/Rx isolation paths needed for carrier aggregation.*



▲ *Fig. 4 Band 2/4 quadplexer on the PCB of the RF front-end module.*

TABLE 1

BAND 2/4 QUADPLEXER PERFORMANCE

(dB)	Tx Insertion Loss	Rx Insertion Loss	Tx Band Isolation	Rx Band Isolation	Tx $2f_0$ Rejection	Tx $3f_0$ Rejection
Band 2	2.0	2.9	58	59	37	38
Band 4	2.0	2.0	61	60	41	14

TABLE 2

BAND 2/4 QUADPLEXER CROSS-BAND ISOLATION

(dB)	Tx Band Isolation	Rx Band Isolation
Band 2 Tx to Band 4 Rx	60 (B2)	65 (B4)
Band 4 Tx to Band 2 Rx	62 (B4)	61 (B2)

In the engineering of the multiplexer module, parasitic crosstalk or direct Tx/Rx signal leakage can degrade isolation and will need to be evaluated in the finished product. Both items need to be addressed in the CA-compliant multiplexer product design. Techniques to address these constraints are well understood.[5,6] Finally, the filter designer uses circuit simulator software as well as 3D electromagnetic simulation to predict multiplexer performance.

BAND 2/4 QUADPLEXER

CA is being deployed in many locations around the globe and CA-capable multiplexers of corresponding LTE band combinations are emerging in the market. For the American wireless market, a recent implementation of a CA-compatible multiplexer is the Band 2 (1.9 GHz PCS) / Band 4 (1.7/2.1 GHz AWS) quadplexer (see ***Figure 3***). Bands 2 and 4 are common North American FDD bands, and since carrier aggregation is already available in some locations,[7] there is a tangible product need for such a quadplexer module. CA-compatibility underscores the value proposition of the Band 2/4 quadplexer module; however, the engineering is challenging for multiple reasons:

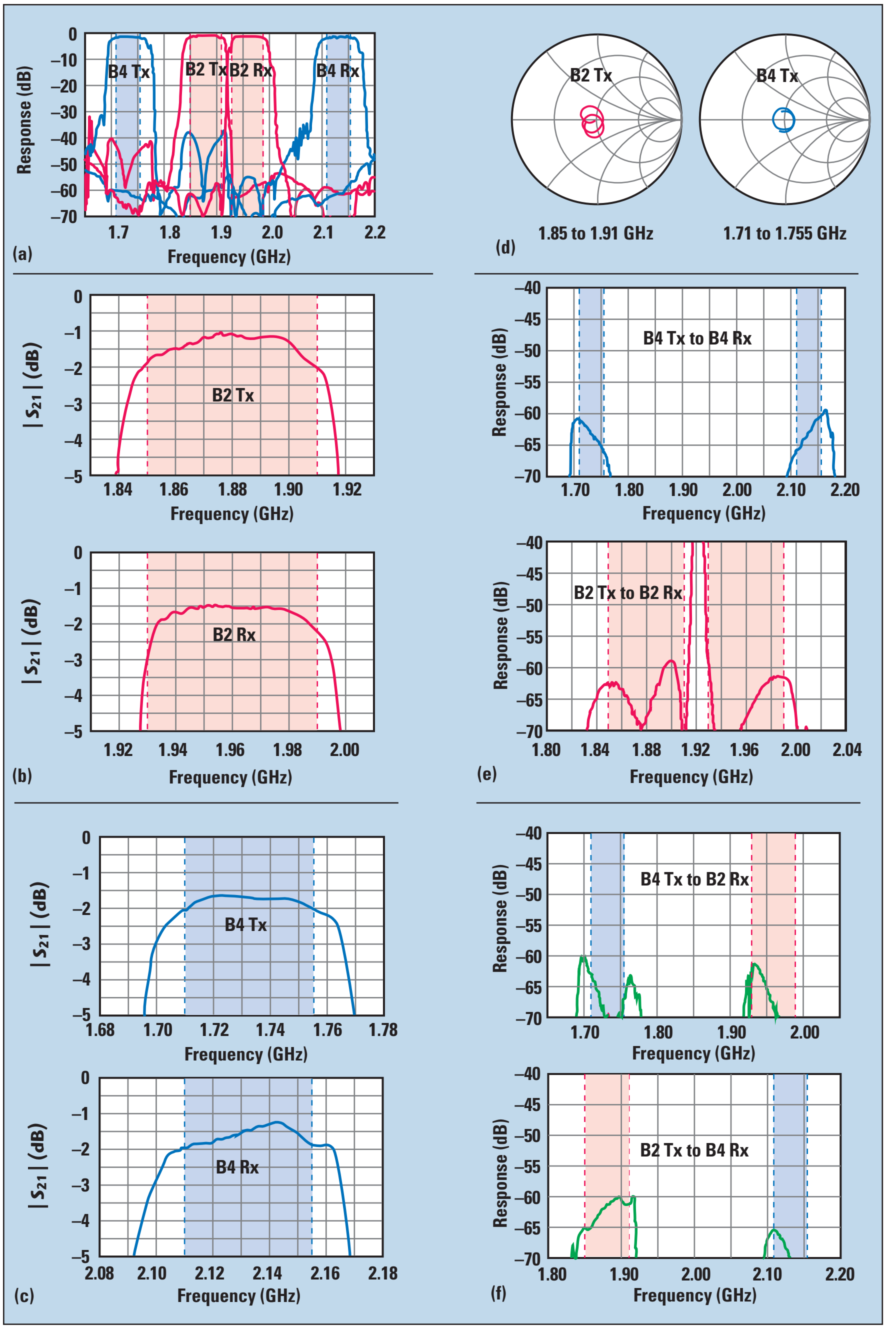
Band 2 Duplexer: The filter band gap (Tx/Rx) is relatively narrow, approximately 1 percent of the operating frequency between 1910 and 1930 MHz. Low insertion loss at both filter passband corners (Band 2 Tx high channel and Rx low channel) requires a sharp roll-off for both Tx and Rx filters. This is non-trivial, even without other filters multiplexed to the same antenna node.

