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- · Radar Applications · Aircraft And Shipboard Applications
- · SATCOM Applications · Links For Satellite Ground Stations
- · ELINT, EW And EMC Applications · Tactical Common Data Links

Electrical Specifications (1 Meter of Fiber)

Liectifical opecifications (1 Meter of Fiber)											
	Noise Input Power Spurious Free Phase Gr								Available Wavelengths		
		Gain	Figure		Dynamic Range	Noise		VSWR	Standard	Optional	
Series	Frequency	(dB)	(dB)	(dBm, Min.)	(dB/Hz, Typ.)	(dBc, Typ.)	(ns)	(In/Out)	(nm)	Wavelengths	
Transmitters and Receivers											
SLL	5 kHz - 2.5 GHz	12	18	-14	103	>100	0.2	2:1	1550/1310	18 CWDM Ch	
	100 MHz - 2.5 GHz	12	18	-14	103	>100	0.2	2:1	1550/1310	18 CWDM Ch	
LBL	50 KHz - 3 GHz	15	11	-14	106	>100	0.2	2:1	1550/1310	18 CWDM Ch, 45 DWDM Ch	
	50 KHz - 4.5 GHz	15	11	-14	106	>100	0.2	2:1	1550/1310	18 CWDM Ch, 45 DWDM Ch	
	10 MHz - 3 GHz	15	11	-14	106	>100	0.2	2:1	1550/1310	18 CWDM Ch, 45 DWDM Ch	
	10 MHz - 4.5 GHz	15	11	-14	106	>100	0.2	2:1	1550/1310	18 CWDM Ch, 45 DWDM Ch	
LBL-HD	950 MHz - 2.5 GHz	0	22	7	114	>100	0.2	2:1	1550/1310	18 CWDM Ch	
SCML	50 kHz - 6 GHz	15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
	100 MHz - 6 GHz	15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
100 MHz -11 GHz		15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
	100 MHz -13 GHz	15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
100 MHz -15 GHz		15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
	100 MHz - 18 GHz	15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
	10 MHz - 18 GHz	15	15	-14	103	>100	0.2	2:1	1550	1310/1490 nm	
High Gain Broadband Receivers											
DR-125G-A	30 KHz -12.5 GHz35	5 O/E (o	r TIG = 2	800 ohms)				2:1		1280-1580	
SCMR-100K20G 100 KHz - 20 GHz32 O/E (or TIG = 2000 ohms) 2:1 1280-1580											

CWDM: Course Wavelength Division Multiplexing, DWDM: Dense Wavelength Division Multiplexing

Enclosures Are Available For Multiple Tx or Rx Combinations





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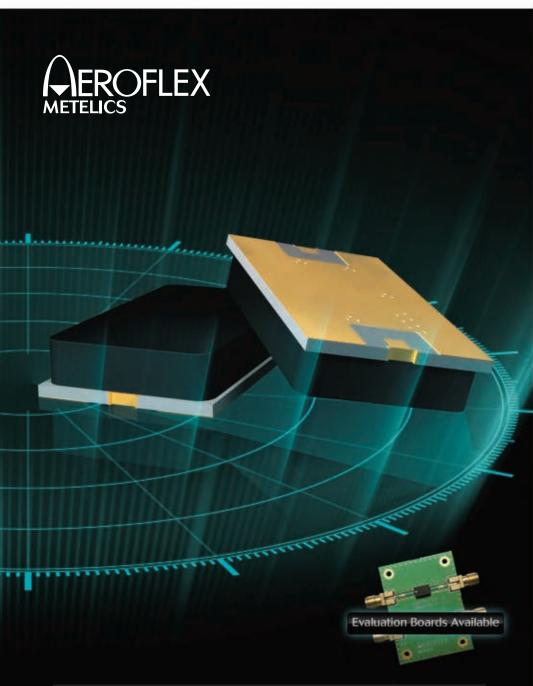
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LM501202-M-C-300	Octave Band, Med Power	500-2000	0.6	30
LM202802-L-C-300	Octave Band, Low Power	2000-8000	1.0	4
LM202802-M-C-300	Octave Band, Med Power	2000-8000	1.2	30
LM401102-Q-C-301	Octave Band, High Power, "Quasi-Active"	400-1000	0.3	100
LM102202-Q-C-301	Octave Band, High Power, "Quasi-Active"	1000-2000	0.5	100
LM202802-Q-C-301	Octave Band, High Power, "Quasi-Active"	2000-8000	1.4	100





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This month's cover image is based on a 1992 paperback edition of *The Time Machine* by H.G. Wells (Tom Doherty Associates LLC, New York, NY).



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RF Design Using ADS 2011: Details recent advances for multi-technology co-design, inherent in RF modules and system-in-package (SiP) designs using EM analysis and a fully integrated design platform.

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Future of Arbitrary Waveform Generators: Presented by Agilent Technologies Inc.

See how engineers can push their design to the limit and bring new insights into their analysis with technology featured in this month's MVP product feature.

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LNA Design and Test Verification: The design of low-noise amplifiers is demonstrated. Design software and a vector network analyzer are integrated to bring the measured and simulated results together for comparison and virtual model verification.

Live webcast: 3/8/11, 12:00 PM EST

RF/Microwave Training Series: Presented by Besser Associates

RF Oscillators: Provides an overview of oscillator design, specifications and the topologies used to meet these performance challenges.

Live webcast: 3/15/11, 11:00 AM EDT

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Real Time Spectrum Analysis of Dynamic RF Systems: Presented by Rohde & Schwarz

A look at new measurements for the development and optimization of synthesizers, radar systems and other transmitters.

Available 3/17/11, 11:00 AM EDT

Executive Interview

Larry Pendergrass, Director of Engineering, Sources/Analyzers Product Line, **Tektronix**, talks about the expanding role of test & measurement instruments in the military and aerospace arena and how today's test solutions are helping to reduce the mission risk.



Special MWJ Webcast

MIMO OTA Expert Forum at CTIA Wireless

Featuring presentations from Agilent, ETS-Lindgren, Elektrobit and Spirent

This Forum highlights the technical features of systems for MIMO Over-The-Air testing of mobile devices and networks.

Simulcast web panel: 3/24/11, 10:30 AM EDT

Online Technical Papers

Solutions for Verifying LTE Signals: Quickly and Accurately Decode LTE Downlink Signal Data

White Paper, Agilent Technologies Inc.

Harmonic Measurement for IEC 61000-4-3 and other Radiated Immunity Standards

Jason Smith and Pat Malloy, AR Worldwide

Using COMSOL to Solve for Currents Along a Thin-wire Antenna Excited by a Lumped Source

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THE BEST OF SAAD

Introduction by Peter Staecker, Chairman, 1991 MTT-S Boston Symposium; Compiled by David Vye



1920-2011

Many of us grew up in the afterglow of Ted Saad's accomplishments. I first met Ted at the Dallas symposium in 1982; the MTT Society of which he was a founding member was celebrating its 30th birthday. Ted was a key figure in MTT's growth and culture: he was the second editor of the MTT Transactions; chaired the Administrative Committee in 1959; and was instrumental in bringing the microwave exhibition to the Society's annual meeting. Ted's first assignment after graduating from MIT in 1941 was with the MIT Rad. Lab., the start of an illustrious career as a microwave practitioner, individual contributor and business executive, and founder of Sage Laboratories. He never forgot the importance of nurturing and recognizing *The Individual*—in his life and in all the lives he touched. As early as the 1960s Ted saw the wave of the future, as he noted below. He was surprised at the business-reach of the *Microwave Journal*, which he co-founded and discussed briefly and with great insight. Because of the principles of excellence he instilled in the editorial practice in both the *Journal* and in the *Transactions*, however, it's not amazing at all. It's just Ted.

ON "CONFERENCES AND EXHIBITIONS"

Usually we reserve the technical sessions at [various conferences] for assessing what the new ideas are and where the technology is going. I believe it is equally important to find out at least two more things, the first is whether the new ideas can be made into useful products and the second is whether there is a market. They will comment on these two facts at the technical sessions, but ultimate proof will come only at the exhibition.

Too many engineers consider it beneath their dignity to spend time visiting more than a few booths at technical exhibitions. The fact is that to do more requires discipline, but it is a useful, even important, part of the education process. For anyone in a position of responsibility it is an ideal time to find out in broad but fairly accurate terms, what is happening. For designers, there are many new ideas to explore and a few to explode. For an editor, it is an easy way to see what is happening and to visit with old friends.

ON "WHO READS MWJ"

I recently reviewed the results of the code-book tabulation [readership study, 1969]. I was surprised to find that the 50 organizations with 100 or more subscribers had a total *Microwave Journal* reader population of about 14,000. That leaves a population of over 22,000 divided between 2550 organizations.

The needs of this audience places a great burden of responsibility on a publication such as the *Microwave Journal*. It is one thing to have a large audience. But it is more important, to guarantee to that audience every effort is being exerted to insure the technical integrity of the material published.

From our first issue we have made every possible effort to do so. Our editorial board, our expert reviewers and our stringent review process are well known. The survey only served to remind me that there was no other intelligent and responsible way to publish for our audience, 14,000 in 50 or 22,000 in 2550.

ON "INSTRUMENTATION, THE COMPUTER AND THE MANPOWER SHORTAGE"

At the IEEE Show, Hewlett-Packard was using a computer to program microwave test equipment. Using time-sharing techniques along with sweepers, network analyzers, appropriate indicators and suitable microwave circuits, the technique promises that it will dramatically reduce the time required to measure microwave components and circuits, both in design and production test.

With proper instrumentation, and I am convinced the computer is a key element, not only should we be able to increase the output of microwave manpower, but also we should be able to achieve results from sources not previously considered productive. It has been my contention that the faster results are made available to the design engineer, and the more information he can see at a glance, the more effectively he will be able to work.

ON "THE INDIVIDUAL"

There is a great need to encourage people to be individuals. The herd instinct is strong in many of us, but we are each of us, because of the privacy of our innermost thoughts, first and foremost individuals. Today there is an increasing trend towards reducing all of us to statistics. What is even worse is the phrase we have been guilty of using – "the average engineer." A much better phrase that we would like to promote is – "the individual engineer."

There is much talk about a shortage of engineers, but a shortage that is much more serious is the shortage of individuals. This is true not only of the microwave industry but of society in general. One of the most important things we can do to help young engineers starting out is to make them aware of their fundamental importance and tremendous potential as individual contributors.

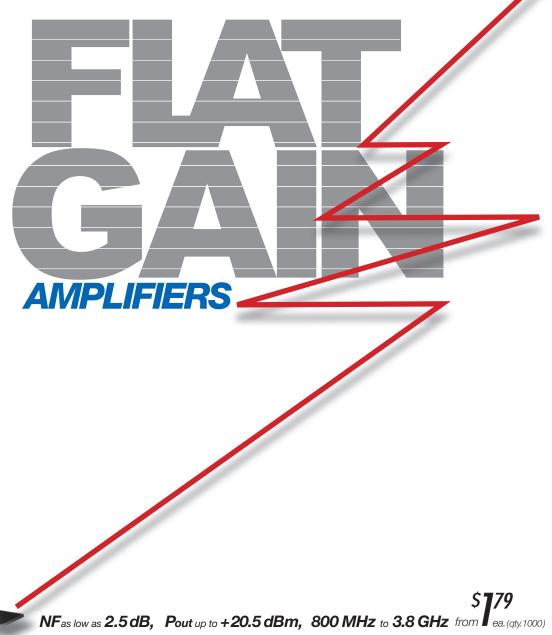
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YSF-162+	1200-1600	20.1	0.2	20.0	21.0	3.2	35	2.69
YSF-232+	1700-2300	20.0	0.2	20.0	21.0	2.8	35	2.69
YSF-272+	2300-2700	19.0	0.7	20.0	21.0	2.5	35	2.59
YSF-382+	3300-3800	14.5	0.9	20.0	21.0	2.5	36	2.59
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TIME IS ON OUR SIDE: OSCILLOSCOPES FOR MICROWAVE ENGINEERING

arly in the first chapter of his microwave textbook, my former undergraduate professor Dr. Peter Rizzi introduced me and my fellow classmates to some of the anomalies in this field of study by making comparisons to its low frequency and optical counterparts. Along with the electrical impact of skin depth and component size relative to wavelength, Dr. Rizzi wrote that another "unique characteristic of microwave work was in the area of measurement technique."

"At low frequencies, it is common to measure voltage and current when studying the properties of a circuit or system. In microwave circuits, however, the voltage and current are not, as a rule, uniquely defined. Furthermore, the direct measurement of microwave voltages is usually accompanied by considerable noise fluctuations, resulting in poor sensitivity, low dynamic range and significant errors. As a result, microwave measurements usually involve the accurate determination of impedance and power rather than voltage and current."

Well, that was the early eighties. Flash forward twenty-plus years and the advancement of RF/microwave measurement techniques and supporting semiconductor and software technology has progressed to the point where direct, time-domain measurements of voltages and currents operating in the microwave range is not only reality, it is becoming critical to de-

sign and debugging. And so the ultimate "time machine" for measuring IV waveforms—the oscilloscope—has renewed interest among RF engineers. In this special report, MWJ editors spoke with technologists from Agilent, Le-Croy, Rohde & Schwarz (R&S) and Tektronix about the state of multi-GHz oscilloscopes, their enabling technologies, performance, features, applications and what to look for from the perspective of a user. This special report details our findings.

BACKGROUND

Digital oscilloscopes can be divided into real-time including digital storage oscilloscopes (DSO), digital phosphor oscilloscopes (DPO) and mixed signal oscilloscopes (MSO) based on the over-sampling methodology and (equivalent time) sampling scopes based on the sequential-sampling methodology. Equivalent time sampling scopes take advantage of the fact that many natural and man-made events are repetitive in nature and therefore samples may be acquired over many repetitions of the signal. These types of scopes typically target the very high-end bandwidth (currently >100 GHz), traditionally with lower sampling rate

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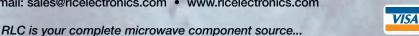
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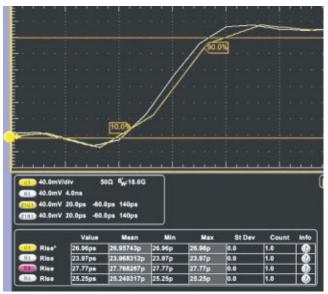
Analog to Digital Converters (ADC). As a result, only repetitive signals can be captured by means of under-sampling. Example applications include characterization of the signal integrity of high-speed communication signals.

Guido Schulze, Product Manager of Oscilloscopes at Rohde & Schwarz, contends that the bulk of digital oscilloscopes are real-time oscilloscopes. While sampling oscilloscopes offer high bandwidth, the tradeoff compared to DSOs is limited dynamic range and the inability to capture intermittent events.

One of the most important elements of a real-time oscilloscope is sample rate, which refers to how frequently it takes a snapshot or samples a signal. The faster an oscilloscope samples, the greater the resolution and detail of the displayed waveform and the less likely it is that critical information or events will be lost, as shown in *Figure 1*. The sample rate/bandwidth ratio has to fulfill the Nyquist criteria of equal to or greater than 2. In practice, a factor above 2.5 to 5 is required; for example, 2 GHz bandwidth requires a 5 Gsample/s maximum sampling rate.

With over-sampling applied, such as the 100G S/s capability found in the Tektronix 70000C Series Oscilloscopes, engineers get more data points to accurately understand rise time performance on signals with ~20 picosecond rise time. "With the 5× oversampling on our latest introduction, Tektronix is making sure that leading-edge signal fidelity designers have what they need to characterize very fast design speeds," says Chris Loberg, Senior Technical Marketing Manager, Tektronix.





▲ Fig. 1 Improved resolution shown of a fast rising edge on a Tektronix MSO72004C real time oscilloscope at 100 GS/s (white trace) vs. 50 GS/s sample rate (yellow trace) using linear interpolation.

An interesting trend of the real-time oscilloscopes is that more and more functionality is being added to the original time domain analysis. Examples are additional digital channels (1 bit comparator instead of 8 bit ADC) for logical analysis, protocol-based trigger and decoding for debugging of protocol-based interfaces, or advanced FFT capabilities for a spectrum display. All these new capabilities support faster debugging of highly integrated designs (embedded designs).

David Graef, Chief Technical Officer at LeCroy, agrees that many signals nowadays are not and cannot be made to be repetitive. For this reason, a broad band (DC to multi-GHz) digitizing oscilloscope is the most generally useful. However, with the very broad band signal path comes noise. Many signals can be characterized using a digitizing oscilloscope with 35 to 40 dB SNR and less than 1 percent THD. However, there are classes of signals that require better than that. Signal analyzers generally employ a down-converter in front of a higher resolution ADC. The total bandwidth covered can be quite wide. The instantaneous bandwidth (bandwidth that is actually digitized for analysis) is quite narrow, generally in the range of a couple of hundred MHz. The SNR and THD in that narrow band can be quite good so signals with very wide dynamic ranges can be analyzed. This is very useful for band-limited signals.

HIGH-BANDWIDTH OSCILLOSCOPES AND THEIR ENABLING TECHNOLOGIES

One of the biggest changes to oscilloscope technology recently has been the shift to higher frequencies, allowing them to operate in the > 20 GHz range. What key enabling technologies have allowed oscilloscopes to operate in the multi-GHz range? This capability has been the result of many engineering innovations and investment in faster chip processes by leading scope vendors. According to Brig Asay of Agilent Technologies, "The cutting edge of process speeds is necessary in order to keep up with the bandwidth demands of engineers. A side benefit of these new processes has been better noise and jitter performance."

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LeCroy's Graef credits a few key with technologies enabling oscilloscopes to operate in the multi-GHz range. "There are a number of facets to this... the signal path (front-end amplifier—ADC—memory), stable sample clock generation and triggering. The availability of very samples. high speed process-

es—SiGe and InP—have allowed much faster front-end amplifiers and ADCs. The ability to achieve the required sample rate using massively interleaved CMOS ADCs as an alternative to faster SiGe ADCs has also allowed high frequencies to be reached. LeCroy has an additional technology—Digital Bandwidth Interleave (DBI)—that allows them to go beyond the limits of raw silicon performance and multiply that by a factor of two or three thereby achieving even higher bandwidths" (see *Figure 2*).

Both Tektronix and LeCroy currently utilize IBM's 8HP process, which offers a significant speed improvement over the previous 7HP process. Using its frequency interleaving technique, LeCroy has been able to push the operating range of its scopes to greater than 20 GHz.