Band 4 Duplexer: The filter passbands with low insertion loss are relatively easy to achieve, since the passband width is narrow and the Tx/Rx band gap is large. However, maintaining high Tx/Rx isolation over this large frequency gap can challenge manufacturing tolerances, since most of the signal suppression is purely electrical (L-C resonance, far from the acoustic zeros of the other filter).

CA-Compliance: High cross-band isolations are additional requirements on the filters (B4 Tx/B2 Rx, B2 Tx/B4 Rx, given the second multiplexer design constraint noted previously). Additional out-of-band attenuation requirements typically trade off against in-band performance (i.e., insertion loss) and need to be balanced carefully.

The passbands of the Band 2 and Band 4 filters are relatively close in frequency, with the Band 4 filter frequencies bracketing both Band 2 passbands. The antenna match cannot rely on a diplexer circuit to isolate filter bands; all filters in this quadplexer need be co-designed to optimize the antenna match and ensure high Tx/Rx isolation (all in-band and cross-band combinations).

Increasing the number of filters connected to the same antenna node leads to increased insertion loss in each filter passband. This is unavoidable since the open circuit condition is never perfect or lossless (refer to the first multiplexer design constraint noted above). Elaborating on this point: to optimize multiplexer performance, it is not only helpful to reap low loss and high Q resonance performance of the resonator building blocks for good in-band filter performance, it is also helpful to garner low loss resonator performance at off-resonance frequencies. With low loss off-resonance performance, the open filter matching condition at the antenna port can be implemented with minimum parasitic loss and does not drain signal off the



▲ *Fig. 5 Measured performance of a Band 2/4 quadplexer showing the frequency coverage (a) Band 2 insertion loss (b) Band 4 insertion loss (c) Bands 2 and 4 Tx impedance match (d) in-band Tx/Rx isolation (e) and cross-band Tx/Rx isolation (f).*

in-band performance of any passband. Using available SAW or BAW resonator filter technologies, part of the Band 2/4 quadplexer optimization process is minimizing the losses of all four filters at all four passband frequencies.

CA-compatible quadplexers for the Band 2/4 combination have been demonstrated by multiple suppliers, and some are available for sale. ***Figure 4*** shows how the quadplexer would typically be integrated with the other RF components in the front-end of a smartphone. Measured performance of an Avago Band 2/4 quadplexer are shown in ***Figure 5*** and the key performance parameters are summarized in ***Tables 1*** and ***2***. The measured data reflects the recommended circuit matching elements.[8]

This quadplexer uses FBAR technology, a flavor of BAW resonator technology. FBAR is known for low loss resonators, both on and off resonance. Low loss fuels the performance of the quadplexer which, in turn, optimizes the phone's performance and user experience: providing increased sensitivity and battery life, while benefitting from fast wireless data traffic using CA.

CONCLUSION

Smartphones continue to excel in popularity and market penetration, and their computing power and wireless connectivity are steadily improving. LTE-Advanced CA of different LTE bands is being rolled out to increase wireless data rates. As this deployment of band combinations continues across different geographies, corresponding CA multiplexers are emerging in the market. These components optimize RF performance, space and ease of integration for handset OEMs. Low loss filter technologies such as FBAR will continue to enable multiplexer performance. Higher levels of integration are feasible for future CA multiplexers, such as integrating three or more FDD bands. When designing such a multiplexer module, filter losses and antenna match need to be managed carefully to ensure an attractive product. ■

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NI Wireless Test System

National Instruments
Austin, Texas

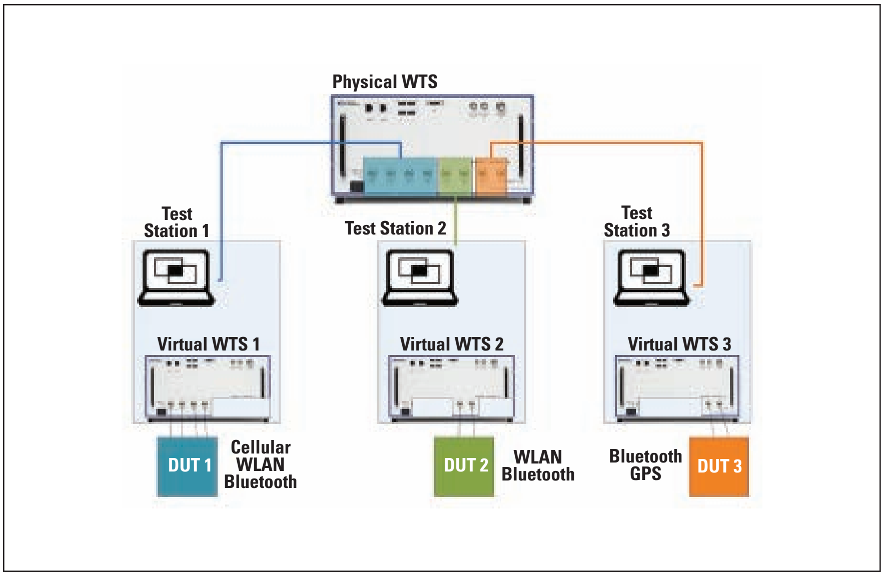
Earlier this year, Tesla Motors CEO Elon Musk commented that in the future, "people may outlaw driving cars because it's too dangerous." He was referring to autonomous-drive vehicles sharing the road with other human-controlled cars. Several companies are working toward a reality that envisions you sitting back and reading this magazine while your car transports you safely, comfortably and efficiently to your destination. While you are fully engrossed in the magazine article, your connected car is occupied with processing multiple streams of data from multiple sources, including an important rescheduling notice from the office, road traffic signs, highway warning systems and other vehicles in the vicinity.