According to Graef, there have been many advances in frequency generation technologies that allow sample clock generation circuits to be built with extremely low jitter. This is required for the oscilloscope acquisition system (ADC) to have sufficiently good performance at very high input frequencies. The availability of low noise, high quality amplifiers—many designed on a SiGe process—and frequency generation techniques (fractional-N synthesizers) along with high quality oscillators at reasonable costs has enabled the oscilloscope time base to be built. Loberg points out that low noise performance becomes even more critical as oscilloscope bandwidths rise. "With the timing performance of a rising edge being characterized in today's labs with jitter tolerances in the femtosecond range, the slightest amount of instrumentbased noise from the amplifiers or

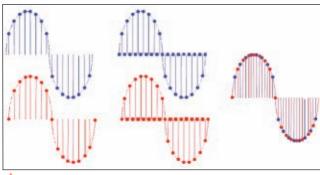


Fig. 2 Interleaving in the time domain involves upsampling the acquired waveforms by inserting intermediate zeros and then adding them together with a half sample period delay for digitizer B's samples.

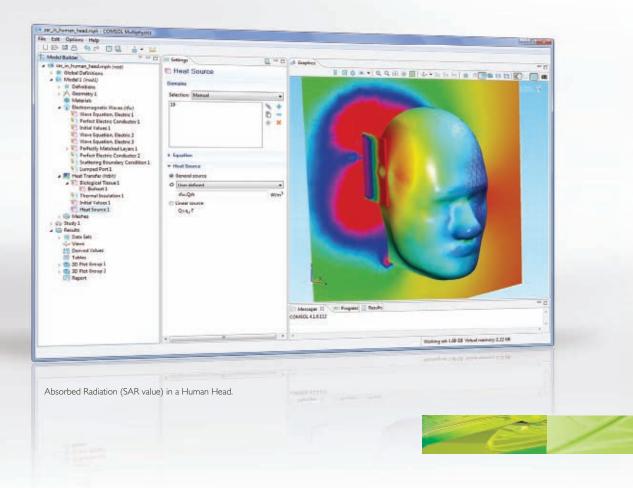


▲ Fig. 3 Agilent's DSO-X front-end module with preamp based on the HB2B InP HBT process also contains the trigger and sampler ICs.

other components in the oscilloscope can have a dramatic effect on signal integrity. Tektronix advises its customers to consider bandwidth needs alongside the ability to minimize noise in the instrument to achieve accurate measurement data that reflects the device's performance alone."

The same processes that enable the signal path also enable the triggering. SiGe and InP circuits can be designed with sufficient bandwidth to allow triggering the oscilloscope up to bandwidths approaching the bandwidth of the scope. In contrast to the 8HP process favored by LeCroy and Tektronix, Agilent has developed a proprietary Indium Phosphide process with a transistor cut-off frequency of greater than 200 GHz (see Figure 3). The use of InP allows Agilent to achieve its performance without the use of interleaving, a technique that uses down-conversion to be able to achieve the bandwidth. According to Agilent, there are some tradeoffs with using this technique, which include higher noise density and mixing errors, but





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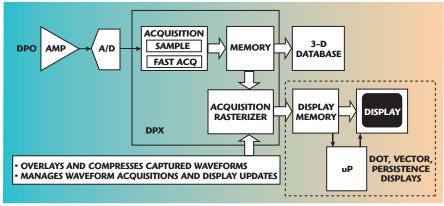


Fig. 4 Simplified block diagram of the Tektronix DPX-based display system.

it is a technology that allows for faster bandwidth.

THE MID-BANDWIDTH OSCILLOSCOPE MARKET

Oscilloscope models ranging from 350 MHz to 2 GHz are the single most popular segment for oscilloscopes and are used to develop and verify products in a broad range of industries and applications. Typically priced under \$20,000, mid-range oscilloscopes are becoming increasingly capable. For instance, the new MSO/DPO5000 Series from Tektronix incorporates many of the most popular features from the company's leading performance oscilloscopes at a much lower price. Features include a >250,000 wfm/s maximum waveform capture rate, fast segmented memory acquisition and long record length to capture long time periods at high resolution, extensive built-in tools for in-depth analysis of complex designs, and a Windowsbased user interface.

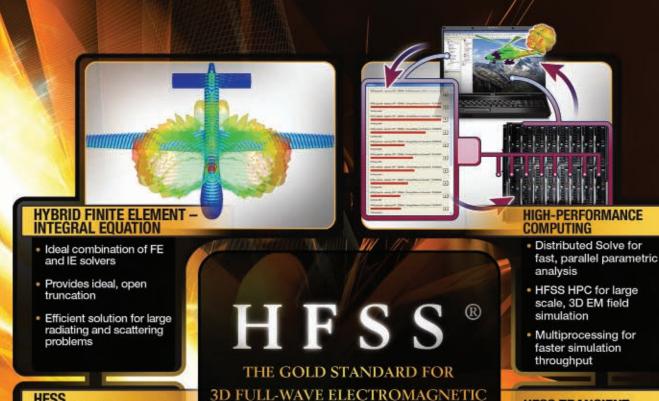
According to Guido Schulze from Rohde & Schwarz, his company's recently introduced RTO digital oscilloscope family uses standard components in building scopes dedicated to the mid-bandwidth oscilloscope market. Schulze attributes the measurement performance of the product family to the in-house designed frontend components. The R&S RTO front-end is based on a low noise amplifier stage and a single-core 10 GHz ADC. Beyond about 350 to 500 MHz, digital oscilloscopes are possible only through customized amplifiers, ADCs and ASICs.

The front-end amplifier used in the R&S instrument provides low noise characteristics and high sensitivity, supporting a vertical range down to 1 mV/div without bandwidth reduction. The respective ASICs are realized in SiGe BiCMOS process and for bandwidth reasons are mounted on a ceramic board. The 10 GHz ADC is built up in a true monolithic single-core design. This approach avoids distortions caused by interleaving of several slower ADCs and enables a high measurement accuracy of > 7 effective number of bits (ENOB).

The processing ASIC is the heart of the R&S RTO oscilloscope. It includes several innovations concerning fast acquisition and analysis and the triggering concept. A main challenge for using a "digital oscilloscope" as a debug tool is the fast processing of the high amount of sample data (e.g. a 10 GHz 8 bit ADC outputs 80 Gsample/s). An acquisition cycle consists of a typically short acquisition time (e.g. 1000 samples at 10 Gsample/s result in 100 ns acquisition time) followed by a relative long processing time where the oscilloscope does not capture the test signal. Schulze (R&S) claims that typical digital oscilloscopes are in most cases more than 99.9 percent blind.

To improve on this, R&S uses a processing ASIC that includes multiple processing paths for the acquisition and post-processing steps. This enables a maximum acquisition and analysis rate of greater than one million waveforms per second. The high acquisition rate enables the fast detection of rare signal anomalies. The fast processing on the other hand allows more waveforms in the analysis and therefore provides higher statistical confidence in the results.

The second part of the processing ASIC relates to the trigger system. The R&S RTO includes a real-time capable digital trigger system (Schul-



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ze comments that the trigger jitter of analog oscilloscopes can be reduced with SW-based post-processing, which has the disadvantage of extending the blind time). The trigger system of the R&S instrument operates with the same sample data as the acquisition unit. Consistency between acquisition and trigger system results in trigger jitter below 1 ps RMS, which is similar to other mid-range oscilloscopes on the market.

Advanced waveform display technology in a mid-range oscilloscope has been an important part of the Tektronix DPO family of oscilloscopes for many years (see Figure 4). Available on its recently introduced MSO/ DPO5000 Series, Digital Phosphor technology (DPX) utilizes a patented parallel processing for a continuous waveform to capture, display, store and analyze complex signals in realtime, using three dimensions of signal information-amplitude, time and distribution of amplitude over time resulting in an intensity graded display.

Another advancement in midrange oscilloscopes has been the sophistication of triggering systems. An intelligent, responsive trigger system dramatically speeds up debugging by "arming" the designer with a wider array of methods to capture a signal of interest. As an example, the Tektronix MSO/DPO5000 Series Oscilloscope comes equipped with an A/B Event trigger that can trigger on one of up to 350 different trigger conditions. Triggering could be setup to look at a digital circuit's setup and hold violation or even look for a serial bus protocol word or addressing scheme and trigger when that "word" is found.

APPLICATIONS

Asked about how the typical RF designer uses an oscilloscope to analyze circuit performance, oscilloscope manufacturers mentioned that a typical traditional RF engineer tends to think in the frequency domain more than the time domain. As Graef of LeCroy puts it, "For a die-hard, old school RF engineer a VNA and a spectrum analyzer would be more the tools of choice. However, many engineers today are working in the RF domain and are required to solve time domain problems." Serial data standards are

now extending in frequency to at least 12.5 Gb/s for common third generation standards. This is traditional RF territory for digital data. Oscilloscopes are very useful for being able to look at and make detailed measurements on jitter or many other characteristics of the signals. Modern high performance sampling or equivalent-time oscilloscopes can also use S-parameter descriptions of a transmission path to de-embed that path from the measurement. Oscilloscopes can also do demodulation of signals so the engineer can look at the information as well as the modulated carrier.

Schulze responded that many RF designers have to deal with analog and digital components in their designs. "Here the basic debug tool is again a digital oscilloscope. An oscilloscope becomes interesting for RF interfaces if the bandwidth requirements exceed the maximum bandwidth of current generations of spectrum analyzers. In such cases, however, the measurement dynamic of the oscilloscope is the limiting parameter (oscilloscopes typically have 8 bit ADCs, spectrum analyzers rather 12-14 bit ADCs)." It is worth noting, of course, that it is not the number of bits that define dynamic range; spurious-free dynamic range (SFDR) is the key figure of merit for RF designers. ŚFDR needs to be specified by fractional bandwidth and at the frequency of interest when using a scope, says Loberg.

A good example for when to use an oscilloscope is a cellular phone chip. It includes all kinds of RF, digital and mixed signal interfaces. An oscilloscope is useful for tests on digital interfaces, e.g. signal integrity or data content. On the RF interface, the oscilloscope, along with spectrum analyzers are used. An interesting combination of the spectrum analyzer and the scope would be the correlation of the data content, signal quality or signal errors between the RF interface and the digital interface (e.g. DigRF).

Typical applications for digital, analog and mixed signal components include standard amplitude and time measurements like voltage swing, rise time, frequency, delay, etc., advanced measurements on histograms and data eyes (e.g. jitter), and protocol decoding (e.g. low speed serial interfaces as I2C or SPI). For RF components,

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Model Range (GHz) Figure (dB) (dB) P1dB Flatness In / Out								
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Note: Specifications degrade slightly below 500 MHZ



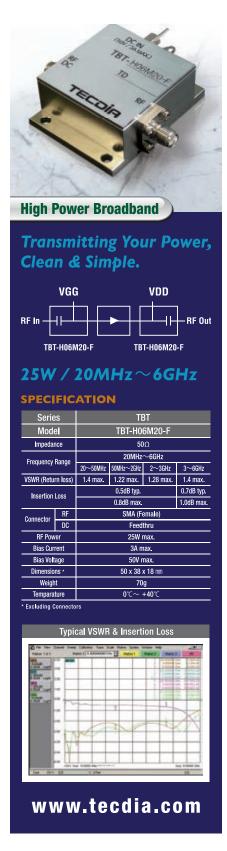
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typical applications include spectrum display and measurements and sometimes more sophisticated measurements like demodulation, etc.

An emerging segment for more sophisticated test and debugging is time-correlated, multi-domain RF analysis using an MSO together with spectrum analysis software, suggests Tektronix's Loberg. The integration of the logic state triggers enables time correlated acquisitions from the digital domain to the analog domain with a timing accuracy of 80 ps when using a high-performance MSO. This allows the designer to easily validate wideband RF and microwave designs and characterize wideband spectral events.

Asay of Agilent believes that wide bandwidth digital oscilloscopes can help the RF designer track down and debug issues with wide bandwidth RF and microwave transmitters when they occur. For example, Asay considered a transmitter design that may have been designed to meet a system-level metric like Error Vector Magnitude (EVM) for a wide bandwidth modulation application (e.g. SATCOM) or multi-channel application (e.g. MIMO). If it is not meeting its EVM specification, it can be difficult to tell where in the transmitter chain the waveform is being most impacted (e.g. power amplifier, preamplifier, LO phase noise, mixer impairments, IQ gain/phase imbalance, or a combination of all of the above). A wide bandwidth digital oscilloscope with Vector Signal Analyzer (VSA) software can help the RF designer evaluate the EVM performance at different stages along the transmitter chain from analog baseband to carrier frequencies up to 32 GHz. This can help gain insight into where issues are occurring, and help quantify the impact of the different stages on the transmitter's system-level performance.

Therefore, one key RF/microwave application is to perform measurements on wide bandwidth X-, Ku- and Ka-band radar and SATCOM transmitters—directly up to 32 GHz, without the use of custom external downconverters. This is important because down-converters can introduce their own impairments into the test signal by adding LO phase noise, amplifier nonlinear distortions and filter group delay. These down-converter impair-

ments could potentially mask the true performance of the transmitter DUT design, and make it difficult to determine how much of the measurement result is actually from the transmitter DUT, or from the external down-converter, or from a combination of both.

That said, many of these problems are the result of using improperly designed or calibrated frequency downconverters. A customizable standard down-converter such as those available with Tektronix oscilloscopes can go a long way toward expanding the role of oscilloscopes for such applications as wideband radar characterization and broadband satellite signal analysis. Advantages of down-converters include the ability to optimize downconverted signals to the optimum SFDR of an oscilloscope, the ability to increase ENOB, better time stability for microwave measurements by making measurements at down-converted frequencies, and the ability to use a less expensive scope. In the case of the latter, down-conversion of multi-GHz signals from 32 to 3 GHz using a midrange scope is much cheaper than direct Ka-band signal analysis.

MEASUREMENTS

Key radar transmitter measurements include evaluating the pulse envelope characteristics (e.g. rise time, fall time, pulse width), and the pulse modulation characteristics (e.g. linear FM chirped frequency and phase). Oscilloscope features such as segmented memory acquisition can be used to evaluate time domain measurements such as rise and fall time. To gain additional insight into the transmitter's performance, VSA software can be used to perform frequency domain measurements such as chirped frequency and phase. It can also be used to view frequency hopping characteristics with a spectrogram measurement.

To illustrate the value of today's digital oscilloscopes for radar applications, Asay (Agilent) used the example of a 2 GHz wide LFM chirp at 10 GHz (X-band). The pulse envelope characteristics (rise time, fall time and pulse width) can be evaluated in the time domain by placing oscilloscope pre-configured measurements on the pulsed radar RF envelope. Segmented memory can also be used to further optimize the number of radar pulses

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captured and analyzed within the oscilloscope's capture memory (2 GSa). Taking this example a step further, consider that the engineer would like to evaluate the spectrum and chirp modulation characteristics. The VSA software can be used on the oscilloscope to evaluate these frequency domain characteristics and perform other key RF/microwave measurements.

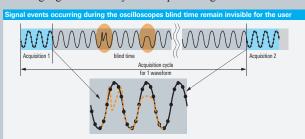
Loberg of Tektronix notes that traditional rise/fall time measurements of pulsed signals are very different than the traditional rise/fall time measurements in the default menu of an oscilloscope since it is not the carrier response, but the envelope response that needs to be measured. For pulse measurements, engineers can select from a full set of over 27 automated scalar and vector measurements that cover individual pulse frame measurements and multi-frame measurements. This includes trending statistics, histograms and FFT of measurement on-time.

Key measurements for SATCOM transmitters include constellation measurements, EVM and spectrum measurements. Oscilloscopes with VSA software can perform these types of measurements for QAM signal formats, as well as advanced formats such as orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) signal formats. As an example, take a 1 GHz wide 16 QAM modulated waveform at X-, Ku-, or Ka-band. The VSA software can be used on the oscilloscope to demodulate the waveform up to 32 GHz (Ka-band) to measure the microwave transmitter's EVM. Many different signal formats can be measured and demodulated,

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including OFDM and OFDMA commercial-off-the-shelf (COTS) formats.

For MIMO applications, evaluating the EVM and antenna crosstalk of multi-channel MIMO RF transmitters is important. Multi-channel phase-coherent oscilloscopes with VSA software can be used to evaluate the EVM of each channel, as well as the antenna crosstalk between the four channels.

An interesting application Loberg highlights concerns the design of frequency hopping radios or radars in which traditional RF analysis tools require the signal of analysis to be located in the center of the RF analysis window. To perform this, engineers are often challenged to capture the signal-of-interest when it occurs exactly in the analysis window or must use a special (non-hopping) test mode to guarantee that a signal is captured. Unfortunately, the most difficult behaviors to troubleshoot occur when hopping systems are actually hopping, behavior that may not be represented in the test mode. Discovering timing and settling issues are not fully vetted with static non-hopping test modes. An MSO together with integrated VSA software can handle these types of measurement challenges.

Loberg adds that Tektronix takes a different approach to the integration of Vector Signal Analysis software on oscilloscopes. Rather than implementing the measurement software at the Virtual Instrument Software Interface (VISA) layer, which limits the size of data transfer for modulation and FFT measurements, Tektronix implements the software directly into the acquisition engine. This makes it easier to setup RF functions like frequency span, resolution bandwidth and acquisition time as independent variables, and allows use of the entire memory of the oscilloscope for measurements. This enables designers to take narrow resolution bandwidth views of very wideband RF signals and not be limited to a fixed number of points for FFT processing.

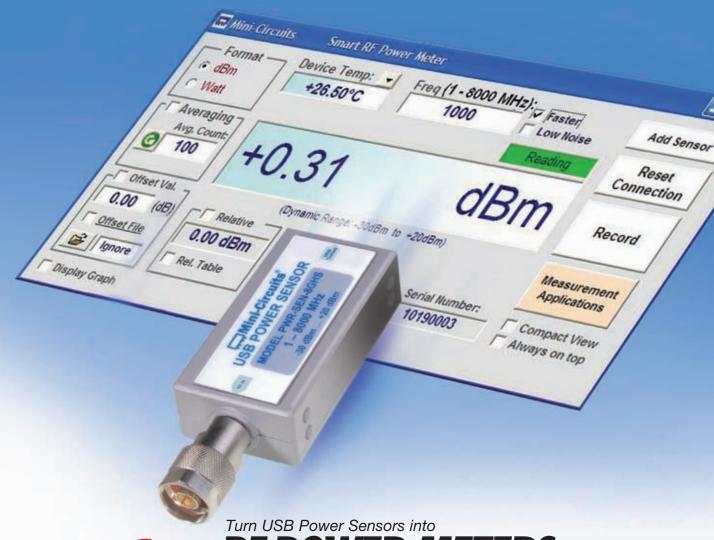
EVALUATION CRITERIA

What are some of the key traits an engineer should look for in an oscilloscope and why? We asked the major oscilloscope providers to outline the key factors and to highlight noteworthy capabilities that each company's scopes bring to the RF test & measurement market. Speed and accuracy along with functionality, such as data processing and display technology, were among the top criteria cited.

Asay (Agilent) underscores the versatility of the oscilloscope by responding, "The answer is that it depends. This depends on what the engineer is doing with the oscilloscope. An engineer using the oscilloscope for RF measurements needs to really look at the noise, effective number of bits and the edge trigger bandwidth of the oscilloscope. All of these specifications make a big impact on applications such as radar. For instance, if you are looking at a radar application of 20 GHz, and only have 15 GHz on the edge trigger, you have the potential of missing key trigger events as scopes are forced to use software to expand the trigger."

Noise is always a concern. The higher the noise of the oscilloscope, the more noise contribution the oscilloscope makes in a measurement. Engineers want to see what they are really measuring, not what the scope contributes. Noise is one of the easiest and most effective ways to evaluate different scopes.

Bandwidth, on the other hand, is limited to the fre-



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quency domain, not the time domain, and therefore does not describe how a particular instrument would fare at capturing spectral components of a complex signal, Loberg points out. In fact, two oscilloscopes that have the same bandwidth performance can have different rise times, amplitude and phase response. Therefore, knowing only the bandwidth of an oscilloscope will not fully describe its measurement capability or its ability to accurately capture complex signals. It is important to consider other factors such as instrument-based noise, frequency flatness and roll-off, the risetime response, etc., to better determine the instrument's ability to make accurate measurements.

Graef (LeCroy) believes that the signal to noise ratio is important. However, baseline noise (noise on a scope with no input signal) is easy to look at but does not tell the whole story. The signal-to-noise ratio with a signal applied is a much better indication of what the user will see in real applications. Effective number of bits is a figure of merit that includes all of the error terms in the digitization chain and that is often used for comparison. However, ENOB alone is not sufficient. The very next question after one learns that the ENOB is 6.2 bits should be, "Is that primarily noise or distortion?" The two parameters SNR and THD should tell the user a great deal about the acquisition per-

Once the characteristics of the acquisition system are deemed to be sufficient, the next traits an engineer should look for are the capabilities to measure and debug the circuit under test. Different scope manufacturers have different approaches to how they make measurements. For example, if vou ask for a rise-time measurement, LeCroy will measure every rise-time in an acquisition. "There could be thousands or even millions of them in a single acquisition. Other manufacturers measure only a few or, in some cases, only one per acquisition. LeCroy can also show a histogram very easily and even allow the user to find the outliers using the company's WaveScan technology. This can all be done on very long memory acquisitions while keeping the responsiveness of the scope very good. Many other manufacturers bog down with

long memory causing the user to lose sight of what they are trying to accomplish and end up focused on making the tool do what they want it to do. Highly responsive scopes with good tools for debugging problems can help the engineer get their job done more quickly with less frustration," said Graef.

Schulze (R&S) commented that it is worth looking into the details of an oscilloscope's specification before a purchase decision is made, listing the following areas to consider:

a) Front-end - Probably the most popular and the most obvious decision criteria is the maximum bandwidth that is supported by an instrument. Other important parameters include:

- Smallest input sensitivity without SW magnification or bandwidth limitations: Many applications use low voltage swings. With probes having attenuations of typically 10:1, a 100 mV signal requires 1 mV/div for full display over 10 divisions
- Intrinsic noise (RMS noise floor) of the oscilloscope at the various amplifier ranges
- Effective number of bits (ENOB):
 This determines the measurement dynamic
- Channel-to-channel isolation: For measurements with multiple input channels also this parameter should be evaluated

b) Acquisition - The capability to "look" at the test signal many times per second is an important performance parameter, i.e. the waveform acquisition rate matters. A comprehensive triggering system with accurate trigger (low jitter) capability is also an important aspect of any oscilloscope. Another important question concerning the data acquisition is the maximum available memory. On certain instruments one channel can use the memory of the other channel if they are switched off (sometimes only one neighboring channel, sometimes all channels).

Combined with longer memory is the ability to find what has been captured in memory. Without good signal processing search tools like the Wave Inspector featured on many of the Tektronix mid-range oscilloscopes, it may not be helpful to capture and store important events if they cannot be found quickly and easily. With Wave Inspector, engineers can search, mark and



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Another consideration on acquisition is probing, says Loberg. A well-matched probing system that provides the ability to accurately transport the signal from the device under test to the front-end of the oscilloscope is as important as the front-end of the instrument itself.

c) Processing - Certainly there are different processing functions like simple and advanced math functions (e.g. add or sub versus FFT), analysis functions (e.g. mask test, histogram) and measurement functions (e.g. cursor, automated measurements). Besides the question whether an individual function is available or not, again the acquisition and analyzing rate is a crucial differentiator. Schulze (R&S) believes a histogram test that can evaluate 1,000,000 waveforms per second is much more powerful than a histogram test at 100 waveforms per second (TTM, TTY, etc.).

d) Usability - The operating concept can make a big difference—a big screen is not everything. As everybody has his own preferences a user should always try to get access to a demo unit to try an instrument upfront. Size and weight also should be considered, carrying around 10 kg versus 20 kg really matters.

As mentioned above, the signal acquisition path needs to have the level of performance required for the application or the scope will not be useful. LeCroy's scopes have excellent signal fidelity that allows the signals to be faithfully acquired. Beyond that, LeCroy's speed of processing and the depth of the "toolbox" are two of

the primary advantages in its scopes. According to Graef, the company's patented X-Stream technology can process waveforms up to $100\times$ faster than competitive instruments.

This capability keeps the scope lively and interactive even with long memories and many complex measurements turned on. Features in LeCroy scopes allow the user to identify the source of a problem—WaveScan, TriggerScan and Histicons are capabilities that allow the user to identify and characterize intermittent or rarely occurring problems. LeCroy's ability to decode many different standards—PCIe, SAS, SATA, USB-to name a few, allows the engineer to look at the physical layer characteristics while looking at the protocol layer messages being sent. Then when an error occurs the error message can be correlated with what is happening at the physical layer. With the ProtoSync capability engineers can get a full protocol layer view and "cross probe" to the physical layer signal that resulted in that error. This is extremely useful for bringing up new designs where it is not clear what is working and what is not. In addition, LeCroy scopes have the ability to allow users to insert their own processing algorithms into the processing stream of the scope. Programs can be written in many different languages including MatLab or C++ and added to the scope's already deep toolbox.

Asay considers accuracy as a leading advantage for the Agilent oscilloscopes. The 90000 X-Series (which was introduced in 2010) has the industry's

lowest noise floor along with the highpre-amplifier bandwidth. Because of the InP-based chips, the scope is able to achieve high bandwidths without design tradeoffs, resulting in a highly accurate test instrument. In addition to lower noise, higher effective bits and lower jitter, the 90000 X-Series also has higher probe bandwidth and higher edge trigger band-



▲ Fig. 5 R&S rapid acquisition capability provides a "persistence" view of rare signal behaviors in this example of a random runt pulse.



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width, which makes it a great instrument for RF measurements.

Loberg emphasizes the importance of sampling rates and signal integrity as well as accurate capture or triggering capability. The company's DPO/DSA/MSO70000 Series claims the most accurate real-time performance of any oscilloscope on the market and features the industry's highest sampling rate performance—100 GS/s—for low noise and high margin visibility. For

applications such as wideband radar system verification, the Tektronix oscilloscopes feature a high stability timebase that maintains the same modulation characteristics from pulse to pulse.

A key differentiator for Tektronix is the availability of digital phosphor displays that Tektronix invented. The DPO architecture dedicates unique ASIC hardware to acquire waveform images, delivering high waveform capture rates that result in a higher

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level of signal visualization. This performance increases the probability of witnessing transient events, where DPOs are suitable for viewing high and low frequencies, repetitive waveforms, transients, and signal variations in real time.

On a very high level, Schulze characterizes the R&S RTO family with the attributes of speed, ease-of-use and accuracy. For speed, Schulze points to the acquisition and analysis rate of up to 1 million waveforms per second. The highly integrated processing ASIC is the key enabler for that standard mode capability. "Looking" at the signal up to one million times per second has the advantage that the user can detect signal faults much faster and achieves more reliable results with his analysis tools based on a high number of acquired waveforms (see *Figure 5*). Now, for the first time, a histogram with up to 1,000,000 wfms/s or a mask test with greater than 600,000 wfms/s is possible. A fast FFT display and HW accelerated math and measurement examples are other key advantages.

The RTO's accuracy is achieved through the low-noise highly sensitive front-end, a single-core ADC with an ENOB >7 and a precise digital trigger system that enables trigger jitter of <1 ps at maximum acquisition rate. High measurement accuracy is also supported by the low noise Rohde & Schwarz active probes as well as the high bandwidth probe interface.

CONCLUSION

Test and measurement equipment manufacturers have made great strides in bringing the classic time-domain circuit/system debugging tool, aka the oscilloscope, into the realm of microwave engineering. This has been made possible by numerous innovations in signal path technology, scope architecture, software and especially in the semiconductor technology employed in the front-end, ADCs and ASICs. Microwave engineers may still have to worry about skin depth and the physical size of their circuit designs relative to wavelength, but with the new class of multi-GHz oscilloscopes, studying circuit behavior through direct observation of IV waveforms, is no longer outside our domain.



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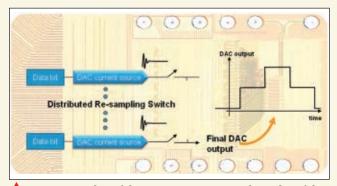




Pushing Radar Designs to the Limit with Highly Realistic Signal Scenarios

n the development of next-generation radar and electronic warfare (EW) systems, typical test scenarios include simulations such as low-observable signals mixed with ground clutter and environmental interferers. Addressing these demanding scenarios requires an arbitrary waveform generator (AWG) or signal-scenario generator (SSG) that has two key attributes. The first is a design that provides wide bandwidth and high resolution simultaneously. The second is built-in capabilities that support the creation of long, complex signal scenarios.

The Agilent M8190A SSG is well equipped for these challenges. With 14-bit resolution at 8 GSa/s or 12-bit resolution at 12 GSa/s, the M8190A offers two modes that ensure excellent



▲ Fig. 1 Resampling of the DAC output improves the quality of the final waveform.

signal fidelity at high frequencies. It also enables long playback time with up to 2 GSa of waveform memory and a variety of advanced sequencing capabilities. For radar and EW system creators, these capabilities can lead to shorter development time and a lower cost of test.

DESIGNING FOR EXCEPTIONAL DAC PERFORMANCE

Typical AWGs force system creators to make a tradeoff between units that offer either wide bandwidth and low resolution or limited bandwidth and high resolution. The respective levels of performance in both bandwidth and resolution depend on the digital-to-analog converter (DAC) used in the AWG. Bandwidth is limited by the DAC sample rate, and accuracy is affected by the quality and performance of the analog components used inside the device.

Within Agilent, researchers at the company's Measurement Research Lab have developed a way to eliminate the spurious signals (spurs) and distortion present in typical DAC designs. Agilent's patented approach focuses on the beginning of the signal-generation process, reducing the need for filtering at the end of the signal chain. This approach is based on two key ideas.

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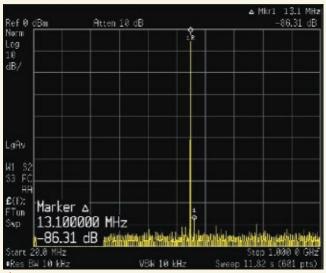
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▲ Fig. 2 A single-tone output at 555 MHz (7.2 GHz sampling rate) had a SFDR of −86.31 dBc in the range to 1 GHz.

One is to let switched current sources settle within the DAC. The other is to resample the signal with a special low-noise clock before outputting the simulated signal (see *Figure 1*).

The resulting DAC output provides spurious-free dynamic range (SFDR) of up to 80 dBc, which is much better than what most other designs can achieve. At 8 GSa/s, the Agilent DAC typically delivers an industry-leading 75 dBc SFDR (excluding second and third harmonics) across an output frequency range of 0 to 3 GHz (see *Figure 2*).

One of the most important design choices was the decision to use a low-temperature, multi-layer ceramic substrate. A package with many layers is necessary in order to meet aggressive specifications for noise and spurious response. The net result is excellent performance at high frequencies. As implemented in the M8190A SSG, the ability to achieve high resolution at high frequency gives system developers greater confidence that they are testing their design, not the signal source.

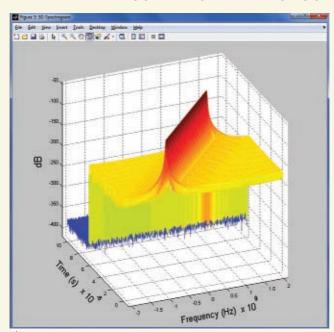
ENABLING COMPLEX SIGNAL SCENARIOS

To create realistic signal scenarios, an AWG or SSG needs more than raw DAC technology. Three additional attributes enable sufficiently long playback times: waveform memory, advanced sequencing capabilities and real-time access to individual memory segments.

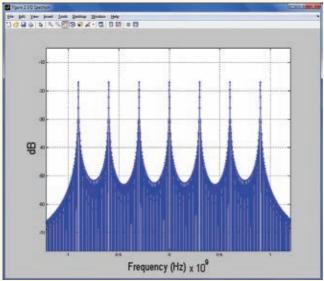
The M8190A SSG can be configured with 128 MSa (standard) to 2 GSa (optional) of waveform memory per output channel. With 2 GSa installed, the maximum playback time of a single unique waveform is 180 ms at the highest sample rate.

The absolute amount of waveform memory is important; however, using the available memory efficiently enables a concept called memory gain. Typical AWGs consume valuable memory space by requiring multiple occurrences of identical segments that are repeated within a sequence. In the M8190A, advanced sequencing capabilities such as stepping, looping and conditional jumping make it possible to create such segments once and reuse them programmatically as needed. These capabilities can be applied to waveforms or waveform sequences.

Specific to the M8190A, up to 256,000 segments can be stored in memory, and up to four billion loops can be defined



▲ Fig. 3 Spectrograph of a chirp that is part of a longer signal scenario.



▲ Fig. 4 Pulse Builder enables creation of sophisticated singleemitter test patterns.

for each segment. Beyond the sequencing of individual segments, it is possible to set up a series of advanced sequences. This enables users to build and playback highly complex scenarios comprised of one or more sequences (see *Figure 3*).

The third attribute is a hardware-based dynamic sequence-control input. This eight-bit bus is used to enable immediate or synchronous switching between segments or sequences. Immediate jumps interrupt the active segment or sequence before completion; synchronous jumps wait until the active segment or sequence is completed. The actuating signals can come from the unit under test, another instrument within the system, or any other external device.

CREATING SIGNALS IN SOFTWARE

Software is a fourth element in the solution set. Examples include Signal Studio from Agilent, MATLAB from The Math-

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Works and LabVIEW from National Instruments. These provide an environment for signal creation, and the results can be downloaded to the SSG memory for playback.

Two versions of Signal Studio are especially relevant in aerospace and defense applications. Signal Studio for Pulse Building (N7620A) simplifies the creation of complex pulse patterns for the testing of radar receivers (see *Figure 4*). Signal Studio for Multitone Distortion (N7621A and N7621B) can

be used to create multi-tone and noise power ratio signals for the testing of satellite transceivers.

Another useful application is Agilent SystemVue electronic systemlevel (ESL) design software. The Radar Model Library for SystemVue (W1905) includes predefined radar signals that can be selected and loaded into the M8190A, for example. The library also provides more than 35 highly parameterized primitive blocks and higher-level reference designs that can be used

Utilizing Software-selectable Output Paths

To address a variety of measurement needs, the Agilent M8190A offers three software-selectable output paths: direct DAC, DC amplifier and AC amplifier. The direct DAC path is optimized for the generation of in-phase/quadrature (I/Q) signals that offer superior SFDR and harmonic distortion. Key attributes include 5 GHz bandwidth, amplitude range of 350 to 700 mV peak-to-peak (fixed offset), differential output, and rise/fall times of approximately 50 ps (20 to 80 percent).

The DC amplifier path is optimized for applications that require serial data and time-domain measurements. Important capabilities include differential output, amplitude range of 600 mV to 1.2 V peak-to-peak (from -1.0 to +3.0 V), rise/fall times of approximately 35 ps (20 to 80 percent), and a Bessel-Thomson filter to ensure low overshoot.

The AC amplifier path is designed for the generation of direct IF/RF signals. This output is single-ended and AC coupled with a power range of -10 to +10 dBm.

to create a working radar system. The block set and its example workspaces serve as algorithmic and architectural reference scenarios to verify radar performance with a variety of signal conditions: target and radar cross section (RCS) scenarios; clutter conditions; jammers and environmental interferers; and different receiver algorithms.

CONCLUSION

Advanced AWGs and SSGs provide important benefits in the development of present and future radar and EW systems. The greatest technical advantage is the possibility of creating simulated signal scenarios with enhanced realism. This helps minimize the need for costly flight testing and enhances the flexibility of ground-based testing.

From a business perspective, greater flexibility makes it possible to test multiple radar or EW designs with a single measurement system, enhancing system reuse. Further, modules such as the M8190A are based on commercial off-the-shelf (COTS) technology such as AXIe. A modular approach helps reduce the size, weight and physical footprint of the test system.