Several key technologies will ultimately make this vision of the Internet of Things (IoT) or Internet of "Everything" possible. For instance, once it's defined, next generation wireless infrastructure, or 5G, will provide a wider data pipe for a larger number of users, based on technologies like massive MIMO, higher frequency bands and new waveforms. Another enabling technology is the creation of more tightly integrated chips, modules and devices that combine wireless connectivity with greater processing power. These devices must support an expanding number of complex wireless standards on a growing collection of radio bands.

Having this kind of wireless connectivity in every device with which people interact forces the cost model of these devices to change. Although consumers have the expectation that devices purposely built for wireless networking – such as cellular phones, access points, and home monitoring systems – have a high price premium for this functionality, for other "things" that now connect to the Internet, consumers might not want to bear the extra cost. Although semiconductor system integration reduces the cost of component production, wireless devices manufacturers still have the costly burden of testing each one rapidly and reliably.

NI'S NEW WIRELESS TEST SYSTEM

NI recently released a new Wireless Test System (WTS) to address the need for a cost-effective test solution that can keep pace with evolving wireless technologies. Based on the PXI platform, the WTS uses a high bandwidth PXI chassis, a quad-core Intel i7 embedded PC and one or more of the award-winning NI



▲ *Fig. 1 Expanding the WTS into multiple virtualized instruments.*

vector signal transceivers (VST). This PXI configuration is internally connected to a rugged RF switch with 8 or 16 Type N RF ports. A metal enclosure makes the system robust enough to meet the demands of high volume production environments.

One of the unique features of the WTS is that you can remotely control it from a PC through a LAN bus using standard commands for programmable instruments (SCPI). With this architecture, the instrument uses a SCPI interpreter to decipher commands and apply the appropriate measurement software. WTS supports measurements for both cellular (from GSM to LTE-A) and wireless connectivity devices (WLAN and Bluetooth). The software algorithms for these measurements are identical to those of other PXI RF test configurations.

REDUCING TEST COST

In addition to the need for modern test systems to reduce capital expenditures, test engineers are required to maximize test throughput – often measured in number of devices tested per hour – and implement parallel test architectures and techniques, while simplifying test development efforts. Typically, test of wireless networking devices requires inserting and removing the device under test (DUT), booting up, configuring the DUT for every test step and performing measurements with the test instruments. In practice, the test system utilizes the RF instruments for only a fraction of the time when testing one device at a time. Given the complexity of wireless test plans for today's devices, testing just one device is an inefficient use of the instruments. As a result, parallel test using a multi-port RF instrument is a common approach that can reduce measurement dead time by making sure that a given test site can access the RF instrument while the other sites are busy with non-measurement tasks. Although the idea of parallel test is simple in theory, implementing a parallel test approach greatly increases the complexity of the test solution.

For example, parallel test requires developers to write test sequences to control and intelligently synchronize both the instrument and the DUTs. Typical test sequences must be designed for multiple sites, keeping track of multiple instrument handles, signal routes and system variables. As a result, designing test software to implement parallel test is a daunting challenge.

Although solving this challenge is difficult with traditional tools, the new WTS simplifies the process with several advanced software features. Two key features of the WTS that simplify parallel test development and make it more scalable are instrument virtualization and pre-coded test steps. Instrument virtualization allows a single WTS to appear – and be programmed as – multiple separate and independent instruments. Using this feature, test developers can write test sequences for a single DUT with their independent, virtualized instrument in mind (see ***Figure 1***). A second key feature is the use of preconfigured test steps with integrated DUT control. These test steps are part of the new NI TestStand Wireless Test Module, an extension of TestStand, the industry-standard test management software. Using the Wireless Test Module, a developer can drag, drop and configure test steps to build a sequence for a single DUT (single site). When the Wireless Test Module executes the sequence, it automatically maps the WTS' RF ports to multiple parallel and independent test sockets, each of which talks with its own virtualized WTS for multi-up DUT testing.

Implementing these techniques has already benefited the testing of intricate automotive infotainment modules that come equipped with multi-band, multi-standard cellular, WLAN and Bluetooth radios as well as GPS receivers, many from different device manufacturers. According to Harman International Industries, this novel approach to test their multi-radio infotainment modules with NI's WTS allowed them to realize important test time reductions.