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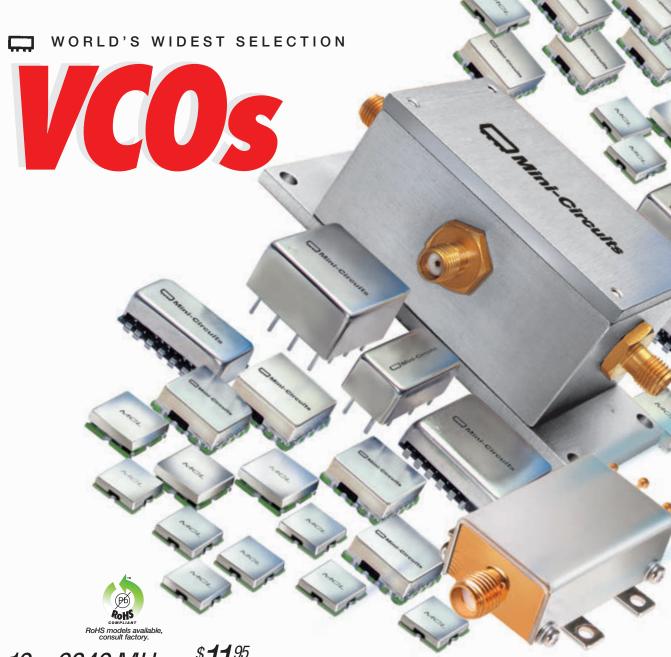
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OCTAVE BA	ND LOW N	OISE AMP	LIFIERS			
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dE		VSWR
CA01-2110 CA12-2110	0.5-1.0 1.0-2.0	28 30	1.0 MAX, 0.7 TYP 1.0 MAX, 0.7 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA12-2110 CA24-2111	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 CA1826-2110	12.0-18.0 18.0-26.5	25 32	1.9 MAX, 1.7 TYP 3.0 MAX, 2.5 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
			D MEDIUM PO			2.0.1
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 CA23-3111	1.2 - 1.6 2.2 - 2.4	25 30	0.6 MAX, 0.4 TYP 0.6 MAX, 0.45 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.43 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 CA910-3110	7.25 - 7.75 9.0 - 10.6	32 25	1.2 MAX, 1.0 TYP 1.4 MAX, 1.2 TYP	+10 MIN +10 MIN	+20 dBm +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 5.9 - 6.4	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114 CA812-6115	8.0 - 12.0	30 30	5.0 MAX, 4.0 TYP 4.5 MAX, 3.5 TYP	+30 MIN +30 MIN	+40 dBm +40 dBm	2.0:1 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 . MIIITI-O	3.5 MAX, 2.8 TYP CTAVE BAND AN	+21 MN APLIFIERS	+31 dBm	2.0:1
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power -out @ P1-dE	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 CA0108-3110	0.1-6.0 0.1-8.0	28 26	1.9 Max, 1.5 TYP 2.2 Max, 1.8 TYP	+10 MIN +10 MIN	+20 dBm +20 dBm	2.0:1 2.0:1
CA0100-3110	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 CA618-4112	2.0-6.0 6.0-18.0	22 25	5.0 MAX, 3.5 TYP 5.0 MAX, 3.5 TYP	+30 MIN +23 MIN	+40 dBm +33 dBm	2.0:1 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 LIMITING A	2.0-18.0 MPI IFIERS	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1
Model No.		Input Dynamic I	Range Output Power	Range Psat Pov	ver Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 d		1 dBm +	-/- 1.5 MAX -/- 1.5 MAX	2.0:1
CLA26-8001 CLA712-5001	2.0 - 6.0 7.0 - 12.4	-50 to +20 d -21 to +10 d		O dBm -	-/- 1.5 MAX -/- 1.5 MAX	2.0:1 2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 d			-/- 1.5 MAX	2.0:1
AMPLIFIERS \		ATED GAIN	ATTENUATION		,	
Model No.	Freq (GHz)	Gain (dB) MIN		ver-out@P1-dB Gair		
CA001-2511A CA05-3110A	0.025-0.150 0.5-5.5	21 23		+12 MIN +18 MIN	30 dB MIN 20 dB MIN	2.0:1 2.0:1
CA56-3110A	5.85-6.425	28		+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0			+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4			+16 MIN	20 dB MIN	1.8:1
CA1518-4110A LOW FREQUE	15.0-18.0 NCY AMPLIF		3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1
Model No.	Freq (GHz)	Gain (dB) MIN		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 CA001-2215	0.04-0.15 0.04-0.15	24 23	3.5 MAX, 2.2 TYP 4.0 MAX, 2.2 TYP	+13 MIN +23 MIN	+23 dBm +33 dBm	2.0:1 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 32	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0		4.0 MAX, 2.8 TYP s to meet your "exact" requ	+15 MIN	+25 dBm	2.0:1
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Defense News

Dan Massé, Associate Technical Editor

MarketWatch

M/A-COM Technology Solutions Inc. (M/A-COM Tech) has extended its position in high power semiconductors with the introduction of its first family of Gallium Nitride (GaN) RF power transistors. This new family of products targets S-band radar pulsed applications and leverages M/A-COM Tech's heritage of providing both standard and custom solutions to meet the most demanding customer requirements. M/A-COM Tech's GaN on Silicon Carbide (SiC) products—offered as transistors and pallets—utilize a 0.5 micron HEMT process and exhibit best-in-class RF performance with respect to power, gain, gain flatness, efficiency and ruggedness over wide-operating bandwidths. Featured benefits of M/A-COM Tech's GaN products include high breakdown voltage, superior power density, easy to broadband, high frequency operation and excellent thermal conductivity properties.

Applied Radar Awarded MDA Phase 2 SBIR Contract

pplied Radar Inc. has been awarded a Phase 2 Small Business Innovative Research (SBIR) contract from the US Missile Defense Agency (MDA) to develop a "Wideband Subarray Digital Receiver/Exciter (DREX)." This contract builds upon Applied Radar's on-going work with the MDA on radar receiver/exciter technology, and greatly expands the bandwidth and throughput of existing technology. "It is a critical enabling component of next-generation ground-based and airborne phased array radars," explained William H. Weedon, Applied Radar's CEO. "It is a key technology that will allow demonstration of advanced digital radar arrays that employ digital beam steering and coherently distributed arrays that are at a much lower cost than current radar technology." The company will be delivering an initial DREX prototype to the US Air Force Research Lab at WPAFB, OH in early 2011, and this new contract allows the R&D company to more fully develop the electronic hardware and software components of the DREX.

SRC Secures Additional Contracts for FORESTER Program

RC Inc., formerly Syracuse Research Corp., recently received two contract awards with a total potential value of up to \$12.3 M for its Foliage Penetrating, Reconnaissance, Surveillance, Tracking and Engagement Radar (FORESTER), a revolutionary airborne radar system that penetrates through foliage to track people and vehicles on the ground.

The US Army Research, Development and Engineering Command Simulation and Training Technology Cen-

ter awarded SRC \$1.3 M for the FORESTER Signal Processing Enhancements Program and another potential \$11 M for the Defense Advanced Research Projects Agency (DARPA) Foliage Penetration (FOPEN) Ground

Moving Target Indicator (GMTI) Radar Exploitation and Planning (GXP) program. The FORESTER Signal Processing Enhancements Program effort runs through fiscal year 2011. The funding for this effort stems from a fiscal year 2010 congressional earmark.

Under the DARPA FOPEN GXP program, SRC will develop a set of tools to improve current FOPEN GMTI caUnder the DARPA FOPEN GXP program, SRC will develop a set of tools to improve current FOPEN GMTI capabilities, and integrate and demonstrate these tools.

pabilities, and integrate and demonstrate these tools. This two-year program has two phases of one year each. Phase one is valued at 5 M, and was incrementally funded for more than 2.5 M until fiscal year 2011 funds are available later this year.

Raytheon Awarded Contract for Space Fence Preliminary Design

aytheon Co. has been awarded a \$107 M US Air Force contract to further the design of the Space Fence system. Under this contract, Raytheon will deliver a pre-

liminary design and test a functional radar prototype to ensure cost and schedule certainty and technical maturity of the final design in support of Milestone B.

"As the amount of debris in space continues to rise, the ability to detect smaller and smaller objects with more affordable, ground-based sensors becomes increasingly urgent," said "As the amount of debris in space continues to rise, the ability to detect smaller... objects with more affordable, groundbased sensors becomes... urgent."

Dave Gulla, Vice President, National & Theater Security Programs for Raytheon Integrated Defense Systems. "Leveraging our vast heritage in radar development, combined with our latest technological advancements, the Raytheon Space Fence solution provides the Air Force with an affordable and much-needed, increased space situational awareness capability for many years to come."

Go to www.mwjournal.com for more defense news items

The work performed during this phase continues to reduce total program risk through the development of a preliminary design, with mature technologies, that meet or exceed Technology Readiness Level 6 and Manufacturing Readiness Level 6. In addition, a functional radar prototype, with hardware and software components representative of the technology in the final design, will demonstrate the maturity of these critical technologies.

Lockheed Martin Receives Contract for High Mobility Artillery Rocket System

ockheed Martin has received a \$139.6 M contract to provide 44 combat-proven High Mobility Artillery Rocket Systems (HIMARS) to the US Army. This order will increase the Army's HIMARS launcher fleet to 375, with deliveries continuing through January 2013. Work on the contract will be performed at the company's facilities in Camden, AR, and Grand Prairie, TX.

"HIMARS brings soldiers an agile, responsive and accurate delivery system of extremely precise fires," said Col. David J. Rice, US Army Program Manager for Precision Fires, Rocket and Missile Systems. "HIMARS continues to impress everybody with its performance and versatility; the system is reliable, robust and exceptionally effective in theater."

The system can accommodate a six-pack of Guided MLRS rockets or one Army Tactical Missile System missile. HIMARS, a highly mobile artillery rocket system based on the Army's FMTV five-ton truck, is designed to launch the entire MLRS Family of Munitions.

HIMARS is designed to enable troops to engage and de-

feat artillery, air defense concentrations, trucks, light armor and personnel carriers, as well as support troop and supply concentrations. HI-MARS can move away from the area at high speed following missile launch, well before enemy forces are able to

"HIMARS brings soldiers an agile, responsive and accurate delivery system of extremely precise fires."

locate the launch site. The US Army and Marines operate HIMARS, as do several international allies. Because of its C-130 transportability, HIMARS can be deployed into areas previously inaccessible to heavier launchers and provides a force multiplier to the modular brigade. It also incorporates the self-loading, autonomous features that have made MLRS the premier rocket artillery system in the world. The HIMARS fire control system, electronics and communications units are interchangeable with the existing MLRS M270A1 launcher.

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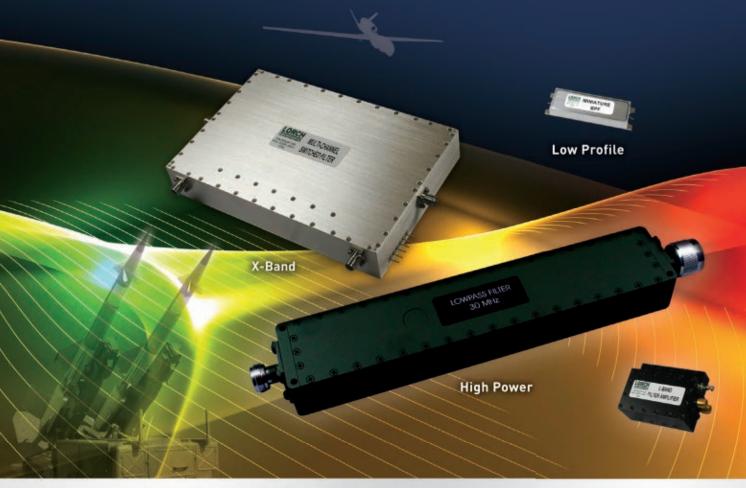
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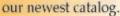
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INTERNATIONAL REPORT

Richard Mumford, International Editor

ITU Welcomes Participation of 12 Universities

he International Telecommunications Union (ITU) has welcomed the first 12 academic institutions admitted to participate in Sector activities under a new Resolution that encourages the involvement of universities and their associated research establishments in the work of the Union.

Algeria's Institut National des Télécommunications et des Technologies de l'Information et de la Communication (INTTIC) and Tunisia's Ecole Nationale d'Ingénieurs de Tunis (ENIT) both join the work of all three ITU Sectors—Radiocommunication (ITU-R), Telecommunication Standardization (ITU-T) and Development (ITU-D). China's Nanjing University of Posts and Telecommunications

"These institutions are the seed-beds that nurture the rising stars of tomorrow's ICT industry..."

(NUPT) and Beijingbased Tsinghua University join the work of ITU-R and ITU-T. Waseda University, Japan, Tunisia's University of Sfax and Ecole Supérieure des Communications de Tunis,

India's Sinhgad Technical Education Society and Aalborg University's Center for Teleinfrastruktur in Denmark, join the work of ITU-T, while the Kigali Institute for Science and Technology in Rwanda, the Open University of Tanzania, and Bucks New University, UK, all join the work of ITU-D.

"We are excited about the important contribution academic institutions will make to enriching ITU's breadth of knowledge in key emerging areas," said ITU Secretary-General Dr. Hamadoun Touré. "These institutions are the seed-beds that nurture the rising stars of tomorrow's ICT industry, be they engineers or business leaders. Their unique perspective will help ITU remain at the forefront of the industry it serves."

Participating in the work of ITU Sectors will give academic and research institutions the opportunity to exchange views, knowledge and experiences with a multiplicity of players from the developed and developing worlds, and from the public and private sectors. It also provides new opportunities for institutions to develop mutually-beneficial partnerships with manufacturers, operators, financial institutions, other research institutions, and public authorities from across ITU's 192 Member States.

Academic institutions will have the chance to play an active part in the ongoing activities of ITU's Sectors and to influence the emergence of new technologies and standards. Their participation in ITU meetings, seminars and workshops will also enable them to enlarge the scope of their work beyond purely technical and commercial concerns, to embrace wider issues in the ICT public policy and regulatory arena.

ESA and Belfast University Go Flat Out with Antenna Research

ulky satellite dishes and ground terminals could become relics of the past thanks to research currently being conducted for the European Space Agency (ESA) by Queen's University Belfast's Institute of Electronics, Communications and Information Technology (ECIT), aimed at developing discrete self-aligning flat antennas. The aim of the 18-month ESA project is to develop a completely self-contained solid-state self-steering antenna that is much lighter and less power hungry than current alternatives.

The ECIT team, led by Professor Vincent Fusco, plans to complete work on a 1.6 GHz demonstrator—capable of providing transfer rates of 0.5 Mbits/s—with a power requirement of just 2 W. It is anticipated that the device will ultimately have the capability to operate at 20 to 30 GHz in order

"The work is especially exciting because it has involved taking a piece of pure university research and bringing it into the real world."

to provide much greater bandwidth. The design currently being worked on is a 4×5 element planar array measuring 30 by 40 cm and 12 mm deep. Uniquely, the circuits are entirely analogue and incorporate specially adapted phase locked loop circuits.

Neil Buchanan, the lead engineer on the project, commented, "The work is especially exciting because it has involved taking a piece of pure university research and bringing it into the real world. We believe that self-tracking antennas offer the prospect of much simpler and more cost effective alternatives to other current approaches. That, we believe, makes them ideally suited to a variety of end uses."

UK Government Proposes Network of Technology and Innovation Centres

he UK government has invited organisations to register their interest in forming a technology and innovation centre focused on the area of high value manufacturing. The centre will be the first of an elite national network of centres, to be established and overseen by the Technology Strategy Board, that will work in partnership with universities and businesses to help commercialise the results of research in specific technology areas where there are potential multi-billion pound global markets.

The Universities and Science Minister, David Willetts, said, "I am pleased that the first of these centres will be focused on high-value manufacturing as a strong



International Report

"Technology innovation centres will work in partnership with universities and businesses." manufacturing base is an essential component of a balanced and dynamic economy, where exports and investment drive growth.

"Technology innovation centres will work in partnership with universities and businesses. They will bridge an

important gap giving innovative firms access to facilities and technical expertise, enabling them to undertake essential development work, which can often be beyond the capability of individual businesses."

Cassidian Opens Engineering Centre in India

assidian has opened a new Engineering Centre in Bengaluru, India, which is the first defence oriented engineering centre operated by a foreign company in India and also a landmark in the company's strategic goal to establish a long-term partnership with India.

The new centre is staffed almost entirely with highly qualified Indian engineers who have undergone extensive training in Europe. It is planned to increase the current number

of 60 employees to more than 200 by the end of 2012. The major objective of the Engineering Centre is to leverage the vast pool of skilled engineers available in India to develop products fulfilling the specific requirements of the Indian customers and to provide consultancy and other services to the aerospace and defence companies in the country.

By integrating the new centre within Cassidian's global Engineering Organization, it will be able to participate in Indian as well as global programmes. The centre will be at the forefront of Engineering and System Development, developing its core competencies in the areas of radar

The major objective of the Engineering Centre is to leverage the vast pool of skilled engineers available in India...

systems, protection systems, avionic systems, engineering IT and 3D visual simulation, aerostructure and aerospace modelling and simulation.

Bengaluru has long been known as the aerospace and defence hub of India. By establishing its Engineering Centre there, Cassidian is confident that the proximity to customers and users will facilitate a mutually beneficial relationship on both sides and thus strengthen Cassidian's future activities in India.



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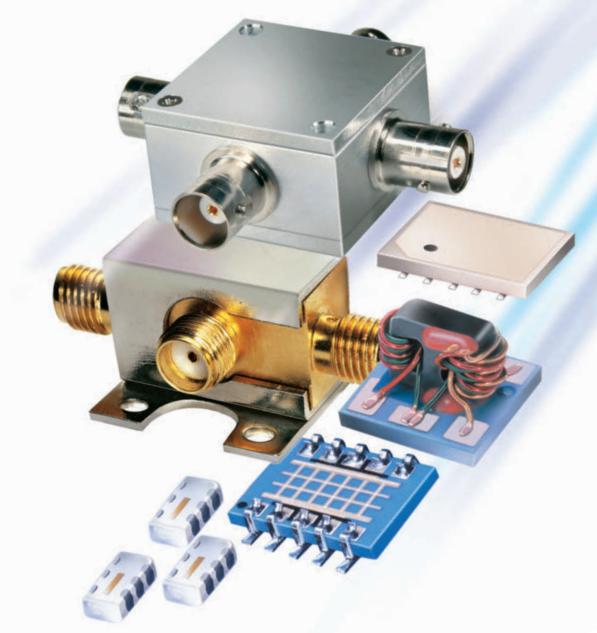
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COMMERCIAL MARKET

Dan Massé, Associate Technical Editor

MarketWatch: E-band Backhaul

Millimeter-wave links at E-band frequencies can be deployed with minimal interference, allowing more efficient spectrum re-use, reducing coordination requirements, and allowing regulators to adopt a "light licensing" scheme at a fraction of the cost of "traditional" licenses, which has a number of backhaul equipment manufacturers touting its usage.

Millimeter-wave technology is still in its infancy compared to the much larger, well established microwave equipment market—projected to reach \$6.5 B by 2014, according to research firm Infonetics Research. Still, Infonetics predicts the 70/80 GHz and 90 GHz equipment will grow to over \$450 M by 2014. They predict nearly 3 / $_4$ of all millimeter-wave equipment purchased for mobile backhaul will be used in metro areas with high cell density and 4G networks where HSPA+, WiMAX and LTE base stations and aggregation points require Gbps speeds.