The WTS' powerful PXI hardware platform in combination with its SCPI interface and intelligent software for implementing the latest cost-saving test architectures give manufacturers of wireless devices the flexibility to keep pace with the advances of the wireless test industry. Even more exciting, once 5G is defined, the combination of NI's WTS instrument virtualization and the Wireless Test Module for test parallelization will enable test engineers to boost test throughput and ultimately lower the cost of testing mobile communications products and the wireless devices that will power the industrial and consumer Internet of Things. With this advance, we can look forward to a world where producing connected cars, homes and a variety of smart appliances is economically viable.

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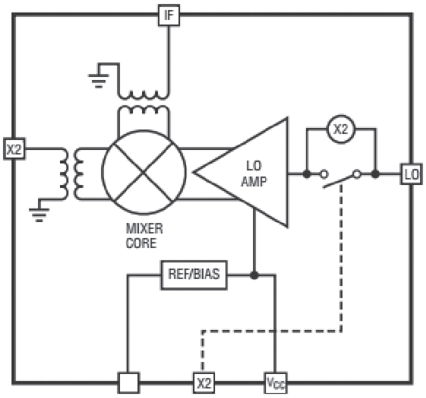

Broadband, High IIP3 Mixer Moves More Data

Linear Technology Corp.
Milpitas, Calif.

To cope with ever increasing Internet traffic, the bandwidth of next-generation wireless access is rapidly expanding. At the same time, the current spectrum simply cannot support the needed bandwidth, so higher frequencies are being evaluated. Multiple options from unlicensed 5.8 GHz terrestrial stations to fleets of low-orbit satellites blanketing the Earth, are being considered. The path to higher bandwidth lies with higher frequencies to deliver on that promise, requiring new mixers with improved performance. The new LTC5549 mixer from Linear Technology has been launched to support just this need.

The LTC5549 is a passive double balanced mixer that functions as either an up- or down-converter. It has a very wide RF frequency range from 2 to 14 GHz. The mixer offers exceptionally high linearity – 28.2 dBm IIP3 at 5.8 GHz and 22.8 dBm at 12 GHz – that improves the dynamic range of both transmitters and receivers. The LTC5549 enables efficient microwave transmitter and receiver designs with an integrated LO buffer that needs only 0 dBm drive, effectively eliminating the need for external high power LO drivers. The LTC5549 also has an integrated, bypassable frequency doubler for the LO signal, allowing the device to use lower cost, commonly available low frequency synthesizers. The double balanced mixer employs wideband integrated balun transformers, optimized to extend the LO and RF frequency bandwidth while enabling single-ended operation. Its IF supports a wide bandwidth from 0.5 to 6 GHz. All three ports are matched to 50 ohms and have excellent port-to-port isolation, minimizing undesirable LO leakage, which eases external filtering.

SiGe BiCMOS TECHNOLOGY

Most microwave mixers are built using discrete GaAs diodes or FETs in hybrid modules. In contrast, the LTC5549 is constructed using a very high frequency advanced SiGe BiCMOS process. SiGe BiCMOS enables a high level of integration, including the on-chip LO buffer and microwave balun transformers. The monolithic die is flipped and soldered onto a tiny 3 × 2 mm lead-frame and encapsulated in a plastic surface-mount package. Bond wires and their associated inductance are eliminated to enhance the device's microwave performance. The inherently small package, along with minimum external circuitry, makes for a very small footprint.

The new mixer's 22.8 dBm IIP3 is a standout in its class and enhances the dynamic range of receivers or transmitters. For a receiver, the higher IIP3 boosts robustness in the presence of close-in high power interference, whether from out-of-band, unintentional emitters or self-induced, such as leak-through from another transmitter in multi-sectored systems. Higher dynamic range receivers provide added design margin and are more forgiving in handling high blockers – as airwaves continually degrade with additional radio deployments.

Similarly for transmitters, a higher IIP3 (hence higher OIP3) mixer produces lower spurious products and improves spectral purity with better ACPR performance. This is particularly important for radios that use higher order modulation, such as 1024 QAM. The improved linearity produces better definition and accuracy of the constellation. Additionally, higher IIP3 allows the mixer to operate at elevated input power and, therefore, more robust output power. The extra design margin eases design constraints, providing flexibility.

DESIGN DIFFERENTIATION

The LTC5549's integrated LO amplifier effectively eliminates the +10 to +17 dBm LO amplifier that is typically required to drive traditional passive microwave mixers. Its 0 dBm LO input level enables the mixer to be driven directly from a PLL/synthesizer without a buffer amplifier. As well as reducing cost, the low LO power produces significantly lower LO leakage to the IF and RF ports, so less external filtering is necessary to contain any out-of-


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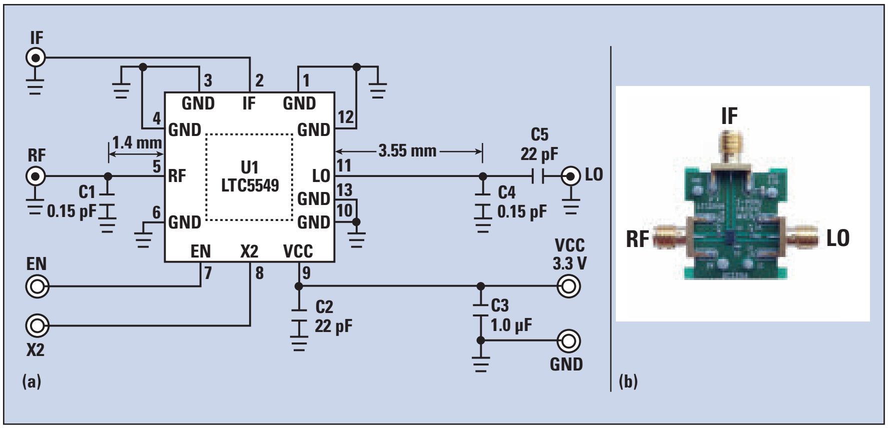
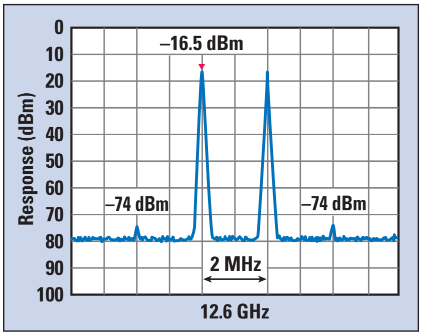