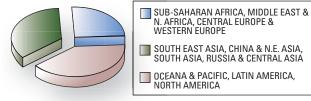
Visant Strategies forecasts that revenue from 60 GHz and 70/80 GHz PTP radios will reach over \$500 M in 2016, with a five fold growth driven by mobile backhaul. The unlicensed 60 GHz radio shipments will also grow at the same rate, but driven by private enterprise and government networks, particularly public safety wireless networks. In 2010, growth in deployments of 70/80 GHz links in the US soared 700 percent above their 2009 levels. Based on registration data available by the FCC, BridgeWave achieved a market leading 64 percent of all 2010 registrations with more than 10,000 gigabit wireless systems in over 50 countries. Other Gbps wireless gear in the E-band is available from Alvarion, Ceragon, DragonWave, E-Band Communications, Gigabeam, Loea, Proxim's GigaLink and Exalt, among others.

At MWC in February, E-Band Communications introduced the E-Link 1000Q radio with next generation spectral efficiency and channel tuning capability for 80 GHz backhaul solutions for 4G/LTE networks. The company claims the radio, which utilizes QPSK modulation for spectrum efficiency, has the industry's highest output power thanks to a quarter-watt output amplifier, driven by proprietary GaAs MMICs and offers the lowest latency in the industry, at less than five microseconds. Meanwhile, Siklu (Israel) claims to offer gigabit-per-second wireless connectivity at the lowest price point in the entire industry—1Gb capacity millimeter radios based on their proprietary CMOS RFIC and direct to antenna interconnect technology going for less than \$3000.

Ground-based Markets for Broadband Satellite Communications to Exceed \$3 B

ccording to a report recently released by Engalco, multi-billion dollar global markets for ground-based broadband satellite communications transceivers are expected within this decade. A series of spacecraft are being launched with highly broadband throughput capabilities. Hylas1 and Ka-SAT are already in orbit and Ka-SAT's total throughput is 70 Gbps. Even more ad-

REGIONAL MONETARY MARKET SEGMENTATION FOR K-/Ka-BASED TRANSCEIVERS IN 2019



Source: Engalco

vanced classes of spacecraft typically have 100 Gbps or greater capacities. They include ViaSat1 (130 Gbps), several Inmarsat satellites, Jupiter 1, MegaSat and Hylas2. Major OEMs such as Boeing and Space-Systems Loral are building these spacecraft and subscriber access is now a reality. The main aim of this effort is to provide high-speed broadband "fiber-like" Internet access to mainly rural subscribers, who would otherwise remain on the "wrong side of the digital divide".

The K/Ka microwave and millimeter-wave bands are generally used with the downlinks centered around 20 GHz and the uplinks centered around 30 GHz. Engalco's report—dubbed BSAT1—provides shipments, average selling prices and total available market data for the ground-based (consumer) transceivers, covering the 2010 to 2019 time scale. BSAT1 focuses on 11 geographic regions and also the following three specified groups of these regions:

- Sub-Saharan Africa, Middle East and N. Africa, Central Europe, Western Europe (collectively termed "Europe, Middle East and Africa" or "EMEA").
- South East Asia, China and N.E. Asia, South Asia, Russia and Central Asia.
- Oceana and Pacific, Latin America and North America. The results of Engalco's research indicate that global shipments just exceeded one-third of a million in 2010 and will increase to almost 2 billion in 2019. By annual value the total (global) markets were almost \$1.4 B in 2010 and will increase at an average annual rate of 9.6 percent to reach nearly \$3.2 B in 2019. There are, however, substantial regional variations in terms of both absolute values and monetary growth rates. In 2010 the Americas enjoyed the bulk of the market with a share of 74 percent—mainly due to the US. But by 2019 Engalco predicts the pattern will have changed radically, as shown in the pie chart.

Military Spending and GaN Adoption Driving RF Power Semiconductor Markets

Ithough spending on RF power semiconductors in wireless infrastructure markets has continued to stagnate, other markets—notably the military—are seeing increased activity. Also, according to a new study from ABI Research, Gallium Nitride—long seen as a promising new "material of choice" for RF power semiconductors—is continuing to gain some market traction. Gallium Nitride

Go to www.mwjournal.com for more commercial market news items



Commercial Market

(GaN) increased its market share in 2010, and is expected to do the same in 2011. Although its adoption has not been as rapid as originally expected, it is nonetheless forecast to be a significant force by 2016.

Other than wireless infrastructure, the vertical market showing the strongest uptick in the RF power semiconductor business has been the military. While the producers of these devices are located in the major industrialized countries, the military market is now so global that equipment buyers may come from anywhere.

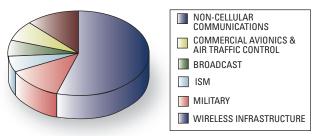
- What are the major market segments and sub-segments for RF power semiconductor devices?
- What are the growth trends and sizes of these market segments?
- How do RF power semiconductor device technologies drive the marketplace?

"RF Power Semiconductors" examines RF power semiconductor devices that have power outputs of greater than 5 W and operate at frequencies of up to 3.8 GHz, which represent the bulk of applications in use today.

4G LTE Deployment Announcements Hog the Limelight

TE equipment expenditure is expected to ramp up quickly in 2011. ABI Research estimates that LTE equipment spending will grow 120 percent in 2011

RF POWER DEVICE MARKETSHARE BY MARKET SEGMENT WORLD MARKET: 2011

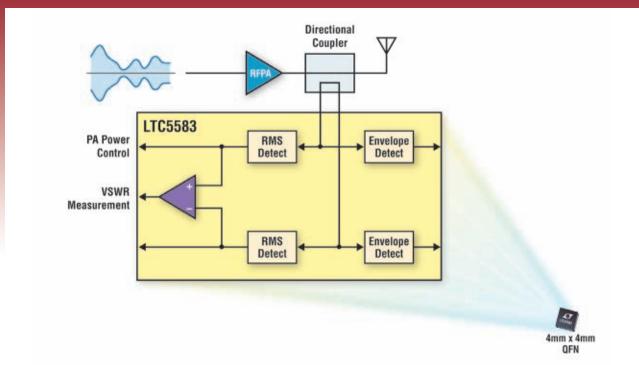


Source: ABI Research

to reach almost \$1 B. This increase is supported by more than 185 deployments and trials around the world. But despite the hype and rhetoric surrounding 4G, the wireless infrastructure deployment market is still largely dominated not just by 3G upgrades, but even by 2G (GSM-EDGE) swap-outs and coverage build-outs. In China, for example, China Mobile has been concluding a major TD-SCDMA push to extend coverage and to improve quality of service for existing covered areas. More than \$22 B has been spent on TD-SCDMA equipment to date. Wireless infrastructure spending will migrate to TD-LTE. China Mobile has been intensively trialling TD-LTE in Shanghai and other cities.



±0.5dB RMS Power Accuracy



6GHz Dual, Matched RMS Detector with **Superior Isolation Simplifies Calibration**

The LTC®5583 delivers outstanding channel-to-channel isolation and 60dB dynamic range using single-ended inputs, eliminating the need for external balun transformers. This dual RF detector offers exceptional accuracy of ±0.5dB error over a temperature range from -40°C to 85°C. The device provides a drop-in solution that simplifies design, improves accuracy and reduces costs.

High Performance RMS Detectors

	LTC5583	LTC5582	LT [®] 5581	LTC5587	
Operating Frequency	40MHz to 6GHz	40MHz to 10GHz	10MHz to 6GHz	10MHz to 6GHz	
# Channels	2	1	1	1	
Dynamic Range (dB)	60	57	40	40	
Detection Range (dBm)	-58 to 2	-56 to 1	-34 to 6	-34 to 6	
Measurement Accuracy (-40°C to 85°C)	±0.5dB	±0.5dB	±1dB	±1dB	
Output Interface	Log-Linear Voltage	Log-Linear Voltage	Log-Linear Voltage	12-Bit Serial ADC	
Power Supply	3.3V/90mA	3.3V/42mA	3V/1.4mA	3.3V/3mA	

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INDUSTRY NEWS

Ceragon Networks Ltd. has entered into a definitive agreement to acquire all of the outstanding shares of **Nera Networks AS** (NAS), headquartered in Bergen, Norway, from Eltek ASA. The consideration for the acquisition is approximately \$48.5 M on a cash-free/debt-free basis. Both companies' assets and core competencies will be combined into a single integrated organization, product family and customer base.

CommScope Inc. agreed to be taken private in a \$3.9 B acquisition by the leveraged-buyout firm **Carlyle Group**, the biggest takeover in the telecommunications-equipment industry in at least two years. CommScope (which had acquired Andrew Corp.), based in Hickory, NC, is working to revive sales after the global recession hurt demand last year. Carlyle is banking on an increase in demand for fiberoptic networks as phone- and Internet-service providers update their systems to accommodate increasing amounts of video and data.

Qualcomm Inc. and **Atheros Communications Inc.** announced that they have entered into a definitive agreement whereby Qualcomm intends to acquire Atheros, a leader in innovative technologies for wireless and wired local area connectivity in the computing, networking and consumer electronics industries. The acquisition is intended to help accelerate the expansion of Qualcomm's technologies and platforms to new businesses beyond cellular and provide access to significant new growth opportunities.

Hittite Microwave Corp. announced it has acquired **Arctic Silicon Devices**, a developer of advanced mixed-signal integrated circuit (IC) technology, located in Trondheim, Norway. The acquisition price was approximately \$12.0 M in cash and equity. The acquisition provides Hittie with new IC design and integration capability and a state-of-the-art product line of analog-to-digital converters (ADC). Arctic Silicon Devices has successfully designed and launched innovative, multifunction low power ADC products that target high performance applications, including test and measurement systems and communication infrastructure. The employees of Arctic Silicon Devices will continue to work at their existing facility.

Aeroflex announced that the company has signed a purchase agreement to acquire the spectrum analyzer assets from **LIGNex1 Co. Ltd.** The primary assets to be acquired under the transaction include bench-top spectrum analyzer product lines that Aeroflex has offered under its own brand. These products include the 2399C, 2394A, 2395A spectrum analyzers as well as the newer 3250 Series spectrum analyzers, along with all the respective intellectual property. The closing is subject to certain delivery requirements by LIGNex1, as well as certain customary closing conditions.

AROUND THE CIRCUIT

Jennifer DiMarco, Staff Editor

Brush Engineered Materials Inc. announced it will change its name to **Materion Corp.** and unify all of its businesses under the new name effective March 8, 2011. The company's common stock will continue to trade on the New York Stock Exchange.

Rosenberger of North America LLC has completed the relocation of its factory and offices to a newly remodeled fifty two thousand square foot (52,000 sq. ft.) facility in Akron, PA. For more information on the complete capabilities offered by the Rosenberger group of companies, contact Rosenberger: P.O. Box 309 Akron, PA 17601, ph: (717) 859-8900, fax: (717) 859-7044.

Raytheon Co. plans to open a Public Safety Regional Technology Center in Los Angeles County this summer and is in the final stages of selecting a specific location with about 25,000 square feet of space.

The ZigBee® Alliance, a global ecosystem of companies creating wireless solutions for use in energy management, commercial and consumer applications, and the Society of Automotive Engineers (SAE) announced their collaboration on ZigBee Smart Energy $^{\text{TM}}$ standard development. Their efforts will make ZigBee Smart Energy the preferred technology supporting Plug-In Electric Vehicles (PEV) and enabling essential vehicle to grid (V2G) communication and power capabilities.

Temex-Ceramics and **Modelithics** have partnered to provide S-Parameter data on Temex-Ceramics' CLX (2225) and CLE (4040) HiQ Power Capacitors. Measured broadband, 0.04 to 2 GHz data was acquired using series and shunt mount fixtures, and is now available for free download from the Modelithics website at www.modelithics.com/mvp/Temex%20Ceramics.

Greenray Industries Inc. announced the celebration of the company's 50th year of operation as a provider of high performance frequency control products.

Valpey Fisher Corp., Microwave Products Group has begun shipping production quantities of a new series of high performance voltage variable attenuators to a major microwave radio manufacturer.

RF Micro Devices Inc. (RFMD) announced it has received its first volume production orders for its Power-SmartTM power platforms. The production orders are in support of a highly anticipated smartphone and tablet product family to be launched by a cellular handset manufacturer beginning in the March, 2011 quarter.

CONTRACTS

Harris Corp. has been awarded an Indefinite Delivery, Indefinite Quantity (IDIQ) contract with a potential total



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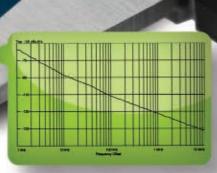


Model	Frequency Range (MHz)	Tuning Voltage (VDC)	DC Blas VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (inch)
DCO Series				the second secon	
DCO50100-5	500 - 1000	0.5 - 15	+5 @ 34 mA	-100	0.3 x 0.3 x 0.1
DCO6080-3	800 - 800	0 - 3	+3 @ 15 mA	-105	0.3 x 0.3 x 0.1
DCO7075-3	700 - 750	0.5 - 3	+3 @ 12 mA	-108	0.3 x 0.3 x 0.1
DCO80100-5	800 - 1000	0.5 - 8	+5 @ 26 mA	-111	0.3 × 0.3 × 0.1
DCO8190-5	810 - 900	0.5 - 16	+5 @ 34 mA	-118	0.3 x 0.3 x 0.1
DCO100200-5	1000 - 2000	0.5 - 24	+5 @ 36 mA	-95	0.3 × 0.3 × 0.1
DCO1198-8	1195 - 1205	0.5 - 8	+8 @ 30 mA	-115	0.3 x 0.3 x 0.1
DCO170340-5	1700 - 3400	0.5 - 24	+5 @ 29 mA	-90	0.3 × 0.3 × 0.1
DCO200400-5 DCO200400-3	2000 - 4000	0.5 - 18	+5 @ 46 mA +3 @ 46 mA	-90 -89	0.3 x 0.3 x 0.1
DCO300600-5 DCO300600-3	3000 - 6000	0.5 - 18	+5 @ 35 mA +3 @ 35 mA	-80 -78	0.3 x 0.3 x 0.1
DCO400800-5 DCO400800-3	4000 - 8000	0.5 - 18	+5 @ 20 mA +3 @ 20 mA	-78 -76	0.3 x 0.3 x 0.1
DCO432493-5 DCO432493-3	4325 - 4950	0.5 - 11	+5 @ 22 mA +3 @ 22 mA	-88 -86	0.3 x 0.3 x 0.1
DCO473542-5 DCO473542-3	4730 - 5420	0.5 - 22	+5 @ 20 mA +3 @ 20 mA	-88 -86	0.3 x 0.3 x 0.1
DCO490517-5 DCO490517-3	4900 - 5175	0.5 - 5	+5 @ 22 mA +3 @ 22 mA	-88 -86	0.3 x 0.3 x 0.1
DCO495550-5 DCO495550-3	4950 - 5500	0.5 - 12	+5 @ 22 mA +3 @ 22 mA	-83 -85	0.3 x 0.3 x 0.1
DCO579582-5	5780 - 5880	0.5 - 10	+5 @ 20 mA	-90	0.3 x 0.3 x 0.1
DCO608634-5 DCO608634-3	6080 - 6340	0.5 - 5	+5 @ 20 mA +3 @ 26 mA	-85 -86	0.3 x 0.3 x 0.1
DCO615712-5 DCO615712-3	6150 - 7120	0.5 - 18	+5 @ 22 mA +3 @ 22 mA	-85 -83	0.3 x 0.3 x 0.1

Model	Frequency Range (GHz)	Tuning Voltage (VDC)	DC Blas VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (Inch)
DXO Series					
DXO810900-5 DXO810900-3	8.1 - 8 925	0.5 - 15	+5 @ 32 mA +3 @ 32 mA	-82 -80	0.3 x 0.3 x 0.1
DXO900965-5 DXO900965-3	9.0 - 9.65	0.5 - 12	+5 @ 27 mA +3 @ 27 mA	-80 -78	0.3 x 0.3 x 0.1
DXO10701095-5	10.70 - 10.95	0.5 - 15	+5 @ 25 mA	-82	0.3 x 0.3 x 0.1
DXO11441200-5	11.44 - 12.0	0.5 - 15	+5 @ 30 mA	-82	0.3 × 0.3 × 0.1
DXO11751220-5	11.75 - 12.2	0.5 - 15	+5 @ 30 mA	-80	0.3 x 0.3 x 0.1

Features

- Exceptional Phase Noise
- Dimensions: 0.3" x 0.3" x 0.1"
- Excellent Tuning Linearity Models Available from 4 to 12 GHz
- High Immunity To Phase Hits Lead Free RoHS Compliant
- Patented Technology



For additional information, contact Synergy's sales and application team. Phone: (973) 881-8800 Fax: (973) 881-8361 E-mail: sales@synergymwave.com 201 McLean Boulevard, Paterson, NJ 07504

Visit Our Website At WWW.SYNERGYMWAVE.COM



AROUND THE CIRCUIT

value of \$475 M to supply military and land mobile radio systems to international partners of the US State Department and US Department of Defense. The five-year contract, awarded by the US Army's Communications Electronics Command (CECOM), certifies Harris as a provider of radios, accessories, communication systems and services to assist US partners with their tactical communication needs. The contract is part of the US government's Foreign Military Sales program, which supports coalition building and interoperability through sales of defense equipment, training and services.

The US Naval Sea Systems Command has awarded ITT Corp. a contract to produce 425 Band C systems and their related spares and equipment for \$16.7 M. Band C is an upgrade for the US military's installed base of vehicle-mounted systems that prevent the detonation of radio-controlled improvised explosive devices (RCIED). This award brings the total number of Band C systems on contract to 1,121 for a total contract value of \$39 M to date. The initial contract was awarded in April 2010.

Crane Aerospace & Electronics, Crane Electronics Inc., Power Solutions, was awarded by the US Department of Defense (DoD), a \$14.2 M contract for production of the Keltec Band 9/10 Transmitter high-voltage power modules for the AN/ALQ-99 tactical jamming system. Under the contract, Power Solutions will work closely with the Navy Airborne Electronic Attack Systems Division in support of the ALQ-99 Pod. These high-voltage modules are designed to drive multiple traveling wave tubes for jamming oncoming missile threats.

SRC Inc., formerly Syracuse Research Corp., recently received two contract awards with a total potential value of up to \$12.3 M for its Foliage Penetrating, Reconnaissance, Surveillance, Tracking and Engagement Radar (FOREST-ER), a revolutionary airborne radar system that penetrates through foliage to track people and vehicles on the ground.