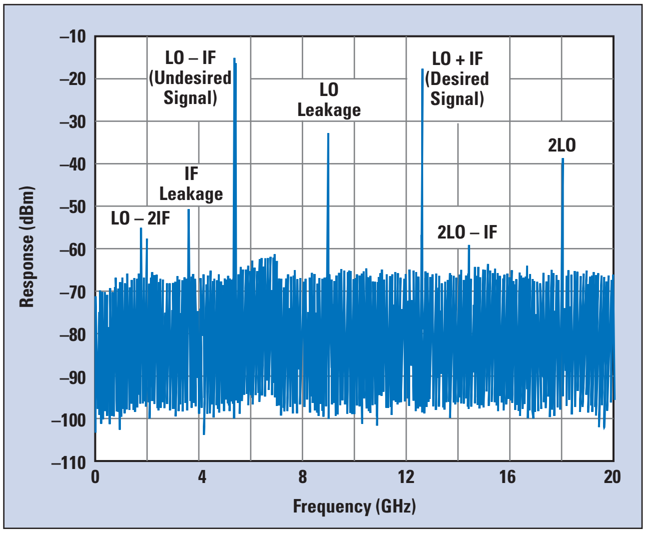
▲ *Fig. 1 LTC5549 evaluation board schematic (a) and assembly (b).*



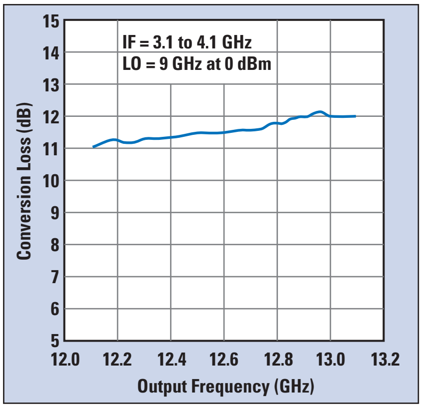
▲ *Fig. 2 Third-order intermodulation measurement at 12.6 GHz with 2 MHz tone separation.*

band emissions associated with the source. Another benefit is not having a high power radiation source on the PC board. This also lowers cost by reducing the RF shielding that plagues many designs requiring high power LO signals.

The LTC5549 incorporates patent-pending advances in planar balun transformer designs, enabling the monolithic mixer to operate over an extremely wide bandwidth. Unprecedented symmetry is achieved, with exceptional balanced operation, optimum spurious cancellation and flat frequency response. For example, the 50 ohm RF port with its built-in transformer and a 0.15 pF external capacitor achieve better than 10 dB return loss from 2 to 14 GHz. Similarly, with a 0.15 pF shunt capacitor and a series capacitor at the LO input, the port is matched from 1 to 12 GHz; return loss better than 10 dB across that entire frequency range. 5G is expected to deliver 1 Gbps data rates. To achieve such speeds, instantaneous radio bandwidth will need to be 1 GHz or higher. The LTC5549 has excellent bandwidth that can support a flat response of more than 1 GHz.



▲ *Fig. 3 Wideband output spectrum showing all spurious products.*



▲ *Fig. 4 The up-conversion mixer conversion loss is approximately 11.5 dB at 12.6 GHz with 1 dB flatness over a 1 GHz bandwidth.*

Microwave test equipment also benefits from a compact, high linearity mixer such as the LTC5549. As RF test equipment pushes to higher frequencies, linearity and bandwidth performance must also be improved to keep pace with the performance of the device-under-test.

3.6 TO 12.6 GHz UP-CONVERTER

To show the performance of the LTC5549, the mixer is used for an up-converter that converts a 3.6 GHz IF signal to a 12.6 GHz RF carrier. The internal 2× LO option is bypassed, so a 0 dBm, 9 GHz signal from a clean laboratory signal source generated the low-side LO drive.

Performance measurements were made using a standard LTC5549 evaluation board (see ***Figure 1***). Because the mixer and evaluation board's components are broadband matched, the board was used as is, without alteration.

Figure 2 shows the mixer's linearity at 12.6 GHz, using two -5 dBm tones separated by 2 MHz. The output third-order intermodulation distortion spurs measured -57.5 dBc, corresponding to an IIP3 of +23.8 dBm. The RF output spectrum from DC to 20 GHz is shown in ***Figure 3***. No external filtering was used to see where all the spurious products fall. The LO leakage power was some 14 dB less than the 12.6 GHz carrier and 3.6 GHz below the carrier frequency, so filtering will not be an issue. The 2LO-IF product is the closest spur and falls 1.8 GHz away from the carrier, with a residual power better than -40 dBc. At 12.6 GHz, the mixer's output exhibited 1 dB flatness over a 1 GHz bandwidth (see ***Figure 4***), showing it is capable of supporting next-generation broadband radios.