Applied Radar Inc. has been awarded a Phase 2 Small Business Innovative Research (SBIR) contract from the US Missile Defense Agency (MDA) to develop a "Wideband Subarray Digital Receiver/Exciter (DREX)." This contract builds upon Applied Radar's on-going work with the MDA on radar receiver/exciter technology, and greatly expands the bandwidth and throughput of existing technology.

Focus Microwaves Corp., a device characterization solutions provider, announced several multi-national Tier 1 foundries and RFIC ODMs have placed orders for advanced noise characterization systems based on Focus NPEx 2.0, an advanced noise characterization toolset, and Agilent Technologies' PNA-X network analyzer.

Singapore's Nanyang Technological University (NTU) has selected **Agilent Technologies Inc.** as the supplier of RF test equipment for its Virtus IC design center of excellence. The move is designed to build a long-term relationship focusing on the growing education market in Asia.

FINANCIAL NEWS

Growth equity investor Summit Partners announced an investment for a minority stake in **M/A-COM Technology Solutions Holdings Inc.**, a supplier of semiconductors, active and passive components, and sub-assemblies for use in radio frequency, microwave and millimeter-wave applications. Financial terms of the transaction were not disclosed.

NEW MARKET ENTRIES

Remcom announced expanded consulting offerings for commercial and government organizations needing electromagnetic (EM) simulation resources. Remcom Consulting provides a combination of EM modeling experts, software developers and high performance computational resources on a per-project basis; this service is designed to help organizations that need EM expertise, but that do not have an ongoing need for EM simulation software.

W.L. Gore & Associates Inc. has expanded its family of GORE® SKYFLEX® Aerospace Materials to include preformed gaskets for multi-face aircraft applications such as hole liners, flange joints, fastener seals and galley or restroom hard-mounts. These lightweight, non-hazardous gaskets ensure continuous protection between flat interfaces, around chamfers and inside a component's mounting hole. By isolating dissimilar materials completely, these new gaskets significantly reduce the likelihood of galvanic corrosion, thereby increasing the life of the component.

PERSONNEL

The Association for Manufacturing Excellence (AME) is pleased to announce that **Douglas Carlberg** has been reelected president of the Association's Southwest region. In addition to serving as the 2011 president of AME's Southwest region, Carlberg was elected to the association's board of directors.



▲ Phil Sorsky

CommScope has appointed **Phil Sorsky** as Vice President of Wireless Sales for Europe. Based in Wokingham, England, he will lead CommScope's Andrew Solutions' European wireless sales organization in its efforts to provide high levels of support and satisfaction to customers from the Atlantic coast to Russia, and from the Nordics to the Mediterranean. A graduate of the Uni-

versity of Birmingham, UK, Sorsky has more than 20 years of telecommunications industry experience, having worked for Juniper Networks, Adobe Systems, Cisco Systems and AT&T.



🔺 Ian Dale

Linwave Technology has appointed lan Dale as a Sales Account Manager. His background is in semiconductor processing and he has many years of experience in the design, development and manufacture of microwave and millimeter-wave devices. Dale has spent the last five years in a technical sales role, supplying advanced RF and microwave components into the military, industrial

Integrated Microwave Assemblies



Advanced Technology - Extensive Experience - Superior Performance



Communications & Power Industries' Beverly Microwave Division (BMD) offers product technology that includes Integrated Microwave Assemblies and Control Components. BMD's broad experience and extensive capabilities in the areas of high power microwave component design for military and non-military radar, satellite, communications, and EW systems makes it uniquely suited to design and manufacture a wide range of components and multi-function assemblies in small, lightweight packages. Coupling that with our experience in other transmission lines and technologies gives us a technical capability that is unparalleled in the microwave industry.

- * Multi-function components
- * RF front ends
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- * High level assemblies & modules
- Design capability up to 40 GHz
- Power handling to 1 MW+ peak
- Integral driver & associated electronics
- * The industry's most extensive high power test facility

Communications & Power Industries Beverly Microwave Division

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AROUND THE CIRCUIT

and communication market sectors. His appointment will play a strategic role in the growth of Linwave Electronic Manufacturing Services and product range.



Link Microtek has expanded its surfacemount product team with the appointment of Chaxu Lad as Sales Engineer covering central and northern England. He joined the company from Teledyne Defence (formerly Filtronic Defence), where he spent six years as a procurement engineer. In addition to his UK responsibilities, Lad will play an impor-

tant role in developing export business, particularly in India, which is an important territory for the company's Azdec range of infra-red mobile communications systems.

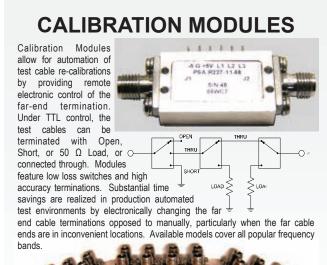
REP APPOINTMENTS

Carlisle Interconnect Technologies announced the appointment of Microwave Marketing Ltd. as technical sales agents and representatives for Carlisle Interconnect Technologies' comprehensive range of RF and microwave connectors, cables and components within Ireland, Portugal, Spain and United Kingdom. Representing the established Carlisle Interconnect Technologies brands CDI, Jerrik and QMI, this strategic appointment strengthens the company's European market presence and fully compliments Microwave Marketing's existing range of solutions for the RF and microwave market. Microwave Marketing can be contacted at: 4 Henley Way, Doddington Road, Lincoln, LN6 3QR UK, Tel: +44 (0) 1522 686 690, Paul Johnson, Sales Director, E-mail: paul@microwavemarketing.com or visit: www.microwavemarketing.com.

TotalTemp Technologies Inc., a manufacturer of temperature cycling and conditioning equipment in San Diego, CA, has announced the appointment of two well established sales representative groups in the eastern US; Eastern Instrumentation of Philadelphia (www.eiphila.com) and EOX **Sales** (www.eoxsales.com). They will be handling product sales for TotalTemp's Next Generation Thermal Platform Systems (Hot/Cold plates), temperature controllers and custom engineered solutions. Eastern Instrumentation will be the exclusive representative for TotalTemp in PA, NJ and DE. Their affiliate, EOX Sales, will represent TotalTemp in the MidAtlantic and Southeastern states.

WEBSITE

In a move to employ social media to assist career development within the engineering community, Rogers Corp. has launched a social media program engaging online communities such as Facebook, Twitter, LinkedIn and You-Tube. The social media presences are linked to the new Rogers Corp. US Careers Center page at Rogers' website, www.rogerscorp.com/careers/us. Here engineers can conduct job searches of open positions at Rogers and apply online.



PSW24-0618-13-11 PACIWAVE

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With an insertion loss of only 0.23 dB typical, these hi-rel, wide-band limiters provide protection against high level signals from +12 dBm to +30 dBm input. The power out of the limiter is +11.5 dBm, typical. Thus protecting

the sensitive devices connected to the limiter output. The surface mount RLM series is housed in a miniature plastic case, 0.25" x 0.31" x 0.17". While the VLM SMA connectorized series is housed in a rugged, patented unibody package for easy connection to sensitive devices following the limiter.

Data sheets, performance curves, measurement data, and environmental specifications are available on our website, *minicircuits.com*. So why wait, order on our website and get delivery as quickly as the next day.

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TACKLING THE MIXED-SIGNAL TESTING CHALLENGES OF SDR

oftware-defined radios (SDR) utilize a combination of FPGAs, DSPs and analog/ RF designs to achieve the radio's system performance. The mixed-signal nature of these SDR designs can introduce system integration testing complexities when the baseband hardware and RF hardware are integrated and tested together. This testing complexity presents itself because the SDR's overall system performance can be impacted by an accumulation of baseband, analog and RF design impairments, which can make issues difficult to isolate in the system integration testing phase.

An example is an FPGA finite impulse response (FIR) filter implementation, impacting the waveform quality and contributing to the SDR's overall measured error vector magnitude (EVM) performance. Additionally, the D/A converter may introduce nonlinearities and the D/A converter clock may introduce jitter, which can also impact the SDR's EVM performance. LO phase noise, IF/RF filters and nonlinear gain/phase distortion from the IF/ RF up-converter and power amplifier can also introduce waveform distortion to the SDR's EVM performance. Thus, the SDR's overall EVM performance is an accumulation of each of the error contributions along the mixed-signal transmitter chain.

SDR orthogonal frequency division multiple access (OFDMA) technologies can also employ multiple-input multiple-output (MIMO) technologies to increase data rates relative to single-input single-output (SISO) approaches. MIMO spatial multiplexing algorithms, multiple transmit/receive IF/RF chains, and multiple antennas and impairments, such as timing errors and cross-coupling between the multiple channels, 2 can further contribute to these mixed-signal testing and debugging complexities.

These problems highlight the need for an improved methodology to probe at various stages along a mixed-signal chain. This enables system engineers to gain insight into the incremental impairments introduced to the waveform at every stage of the mixed-signal SDR design. Furthermore, probing at various stages of an FPGA implementation and debugging with the same vector signal analysis (VSA) measurement software used to measure the analog IQ, IF and RF stages can provide an additional level of insight into issues occurring in the FPGA implementation itself. This article reveals several case

GREG JUE AND BRAD FRIEDEN
Agilent Technologies Inc., Santa Clara, CA

Highest dynamic range. Highest integration. ADI's RF mixers make the difference. RF Performance at All Integration Levels 40 ADL5365 35 ADRF6602 30 NPUT IP3 (dBm) 25 ADL5355 20 15 10 1700 1750 2000 2050 2100 1850 RF FREQUENCY (MHz) ADRF660x Integrated Mixer - ISP NOV



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ADL5355/ADL5356/ADL5357/ADL5358

Single and dual integrated high dynamic range narrow-band mixers. Integrated IF amplifiers provide 9 dB of power gain with excellent linearity.



Integrated Mixers

ADRF6601/ADRF6602/ADRF6603/ADRF6604
Active mixers with integrated low phase noise VCO, plus integer-N and fractional-N PLL.
300 MHz to 3600 MHz operation with
30 dBm input IP3 and low phase noise.



Active Mixers ADL5801/ADL5802

Single and dual integrated high dynamic range active mixers for Tx and Rx paths. Wideband 6 GHz operation, industry-leading noise figure and linearity performance.

Active, passive, single, or dual: industry-leading mixers from ADI

When your design goal is to reduce component count, but you can't sacrifice peak performance, there is only one place you should turn: Analog Devices. Our ADL5365 high dynamic range passive mixer integrates an RF balun, LO buffer amplifier, and an RF switch, yet still provides an industry-leading input IP3 of 36 dBm. The ADRF660x family of active mixers integrates a PLL/VCO and RF balun into a solution that reduces design footprints by more than 60% while delivering an impressive 30 dBm input IP3. Explore our extensive family of RF mixers and free RF design tools, part of the world's broadest RF IC portfolio for the entire signal chain, at www.analog.com/mixers.





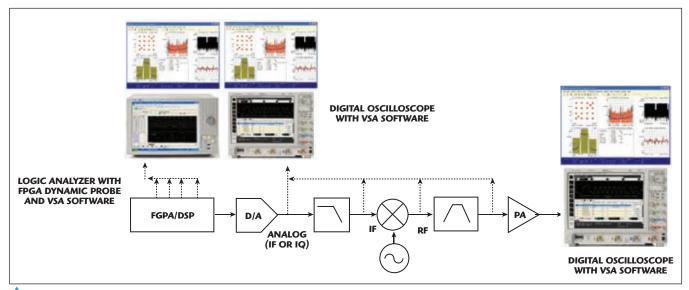


Fig. 1 Probing at various stages along an SDR mixed-signal chain using VSA software on logic analyzers and digital oscilloscopes.



▲ Fig. 2 Mixed-signal SDR test setup using a logic analyzer with dynamic probe and VSA software and a digital oscilloscope with VSA software.

studies, which highlight an improved test methodology for mixed-signal SDRs.

AN IMPROVED SDR MIXED-SIGNAL TESTING METHODOLOGY

The improved SDR mixed-signal testing methodology shown in *Figure 1* illustrates how the SDR system engineer can probe at various stages along a mixed-signal chain. This methodology enables the engineer to gain visibility into the incremental impairments occurring along the mixed-signal transmitter chain, and can also be used in debugging issues in the system integration testing phase. Vector signal analysis (VSA) software is used on both a logic analyzer and a digital oscilloscope to analyze the waveform distortion and EVM at various stages along the SDR mixed-signal chain.

An FPGA dynamic probe can be used with the logic analyzer to select intermediate digital probe points (signal banks) within an FPGA implementation. The probe points can be demodulated with the VSA software to determine the effects of the FPGA's implementation on the SDR's EVM error budget (that is measuring the EVM performance of a FIR root raised cosine filter). When probing along a MIMO physical layer coding chain, the dynamic probe capability can

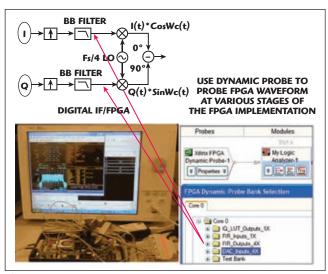
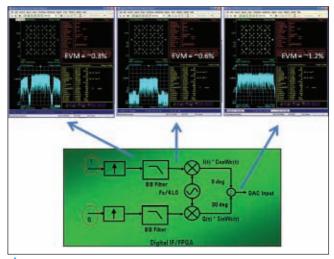


Fig. 3 FPGA dynamic probe banks for mobile WiMAX IQ modulator implementation.



▲ Fig. 4 FPGA dynamic probe measurement result showing demodulation at various stages of the IQ modulator implementation.

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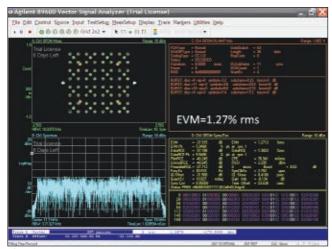
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▲ Fig. 5 D/A converter board output measured with the digital oscilloscope and VSA software.

also be used to compare the measured test vectors with expected vectors to find issues such as bit reversals.

Once the SDR waveform has been converted to analog with D/A converter(s), it can be measured at various stages such as analog IQ, IF, or RF using a digital oscilloscope with the VSA software. This allows the engineer to determine how various analog impairments such as LO phase noise, IF/RF filters, and nonlinear gain/phase distortion from the IF/RF up-converter and power amplifier (PA) are

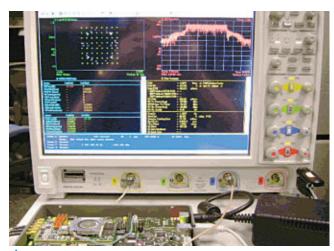


Fig. 6 FPGA two-channel MIMO test setup with digital oscilloscope.

impacting the SDR's EVM performance.

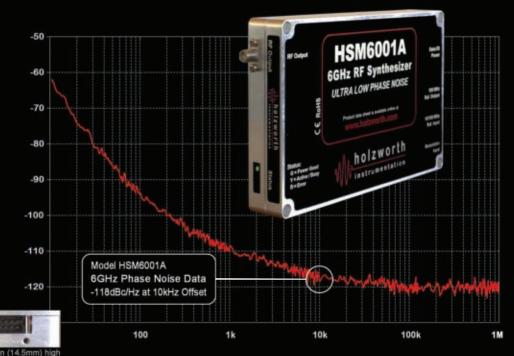
The VSA software provides measurement continuity between the digital domain using the logic analyzer and the IQ, IF, RF domain using the digital oscilloscope. This enables the engineer to diagnose issues and gain insight into waveform impairments in both the digital and analog/RF domains. Many commercial-off-the-shelf (COTS) signal formats are supported by VSA software, including OFDM and OFDMA signal formats. Two- and four-

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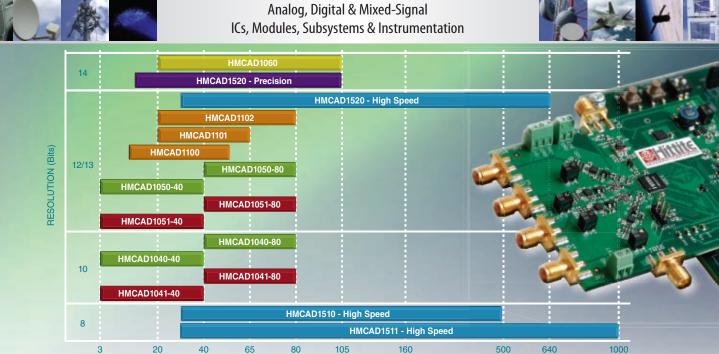




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HMCAD1511	8-Bit	1 GSPS	1, 2, 4	710 mW	49.8	49 / 64 [1]	LP7D	EKIT01-HMCAD1511
HMCAD1510	8-Bit	500 MSPS	1, 2, 4	295 mW	49.8	49 / 65 [1]	LP7D	EKIT01-HMCAD1510
HMCAD1102	13 / 12-Bit	80 MSPS	8	59 mW / Channel	70.1	77	LP9	EKIT01-HMCAD1102
HMCAD1101	13 / 12-Bit	65 MSPS	8	51 mW / Channel	72.2	82	LP9	EKIT01-HMCAD1101
HMCAD1100	13 / 12-Bit	50 MSPS	8	41 mW / Channel	72.2	82	LP9	EKIT01-HMCAD1100
HMCAD1060	14-Bit	105 MSPS	4	157 mW / Channel	74.3	80	LP7D	EKIT01-HMCAD1060
HMCAD1050-80	13 / 12-Bit	80 MSPS	2	102 mW	72	77	LP9	EKIT01-HMCAD1050-80
HMCAD1050-40	13 / 12-Bit	40 MSPS	2	55 mW	72.7	81	LP9	EKIT01-HMCAD1050-40
HMCAD1051-80	13 / 12-Bit	80 MSPS	1	60 mW	72	77	LP6H	EKIT01-HMCAD1051-80
HMCAD1051-40	13 / 12-Bit	40 MSPS	1	33 mW	72.7	81	LP6H	EKIT01-HMCAD1051-40
HMCAD1040-80	10-Bit	80 MSPS	2	78 mW	61.6	75	LP9	EKIT01-HMCAD1040-80
HMCAD1040-40	10-Bit	40 MSPS	2	43 mW	61.6	81	LP9	EKIT01-HMCAD1040-40
HMCAD1041-80	10-Bit	80 MSPS	1	46 mW	61.6	75	LP6H	EKIT01-HMCAD1041-80
HMCAD1041-40	10-Bit	40 MSPS	1	25 mW	61.6	81	LP6H	EKIT01-HMCAD1041-40

[1] Excluding Interleaving Spurs. [2] Supply Voltage (Vdd): +1.8 Vdc Analog Supply (AVdd) and +1.8 Vdc Digital Supply (DVdd). [3] Output Supply Voltage (OVdd): +1.7 to +3.6 Vdc.



channel MIMO demodulation can be performed using a digital oscilloscope with the VSA software for OFDMA waveforms such as LTE.