The LTC5549 exhibits excellent IIP3 that can enhance the dynamic range of either receiver or transmitter applications. It has an integrated LO buffer, producing very low LO leakage and reducing cost. Its integrated on-chip balun transformers provide extraordinarily wide bandwidth to simplify designs and enable a very compact layout.

VENDORVIEW

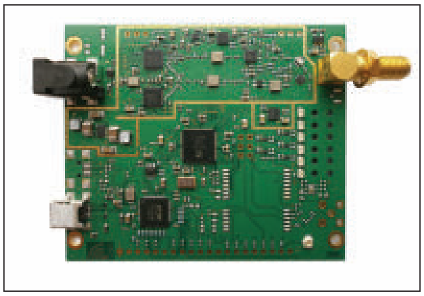
Linear Technology Corp.
Milpitas, Calif.
www.linear.com

Smart System Solution for IoT Radio Communications

IMST GmbH
Kamp-Lintfort, Germany

The Internet of Things (IoT) is the recognized next step of ubiquitous networking of machines and devices. Smart appliances currently evolve in conjunction with small, lightweight devices which generate completely new requirements for the underlying radio communication technology. Significantly, material costs of these devices are often well below $10, such that a wireless communication component has strong demands on the target pricing. The classical ISM bands are suitable candidates for license-free radio communications, utilizing cheap radio transceivers compared to WLAN solutions or cellular radio technologies. However, transmission ranges of only a few meters have been a significant hurdle to network implementation in the past.

To address this issue, a new transceiver front-end technology called LoRa™ (an abbreviation for long range) has been developed and patented by the semiconductor company Semtech. It allows for much longer distances compared to the classical ISM band radio front-ends, with up to 15 km range. The long range is achieved under line-of-sight conditions using a correlation mechanism based on spread spectrum technology in the front-end of the transceiver, with the trade-off of reduced transmission bit rates at the longer distances.



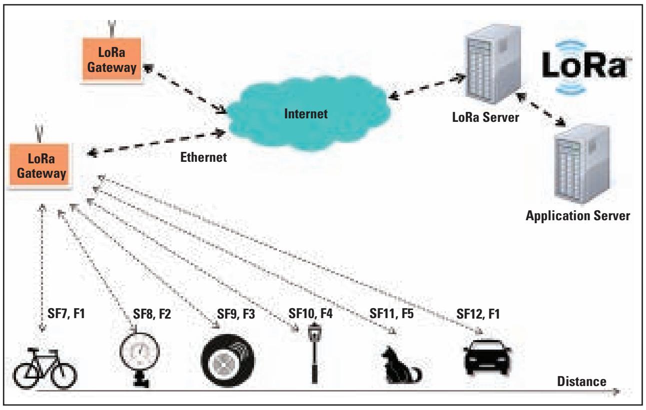
▲ *Fig. 1 The IMST LoRa iC880A concentrator module.*

Cellular systems with a coverage area of many square kilometers are possible. According to the envisaged applications, tens to hundreds of end nodes will have to be handled within one communication cell. Thus, the central communication point – the concentrator, as the radio part of a LoRa gateway – must be capable of massive parallel receive operation on many channels, each of them individually configured for certain distances and bit rates. There are many applications which will be supported by long range cellular license-free communications such as agriculture, industrial, logistics, smart environment, smart metering, smart city and smart home. Public telecom operators as well as private companies are currently implementing LoRa-based system solutions with the corresponding access networks and the necessary IT infrastructure. The deployment of LoRa technology is structured and organized by the LoRa Alliance (www.lora-alliance.org), where semiconductor companies, radio equipment manufacturers, firmware and software providers, mobile operators, IT companies and test houses work together to set up a complete LoRa ecosystem, including the required quality procedures and system certifications.

The novelty of the air interface is mainly characterized by the introduction of a spreading factor, which denotes the relationship of transmission time to bit rate due to the spread spectrum transmission mentioned earlier. It utilizes a bandwidth of 125, 250 or 500 kHz in the available ISM radio bands (e.g., about 868 MHz in Europe), together with frequency selection and frequency hopping options, to transmit with a transmitter-specific hopping code for user separation. A transmission channel is mainly characterized by the spreading factor and the frequency. The configuration parameter space is enhanced by two very important dimensions utilizing these two parameters.

Whereas the end nodes are capable of transmitting data packets on only one channel, the current IMST concentrator module – iC880A – is able to receive packets of different end nodes on eight channels in parallel. The IMST LoRa iC880A concentrator module (see ***Figure 1***) is fully certified according to the European R&TTE guidelines, offering a comprehensive set of firmware options for media access and networking. Operating in the 868 MHz frequency band and measuring 79.8 × 67.3 mm, key features include: sensitivity down to -138 dBm, output power to 20 dBm, USB or SPI interface with optional GPS, SX1301 baseband processor, 2 × SX1257 Tx/Rx front-ends, 49 × LoRa demodulators, 1(G)FSK demodulator and 8+1+1 parallel demodulation paths for LoRa and GFSK demodulation. A complete LoRa explorer kit is available for networking trials, and LoRaWAN™ and IMST LR_Base/LR_Starnet firmware is available for the optimal choice of MAC and networking features.

The concentrator architecture is fully scalable if more channels are required, with the expense of additional hardware. Several users may share a channel in the time domain if a duty cycle for each user is introduced. With this capability of parallel reception, the handling of large LoRa cells with hundreds of end nodes is feasible and maintainable.



▲ *Fig. 2 Typical architecture of a LoRa network with different applications and different spreading factors (SF) and frequency channels (F). The concentrator is the central radio part of the gateway.*

While a mesh network structure always imposes a heavy protocol overhead, which does not fit with the notion of lightweight implementation, a star structure with a central communication point in the middle of a cell appears to be the right means of administering the deployed end nodes with central control, strong synchronization and minimum protocol overhead (see ***Figure 2***).

The protocol stack firmware has to cope with such new and promising architecture and use cases with their specific user scenarios. Communication capacity has to be optimized – this is particularly important with the lower bit rates compared to traditional short range wireless communication. Furthermore, the media access control (MAC) has to be organized in such a way that the number of collisions on the radio channel is minimized and the transmitted power and used spreading factor are set to the actual required minimum, depending on the data rate and the distance of the end nodes to the concentrator in the middle of the cell.

This is done with an adaptive data rate (ADR) access scheme. The first MAC implementations were quite simple with only random access to the channel; since then, more complex MAC designs have been realized. With a view to regulatory requirements, adaptive frequency agility (AFA) and listen before talk (LBT) are two strategies to avoid the duty cycle restrictions of the ISM bands. Other implementations with central control and central synchronization aim to maximize system capacity while minimizing power consumption of the sensors, simultaneously allowing for long term battery operation of the end nodes.

LoRa-based communication systems will complement the mobile networks in an ideal manner – no costs for air time will occur, the devices are inexpensive and can reach long ranges. Gateways built from the concentrator will enable a communication path to the Internet, either via mobile cellular technology, DSL subscriber line, Ethernet or wireless LAN connections.

IMST GmbH
Kamp-Lintfort, Germany
www.wireless-solutions.de
www.webshop.imst.de

Tech Brief

Low g-Sensitivity, Ultra-Low Power OCXOs

CTS Corp.
Elkhart, Ind.

CTS has expanded its OCXO portfolio with the addition of a low g-sensitivity option on their miniature, high performance, ultra-low power OCXOs. Models 144, VFOV405 and VFOV504 now include low g-sensitivity at 10 and 100 MHz to 2^{-10}/g. This is an order-of-magnitude improvement under dynamic conditions. Added to the size, weight, power (SWaP) and other performance features, these products are highly attractive compared to the industry's standard OCXOs, which are large and power hungry.

The 144, VFOV405 and VFOV504 models cover HF, VHF and UHF bands and come in TO-8, cold-welded, evacuated enclosures. The addition of the low g-sensitivity option provides compelling solutions for the most challenging, high performance, frequency control needs, especially under dynamic conditions.

CTS LPOCXOs are designed into defense, aerospace, industrial and commercial applications. They are used in Tx/Rx, GPS and local and master reference sources for ground, airborne, shipboard, undersea and space systems. CTS products are known for precision (≤ 10 ppb, -40°/+85°C), low static phase noise (to -100 dBc/Hz at 1 Hz, -170 dBc/Hz floor) and ultra-low power consumption (to 0.12 W steady state and 0.4 W start-up, typical). This performance is now combined with low g-sensitivity in a TO-8 package. In addition to low g-sensitivity, CTS also addresses the vibration and shock levels associated with all the markets they serve.

CTS Corp.,
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Albert.Riso@ctscorp.com

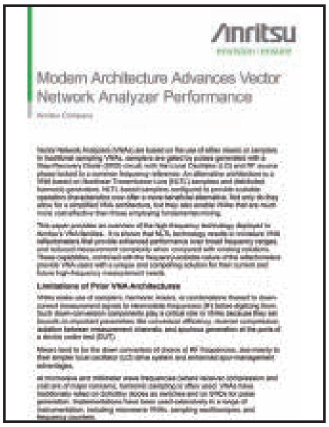
Company Showcase

Website Redesign

Anokiwave launched the redesign of their website to provide visitors, customers and partners with relevant and easy-to-find information about their new mmWave Silicon ICs, AESA ASICs and III/V products. The new look and improved functionality allows users to access new product information and the company's blog with articles authored by their engineering team. The new website also includes new product information with datasheets, company overview and leadership team bios, links to Anokiwave's social media pages and the latest company buzz.

Anokiwave Inc.

www.anokiwave.com



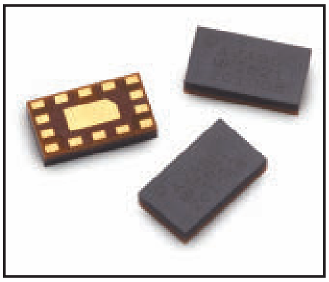
Modern Vector Network Analyzer

VENDORVIEW

Modern Vector Network Analyzer (VNA) architectures such as those based on Nonlinear Transmission Line (NLTL) samplers and distributed harmonic generators now offer a beneficial alternative to traditional sampling VNAs. They allow for a simplified architecture and also enable VNAs that are much more cost effective. It is shown that NLTL technology results in miniature VNA reflectometers that provide enhanced performance over broad frequency ranges and reduced measurement complexity, providing VNA users a unique and compelling solution for their high-frequency measurement needs.

Anritsu Co.

www.goanritsu.com/VNAFam



LTE Carrier Aggregation Multiplexers

The number of cellular bands used concurrently under LTE Advanced continues to increase. Multiple carrier frequency bands are being aggregated to provide higher data throughput. Leveraging unique FBAR filtering technology and in-house RF module expertise, Avago Technologies provides the industry's most comprehensive and advanced portfolio of LTE carrier aggregation (CA) multiplexers enabling mobile data aggregation of more than 25 frequency segments.