Several case studies will now be examined, including a mobile $WiMAX^{TM}$ case study, using the logic analyzer and the FPGA dynamic probe with the VSA software. An LTE MIMO case study using the digital oscilloscope with the VSA software will also be examined.

MOBILE WIMAX CASE STUDY

The test setup shown in **Figure 2** is used to probe at various stages along a Mobile WiMAX IQ modulator FPGA implementation using a logic analyzer with FPGA dynamic probe (left). An FPGA dynamic probe is used to select various internal FPGA signal banks, which are then demodulated by the VSA software in the logic analyzer (left) to evaluate the FPGA design at various probe points in the implemen-

tation. The FPGA development board being tested also has a D/A converter to convert the digital IF to an analog IF, which is then demodulated by the digital oscilloscope (right) and the VSA software in the oscilloscope.

Figure 3 graphically illustrates the FPGA implementation being probed and shows the signal bank selection menu in the logic analyzer. IQ data at 1 sample/symbol are stored in LUTs, then up-sampled with 4× oversampling and FIR filtered. The up-sampled and filtered IQ are then digitally modulated on a digital IF carrier using an Fs/4 multiplexing technique. A signal bank has been created for each of these points along the signal path.

Xilinx Chipscope Pro is used to configure the debug MUX ATC2 core. The core allows the user to quickly access incremental sets of internal signals in a mouse click. For this example, the core has been configured with four banks of pre-selected signals, three of which are highlighted here. They include: 1) FIR inputs at 1× oversampling; 2) FIR outputs with 4× oversampling; and 3) multiplexed digital Fs/4 IF output (DAC inputs) with $4 \times$ oversampling.

Through the logic analyzer interface, a test point can be selected, which switches the MUX inside the FPGA to bring out the particular signal of interest. That signal, such as the FIR filter output, is captured in the logic analyzer memory and is then exported to the VSA software. The signal is demodulated and analyzed with the VSA software.

Figure 4 shows the demodulation results at each of the three test points: FIR inputs at $1 \times$ oversampling (left), FIR outputs with $4\times$ oversampling (middle) and multiplexed digital Fs/4 IF output (DAC inputs with $4\times$ oversampling (right)).

The VSA demodulation and spectrum measurements in the figure show the performance at various stages along the FPGA implementation. The spectrum on the left VSA display shows the aliasing in the unfiltered waveform with 1 sample/symbol. The EVM is approximately 0.3 percent RMS. The spectrum on the middle VSA display shows the 4× upsampled and FIR filtered waveform. The EVM is slightly degraded at approximately 0.6 percent RMS, due to the FIR tap coefficients implemented



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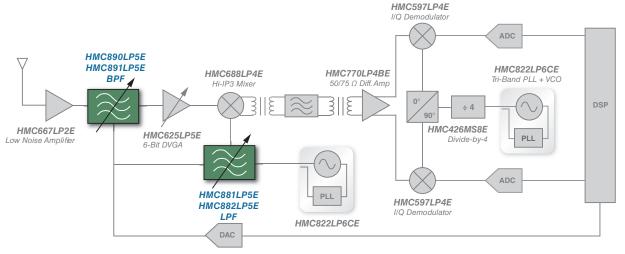


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	2 - 3.9	10	9	0.9 x Fcenter	1.15 x Fcenter	200	HMC891LP5E
	4 - 7.7	15	9	0.9 x Fcenter	1.13 x Fcenter	200	HMC892LP5E
NEW	4.8 - 9.5	7	6.5	0.9 x Fcenter	1.1 x Fcenter	200	HMC893LP5E
	9 - 19	9.5	18	0.81 x Fcenter	1.17 x Fcenter	200	HMC897LP4E

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Fig. 7 LTE OFDMA MIMO VSA demodulation results.

in the FPGA. The spectrum on the right VSA display is the digital IF spectrum centered at 11.2 MHz, which is Fs/4 for the 44.8 MHz clock being used for the D/A converter. The EVM is again incrementally degraded (relative to the FIR outputs) at approximately 1.2 percent, due to the distortion introduced by the Fs/4 fixed-point multiplexing used to

generate the modulated digital IF. This particular implementation does not reveal any significant issues; however, this methodology would provide insight issues if they were occurring (such as incorrect tap coefficient in one of the FIRs). The demodulation results at the D/A converter output and measured with the digital oscilloscope are shown in **Figure 5**.

The D/A converter output EVM (measured with the oscilloscope) is approximately 1.3 percent, and is not significantly different than the EVM measured at the D/A converter digital inputs with the logic analyzer. Thus, the D/A converter is not contributing significant waveform distortion in this example. However, this shows an approach to measuring the waveform EVM distortion contributed by an SDR's D/A converter.

LTE CASE STUDY USING DIGITAL OSCILLOSCOPE FOR MIMO DEMODULATION

The FPGA board used in the previous case study is re-configured with a bit file for two-channel LTE MIMO. The development board has two D/A converters, enabling it to be used for two-channel MIMO. Multi-channel oscilloscopes, with the VSA software, are well-suited for two- or four-channel MIMO applications, due to their multi-channel phase coherent inputs. A two-channel MIMO test setup with a digital oscilloscope is shown in **Fig**ure 6. MIMO demodulation requires well-conditioned timing between the antenna channels to maintain orthogonality of the reference signals (pilots).

The VSA demodulation results are shown in *Figure 7*. The constellation is shown in the upper left, showing the 16 QAM constellation for the physical downlink shared channel (PDSCH), as well as sync and control channels. The various channels being measured, their modulation formats and individual EVMs are shown in the frame summary table on the lower left of the figure.

The error summary, on the upper right of the figure, shows the composite EVM of approximately 0.96 percent measured on the FPGA development board with D/A converters. The MIMO information table, on the lower right, shows information about the orthogonal reference signals (pilots),

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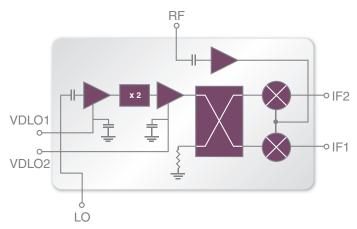
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5.5 - 8.6	I/Q Upconverter / Transmitter with VGA	DC - 3	16.5	-30	29	LC5	HMC925LC5
10 - 16	I/Q Upconverter / Transmitter with VGA	DC - 3	17	-30	14	LC5	HMC924LC5
17.7 - 23.6	I/Q Upconverter / Transmitter	DC - 3.5	15	-35	35	LC5	HMC819LC5
16 - 21	I/Q Upconverter / Transmitter	0.01 - 3.5	12	-20	30	LC5	HMC710LC5
21 - 27	I/Q Upconverter / Transmitter	DC - 3.75	12	-20	27	LC5	HMC815LC5

	RF Frequency (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	Image Rejection (dB)	IIP3 (dBm)	Package	Part Number
	5.6 - 8.6	I/Q Downconverter / Receiver	DC - 3.5	13	20	3	LP4	HMC951LP4E
	12 - 16	I/Q Downconverter / Receiver	DC - 3.5	14	32	-1	LC5	HMC869LC5
NEW!	17 - 20	I/Q Downconverter / Receiver	DC - 3.5	14	40	0	LP4	HMC966LP4E
NEW!	21 - 24	I/Q Downconverter / Receiver	DC - 3.5	15	25	1	LP4	HMC967LP4E
	21 - 25	I/Q Downconverter / Receiver	DC - 3.5	9	18	2	LC5	HMC571LC5
	24 - 28	I/Q Downconverter / Receiver	DC - 3.5	8	18	5	LC5	HMC572LC5

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antenna cross-talk and timing error.

This same test setup with the digital oscilloscope and VSA software can also be used to perform MIMO measurements on multi-channel RF transmitters, where crosstalk and cross-coupling between antenna channels may be critical. In addition, other RF impairments such as LO phase noise and power amplifier gain compression and phase distortion at various stages in the IF/RF up-converter chain could be evaluated with this test setup.

CONCLUSION

Mixed-signal SDRs present system-level integration testing challenges for the system engineer. Waveform impairments can be an accumulation of mixed-signal impairments occurring in the FPGA implementation, D/A converter, IF/RF up-converter and power amplifier. MIMO can further add to the test and debug complexities with multiple IF/RF transmit chains and antennas. Using VSA software on both a logic analyzer and a digital

oscilloscope enables the engineer to probe along the mixed-signal SDR chain to isolate issues and gain insight into where waveform impairments are occurring. The logic analyzer's FPGA dynamic probe capability adds another level of debugging capability by enabling SDR FPGA engineers to select various internal FPGA signal banks to evaluate the design with the VSA software at various probe points in the implementation. The continuity provided with the VSA software on both a logic analyzer and a digital oscilloscope provides the system engineer with a powerful cross-domain analysis tool to gain insight into the mixedsignal SDR performance, whether it is digital baseband, analog IF/RF, or both.

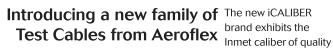
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- "Solutions for MIMO RF Test and Debug—Ensuring Quick and Accurate Four-channel, Phase-coherent MIMO Measurements," Application Note, www.agilent.com/find/pow-erofx.

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Brad Frieden received his MSEE degree from the University of Texas at Austin. He is a logic and protocol analyzer applications specialist with Agilent's Digital Debug Solutions team. He has specialized in FPGA measurements with the FPGA Dynamic Probe and written a variety of articles on this topic and other logic analyzer applications.



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NARROWBAND VECTOR INTERMODULATION MEASUREMENTS

This novel measurement technique determines accurately the magnitude and phase of nonlinear scattering parameters of nonlinear devices. For these measurements, it is necessary to extend a conventional vector network analyzer with an external phase reference and an additional test-set. This new measurement system provides the possibility of carrying out calibrated narrowband vector intermodulation measurements and offers users different types of test-sets for special intermodulation measurements. The precise modeling of the components helps to identify, diagnose and eliminate the causes of nonlinear distortions. The accuracy of vector intermodulation measurements is verified by various measurements presented in this article.

Imost all electrical elements and components have more or less nonlinear characteristics: they generate harmonics, mixture and intermodulation (IM) products. In order to prevent these effects from affecting the performance or even damaging the system functionality, a nonlinear characterization is necessary to obtain high end results. In this context, nonlinear microwave design is introduced for power amplifier optimization.¹

The large-signal network analyzer (LSNA)² was the first system providing nonlinear vector harmonic measurements. The LSNA uses broadband detectors³ or broadband samplers⁴ and supports only two-port measurements. In addition to the LSNA, a modified architecture for one-port measurements has been described.⁵ This modified architecture, using a commercial VNA, external software, additional comb generators and the power head for the calibration, enables nonlinear two-port measurements.⁶

Among the above-mentioned advantages, the vector IM-measurement provides additional benefits, such as better modeling and IM-source detection. A first verification of the nonlinear vector intermodulation reflection measurement by detecting the location of the IM-source was presented. A passive intermodulation analyzer (PIA) to measure scalar passive IM (PIM), such as in cables, connectors, etc., is already available, providing scalar results, similar to those from a spectrum analyzer.

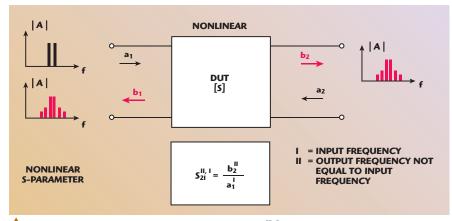
The novel vector multi-port nonlinear system (NonLin-IM)⁹ allows users to determine the magnitude and phase of the frequency converting scattering parameters of narrow-

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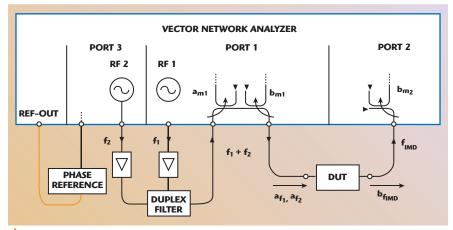


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igtriangleq Fig. 1 Frequency converting scattering parameter $S_{21}^{II,\,I}$ for intermodulation applications.



▲ Fig. 2 Block diagram of the full measurement set-up for intermodulation transmission measurements.

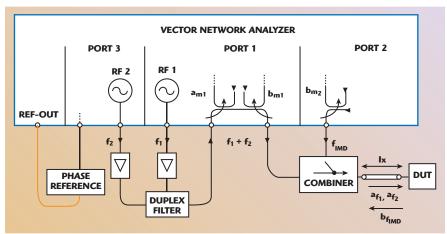


Fig. 3 Block diagram of the full measurement set-up for intermodulation reflection measurements.

band IM-measurements with high precision and high dynamic range, using a phase reference generator. The phase information allows a better modeling of the measured devices and the detection of one dominant IM-source.

Figure 1 shows the basics of the nonlinear scattering parameters for

IM-measurements. The incident wave a_1 consists of the two frequencies f_I and f_{II} ; the transmitted wave b_2 and the reflected wave b_1 include further component frequencies, arising from intermodulation, harmonic, or mixture products. The nonlinear scattering parameters describe precisely the relation between input and intermodulation frequencies. The fig-

ure explains the nonlinear transmission parameter S_{21} for a relation of the transmitted wave b_2^{II} (at the frequency f_{II}) to the incident wave a_1^{I} (at the fundamental frequency f_I).

ARCHITECTURE AND NOMENCLATURE FOR INTERMODULATION MEASUREMENT

The IM-products of some measured nonlinear devices, such as amplifiers, are stronger at the output compared to the input. Due to the different behavior of these devices at the input and output, it is necessarily to measure the reflection at the input and the transmission at the output. This system allows both measurements with a vector network analyzer (VNA) and additional equipment. The block diagram of the measurement setup for intermodulation transmission measurements with a three-port VNA is shown in Figure 2. Figure 3 shows the measurement setup for intermodulation reflection measurements with a three-port VNA.

For VNAs without open test-set, the system also provides measurement setups with a four-port VNA, as shown in *Figure 4*. VNAs with only one RF source are also supported. **Figure 5** shows a test-set to control IM-products at the RX-path of duplex-filters or switches in RF frontends with a high TX-signal and a medium antenna signal. The VNA-setup includes a synthesizer to provide the phase reference, which is driven by a 10 MHz crystal oscillator (XCO). The two amplifiers are used to increase the power of the signals at the input of the device and so the associated dynamic range. In order to prevent the measurement from being affected by the self-intermodulation of the VNA, a duplex filter is needed. An additional Wilkinson-coupler is used to measure the IM-reflection at the input of the device and to isolate the measuring

Figure 6 shows the photograph of the implemented six-port vector network analyzer. This expanded VNA is based on a Rohde & Schwarz ZVT 20 six-port VNA. The nonlinear IM-measurement requires five channels of the ZVT. The calibration of the VNA with combiner, as shown in Figure 6, was performed using the without-thru calibration procedure. This pat-

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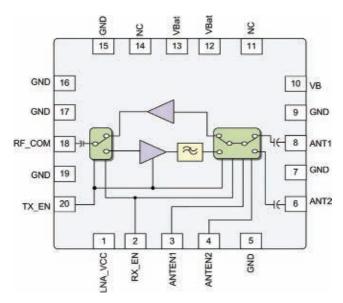
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SPECIFICATIONS

Freq Range	Freq Range	PA Gain	Р _{оит}	OP1dB	V _{cc}	PA I _{cc}	LNA Gain	NF	LNA I _{cc}	Antenna	Package	Part
(Min) (MHz)	(Max) (MHz)	(dB)	(dВm)	(dBm)	(V)	(mA)	(dB)	(dB)	(mA)	Switch	(mm)	Number
2400	2500	28.0	22.0	22.0	3.3	200	11.5	2.5	8	DPDT	QFN 3.5 x 3.5	RF6575

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RF6575 BLOCK DIAGRAM



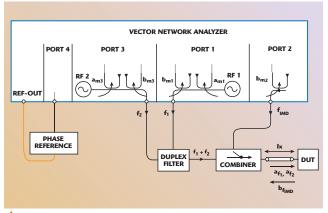
FEATURES

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▲ Fig. 4 Block diagram of the full measurement set-up for intermodulation reflection measurements with a four-port VNA.

ented procedure is the only known multi-port calibration method available for frequency converting measurements using one-port standards, since all eight error correction data (for two-port measurements) are absolutely provided in magnitude and phase.

The output of the phase reference generator is connected to the fifth channel of the VNA. It serves as a phase reference to measure the absolute phase of the measured waves. The VNA internal LO and the internal RF synthesizers have an unknown random phase offset, compared with the XCO. Linear measurements are based on the ra-

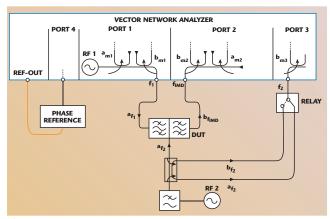


Fig. 5 Block diagram of the measurement set-up for IM measurements at the RX port with a four-port VNA (eg. ENA).

tio between the reflected or transmitted wave and incident wave at the same frequency, so the unknown phase offset is eliminated. However, this is not the case for frequency converting measurements, where the measured waves, such as a_{1m} and b_{2m} , are not at the same frequency. The use of the phase reference generator, shown in $\it Figure~7~(SG~1624~for~1.6~to~2.4~GHz),$ eliminates this unknown phase error, because the signal at the output of the phase reference generator is in phase with the XCO.

For a description of the different frequency conversions, the following nomenclature was fixed:



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• $S_{21}^{IM3L,f1}$ (Transmission parameter of the frequency conversion from f_1 to the lower IM3-product)

• $S_{11}^{IM3L,f1}$ (Reflection parameter of the frequency conversion from f_1 to the lower IM3-product)

• $S_{21}^{IM3U,f1}$ (Transmission parameter of the frequency conversion from f_1 to the upper IM3-product)

• $S_{11}^{-1M3U,f1}$ (Reflection parameter of the frequency conversion from f_1 to the upper IM3-product)

The system can also measure higher order IM-products, such as $S_{21}^{IM5L,f1}$, $S_{11}^{IM5L,f1}$, $S_{21}^{IM5U,f1}$, $S_{11}^{IM5U,f1}$, etc.

MEASUREMENT RESULTS AND VERIFICATION

For the verification of the intermodulation measurement with the novel phase reference generator, the technique described previously by the authors⁷ was used. With the phase information, it is possible to detect the

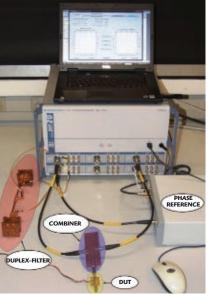


Fig. 6 Photograph of the extended VNA set-up.