Avago Technologies

http://go.avagotech.com/LTE-CA

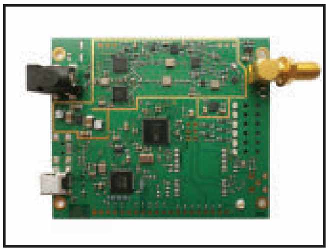
TL-P PIM Test Solutions

VENDORVIEW

The TL-P product line is the ideal solution for bench top PIM analyzers in an indoor environment (lab or factory testing) offering excellent return loss performance. It joins a user-friendly handling that is new to the market, as well as durability and reliable PIM results in one product – an investment that boosts total cost of ownership. With its light weight and smooth physical characteristics, HUBER+SUHNER's TL-P is also a great asset for field test applications.

HUBER+SUHNER

www.hubersuhner.com

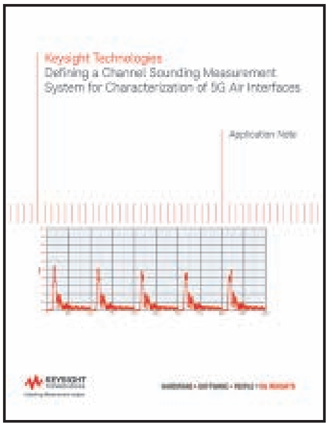


LoRa Concentrator Module

The IMST LoRa™ concentrator module iC880A is targeted for a huge variety of IoT applications. It is a multi-channel, high performance transmitter/receiver module designed to receive several LoRa packets simultaneously using different spreading factors on multiple frequency channels. It can easily be integrated into a gateway as a complete RF front-end. The module is fully certified according to the European R&TTE guidelines. A comprehensive set of firmware options for medium access and networking is available.

IMST GmbH

www.imst.com



5G Channel Sounding

VENDORVIEW

This new 5G application note provides insight into defining a channel-sounding measurement system for characterization of 5G air interfaces through a variety of measurement methods. The emerging 5G standard will almost certainly incorporate a combination of millimeter wave (mmWave) frequencies, ultra-broad bandwidths and massive multiple-input-multiple-output (MIMO) methods. Although each of these adds difficulty to the design of transmitters and receivers, the most significant unknowns are in the over-the-air radio channels between user equipment and base station. Keysight's 5G solutions are ready to enable deeper insights as the standards evolve.

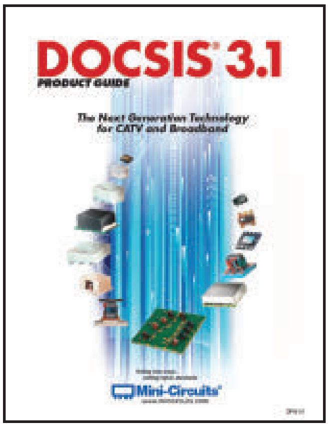
Keysight Technologies

www.keysight.com/find/5G

Company Showcase

DOCSIS 3.1 Product Guide

VENDORVIEW



Mini-Circuits' new DOCSIS® 3.1 Product Guide, a 116-page full-color catalog, showcases the company's line of "next generation" products for CATV and broadband markets. The guide provides detailed information on Mini-Circuits' wide range of RF components, all carefully specified to meet DOCSIS 3.1 standards. This includes everything from passive devices such as its transformers, couplers, and splitter/combiners to active elements such as amplifiers, equalizers and more. With over 70 different DOCSIS®-compliant models, chances are Mini-Circuits has your application covered.

Mini-Circuits

www.minicircuits.com

NI AWR Design Environment V12.01

VENDORVIEW

NI AWR Design Environment

NI AWR Design Environment™ is complete high-frequency design software for system simulation, circuit simulation, and electromagnetic analysis. V12.01 has been released and continues to build upon the new load-pull features of V12. In addition, the V12.01 update includes multiple improvements to system simulation within Visual System Simulator™, layout, tuning, yield analysis and optimization capabilities within NI AWR Design Environment, inclusive of Microwave Office and AXIEM and Analyst™ 3D EM simulators.

National Instruments

www.ni.com

Channel Sounding Test Solution

VENDORVIEW

Rohde & Schwarz supports research activities to make the spectrum in the millimeter wave range usable for 5G with a new channel sounding solution. It is based on the R&S SMW200A vector signal generator and the R&S FSW85 signal and spectrum analyzer, the only device on the market that covers 2 Hz to 85 GHz in a single sweep without the need of external harmonic mixers. Equipped with the R&S FSW B2000 option, it can even analyze signals with a bandwidth of up to 2 GHz.

Rohde & Schwarz GmbH & Co. KG

www.rohde-schwarz.com

Low PIM Switch for T&M

VENDORVIEW

The saving potential of SPINNER's low PIM switches in RF testing environments is immense. They spare you the hassle of undocking and redocking measurement cables when performing different measurements on the same DUT. Technically speaking, these are DPDT switches with two parallel-switching inputs and outputs. They are available with 7-16 and 4.3-10 connectors and specified for -165 dBc (typ. -170 dBc). A perfect fit for measuring VSWR and PIM in the frequency range between 330 MHz and 3800 MHz.

Spinner GmbH

www.spinner-group.com

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