Fig. 7 Novel phase reference generator with very low phase noise and small step size.

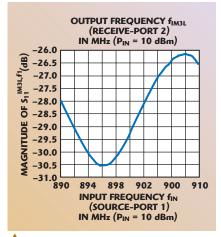
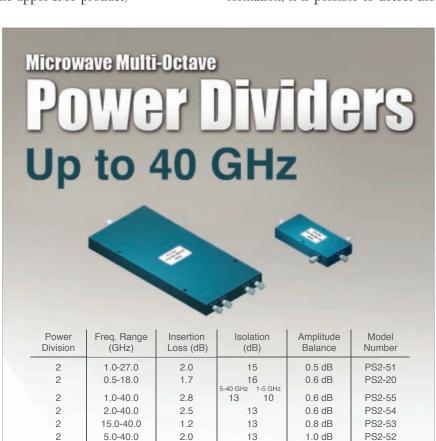


Fig. 8 Magnitude of the transmission from the 1st fundamental frequency to the lower 3rd order IM product (S₁₁^{IM3L}, f1) of an amplifier.

distance to the nonlinear device by using the intermodulation reflection measurement. As a nonlinear device under test, an amplifier with cable at the input was used, as shown in **Figure 8**.

The dynamic range of the system used (VNA without additional amplifiers) is approximately 80 dBc. For the



16

15

16

16

17

12

20

16

15

15

0.5 dB

0.8 dB

0.5 dB

0.5 dB

0.5 dB

0.8 dB

0.4 dB

1.2 dB

0.6 dB

0.5 dB

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3

4

4

4

4

4

8

8

8

2.0-20.0

1.0-27.0

5.0-27.0

0.5-18.0

2.0-18.0

15 0-40 0

0.5-6.0

0.5-18.0

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first measurement, the DUT (amplifier) was directly connected to the calibrated port (output of the Wilkinson-combiner). Figure 9 shows the measurement results for the phase of the nonlinear S-parameter $S_{11}^{-IM3L,f1}$. In this figure, the bottom axis represents the first fundamental frequency and the top axis the intermodulation of the third order resulting from the basic frequencies f_1 and f_2 (f_{IM3L} = $2f_1 - f_2$). This was a very small band

measurement of 20 MHz. The fundamental frequency f₁ was stepped from 890 to 910 MHz. The second fundamental frequency f2 was set to $f_1 + 50$ MHz to correspond with the duplex-filter. The lower intermodulation products of the third order were arising from 840 to 860 MHz. The amplifier has a frequency converting reflection $S_{11}^{IM3L,f1}$ of approximately -28 dB, so the intermodulation products are well detectable. The phase

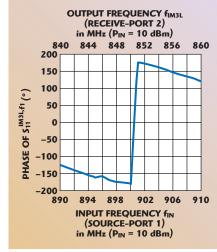


Fig. 9 Phase of the transmission from the 1^{st} fundamental frequency to the lower 3^{rd} order IM produce $(S_{11}^{IM3,fl})$ of an amplifier.

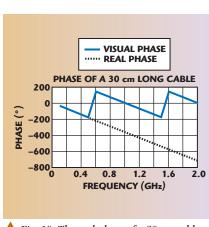


Fig. 10 The real phase of a 30 cm cable and the corresponding display on a VNA.

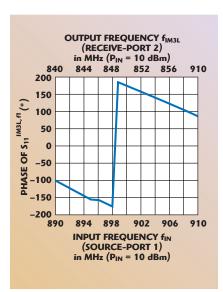
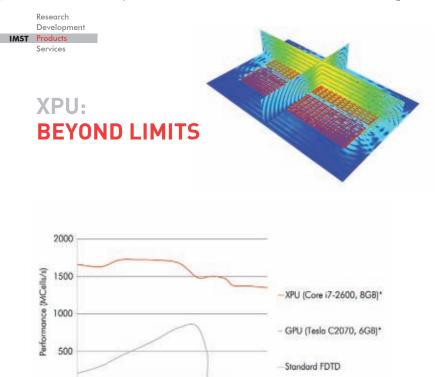


Fig. 11 Phase of the transmission from the 1st fundamental frequency to the lower IMP3 of an amplifier with a 1.23 m cable at the input.



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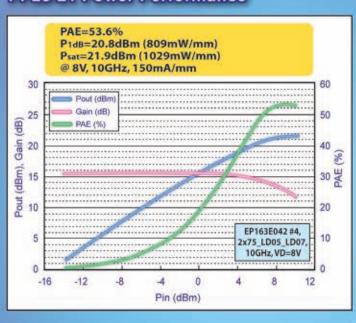


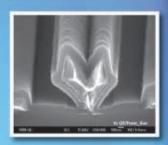
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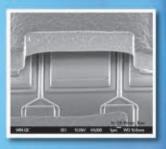
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PP25-21 Power Performance

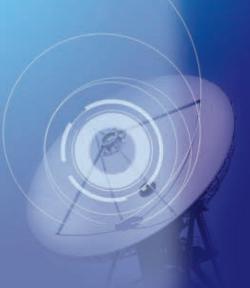






Comparison Table for 0.1µm, 0.15µm, 0.25µm and 0.5µm pHEMT

	PP10	PP15	PP25-21	PP50-11
Vto (V)	-0.9	-1.2	-1.2	-1.4
Idss (mA/mm)	450	500	345	350
Idmax (mA/mm)	720	650	460	480
GM (mS/mm)	750	495	380	310
VDG (V)	9	10	19.2	20
ft (GHz)	130	85	65~72	32
Fmax (GHz)	175	180	160	85
PldB (mW/mm)	533.25 (3.5V)	670 (5V)	809 (8V)	587 (8V)
Psat (mW/mm)	764.3 (3.5V)	820 (5V)	1029 (8V)	851 (8V)
Gain (dB)	14.35	18.1	15.6	15.5
PAE (%)	53.57	55	53.6	53.5
Frequency	29 GHz	10 GHz	10 GHz	10 GHz





Tel:+886-3-397-5999 E-mail:sales@winfoundry.com Fax: +886-3-397-5069 http://www.winfoundry.com of $S_{11}^{IM3L,fl}$ makes a phase change of 110° . For the detection of the location of the IM distortion, the gradient and the equation described by the authors was previously used. Figure 10 shows the visible and the real phase of a 30 cm cable. As can be seen, the visible phase is just between $\pm 180^\circ$. The knowledge of the real phase is necessary to calculate the correct length of the cable at the input of the device. To get the correct phase the gradient of

the phase is used.

To detect the length of the cable, the equation $lx = \phi(f)/\beta(f)$ has to be modified for the three frequencies to:

$$\begin{split} 1x &= < S_{11}^{~{\rm IM3L,fl}} / (\beta(f_2) - \\ 2\beta(f_1) - \beta(f_{{\rm IM3L}})) \end{split} \tag{1}$$

Figure 11 shows the phase response of the amplifier with 1.23 m cable at

the input.

After subtracting the phase of the device, the phase obtained with Equation 1 and 2

$$\beta(f) = (2f\pi) / c_0 \tag{2}$$

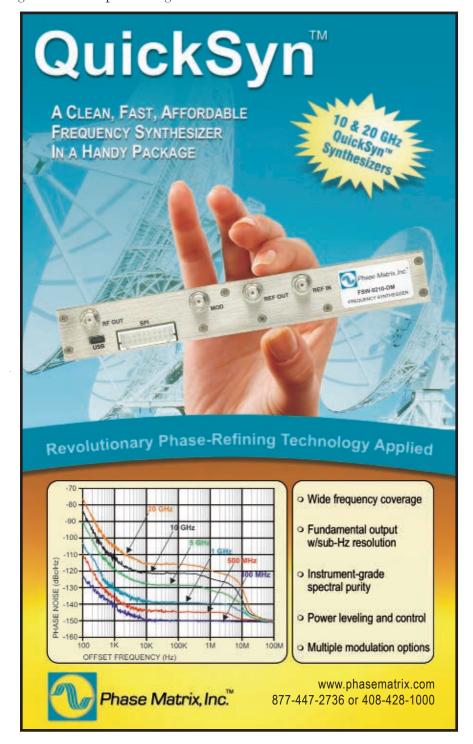
the detected electrical length of the cable is 1.24 m, while its physical length is 1.23 m. This result proves the high phase accuracy of the phase reference generator and the system.

CONCLUSION

This article describes a multi-port measurement system to determine nonlinear intermodulation distortion with an extended VNA and a novel phase reference generator. This system allows users to determine the magnitude and phase of nonlinear scattering parameters for narrowband intermodulation measurements with small step size and high precision. Additionally, a number of test-sets for the various intermodulation measurements are also supported. Measurements of IM-distortion caused by an amplifier and the detection of the length of the cable connected to the device are presented, providing a first evaluation of the system performance. The technique shown provides an excellent foundation for accurate modeling of RF components.

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Holger Heuermann received his PhD degree in electrical engineering from the University of Bochum, Germany, in 1995. From 1995 to 1998, he worked at Rosenberger

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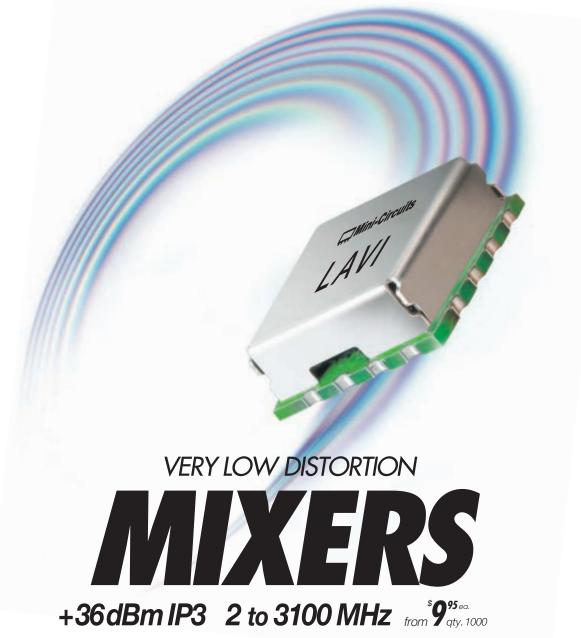




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> ciency can be improved by operating devices in their nonlinear regions, where the natural device distortion products can be represented by harmonic components.

Executive Interviews

The Cardiff Centre for High Frequency Engineering, at Cardiff University in Wales, has been researching time domain techniques and load pull measurement technologies in close cooperation with industry leaders in the mobile wireless and aerospace defense area for over a decade. The need for a practical design methodology for optimizing power amplifier designs has led to the development of the open-loop, active harmonic source and load pull techniques.

band frequencies in the US and other countries, some very attractive spectrum is being opened up that creates opportunities for commercial and military wireless technologies and applications in the 200 to 800 MHz frequency band. This, in turn, is leading to a growing need for high efficiency UHF power amplifiers and a renewed development in advanced amplifier topologies that can operate over a wide fractional bandwidth. In this article, a new active load pull technology is presented, that not only simplifies UHF testing, but also removes several of the limitations and inaccuracies common to passive load pull mea-

ith the move to digital television and

the subsequent reallocation of UHF

Of course, the demand for more efficient and lower cost design spans all wireless communications at all frequency ranges. Since this trend is directly tied to power amplifiers, an improvement in power-added efficiency (PAE) across a wider fractional band of operation can lead to the need for fewer components in multi-band designs. Traditional testing approaches are starting to reach their limits, leading to such problems as multiple design cycles due to poor correlation between expected and actual results. For complex wireless radio formats, including those technologies proposed for implementation at UHF frequencies, effi-

EVOLUTION OF NONLINEAR MEASUREMENT TECHNIQUES

Network analyzers and S-parameter theory are typically used for testing both passive and active components. Across any frequency, as long as active components are kept in the linear region, S-parameter measurements are the accepted standard for CW testing. Network analyzers can be used at frequencies as low as 9 kHz and beyond 100 GHz. However, as active components move into nonlinear regions, the theory and measurements become more complex.

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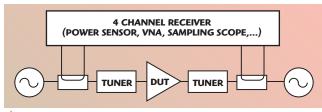


Fig. 1 Typical configuration for passive source/load pull.

Typical network analyzers are swept frequency instruments and the need for accurate phase correlation across the harmonics has been a challenge. While recent advances in calibration techniques make it possible to measure an accurate harmonic response for a repetitive signal, device and PA design-

ers still need load pull capability to test under a variety of impedances.

Passive load pull solutions have been a valuable tool for device and (PA) power amplifier designers for some time. A power sensor, VNA or sampling scope can be used for nonlinear measurements. shown in **Figure 1**. Impedance values of the harmonics at the device under test (DUT) input and output can be

adjusted using tuners to provide impedance values for designing matching circuits and power levels. A typical configuration consists of one tuner at the input, to reduce the mismatch between the input source and the device under test, and one tuner at the output to generate the required loading

condition. Tuner positioning is highly accurate and repeatable and this allows them to be calibrated. During the calibration, an accurate relationship is established between the position of the slug and the sliding short. Based on this calibration stage, the power inserted into the DUT can be determined from the power level set by the input source, while the output power can then be calculated from the power sensor reading. Tuners can be concatenated to allow for the additional control of harmonic impedances and to look at multiple harmonics. Passive tuners are also available that can handle multiple harmonics in a single tuner.

The biggest disadvantage of these systems is that they generate impedances over a large frequency range and not just the harmonic impedances; they can only control impedance at a single frequency. Impedance control is achieved by positioning the slug, which physically affects all remaining tuner operating frequencies. Consequently, harmonic impedances are not only uncontrollable, but also change their value with every new position, resulting in measurement artifacts that are not representative of real circuits. This can lead to significant performance variations between load pull measurements and realized power amplifier performance.

The same disadvantage is true for harmonic tuners (passive tuners with multiple slugs and sliding shorts) that allow a limited control of harmonic impedances as the higher harmonics (above 3rd harmonic) are not controlled and still have large variance from real circuits. For instance, a small current coming from the DUT can be transformed, due to ohm's law, into a very large voltage with harmonic impedances (above 3rd harmonic) that are easily generated by the tuners. The uncontrolled load variations make it impossible to achieve clean waveforms as required for waveform engineering. Further, coupling artifacts can create significant capacitive and inductive loading, making the time-domain waveforms highly distorted.

The position of the passive tuner between the DUT and the measuring receiver makes it difficult to distinguish artifacts from the tuner and the DUT itself. This effect has potential impact on the input or output match-



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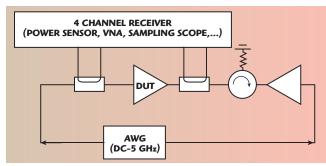


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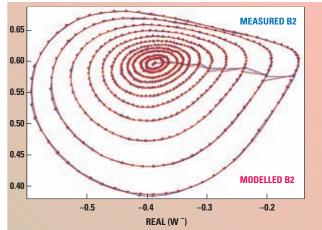
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▲ Fig. 2 Typical configuration for open-loop and active source/load pull configuration.



▲ Fig. 3 Commonality of voltage and current data allows for easy interchangeability between measurement and simulation.

ing network in a PA design. Also, due to the losses between the DUT and the tuners, only part of the Smith Chart can be covered. At lower frequencies, this effect is mitigated by the relatively low losses. However, it can increase significantly for higher frequencies, such as the harmonics of a signal.

For UHF applications, passive tuners represent a physical challenge as their size is proportional to wavelength, as shown in *Table 1*. The control of the reflection coefficients at lower frequencies is limited by the prohibitive length requirements for the coax-

ial line for the respective wavelength. Passive tuners that operate in the several hundreds of megahertz can be three feet long or more. Adding these tuners to either side of the DUT creates a number of challenges. For on wafer applications, the tuner size and weight can add to the cost and complexity of the probe station. In addition, there are vibration concerns as impedances on these large tuners are varied. The move to increase PA performance at UHF frequencies clearly creates a problem for passive load pull.

OPEN-LOOP, ACTIVE LOAD PULL

A new approach to nonlinear measurements, that addresses many of the problems just described, is called open-loop, active load pull or active load pull for short. This technique uses a separate coherent signal source to stimulate either the source or load side of the DUT, thus removing any uncontrolled interaction between the DUT and load pull system. This configuration is shown in *Figure 2*. The open-loop system absorbs the signal that is generated by the device under test and injects a signal that is generated by an independent source back into the device. The amplifier bandwidth is large enough to cover all harmonic frequencies where impedance control is required.

For UHF applications, the need for passive tuners—and their physical size challenges—disappears. With active load pull, impedance variations are created electronically. Eliminating the need for passive tuners removes the physical constraints for performing load pull measurements at low frequencies. Measurements at 2 GHz, 200 MHz, or 200 kHz become a function of source, not wavelength.

Within the open-loop architecture, all in-band and out-of-band impedances are tightly controlled. All the frequencies at which the active load pull is operating are controlled by the load source, while all other frequencies are terminated into 50 Ω . When no signal is output by the arbitrary waveform generator (AWG), the active source/load pull architecture presents a broadband 50 Ω impedance environment and, therefore, a reflection coefficient that is nearly zero over the entire bandwidth of the system. The 50 Ω environment is changed only at



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the frequencies that the AWG produces. As a consequence, the open-loop active load pull architecture does not face problems with coupling artifacts, as previously noted with passive tuner techniques.

With an AWG capable of generating any signal within a more than 5 GHz bandwidth on each channel, it is possible to control and modulate all frequency components in phase and magnitude irrespective of whether it is

a CW or a complex multi-tone signal. Interestingly, the open-loop architectures can even be safely used to generate reflection coefficients larger than unity. This allows for unique investigations of the interaction between a driver and main PA stage. Due to the stability of the open-loop architecture, it can be easily used in measurement systems.

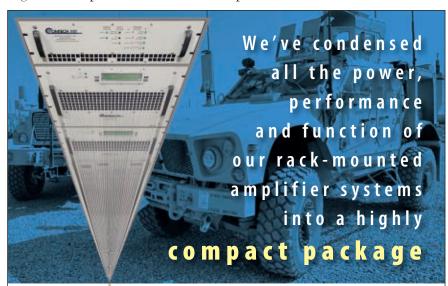
Another usage is related to load pull measurements at baseband frequencies. Electrical memory effects are a resultant hysteresis of a rapidly changing modulation envelope signal due to the parasitic capacitance across the surface of the transistor. The phenomena and effect are represented in the baseband measurement of the modulated signal. The impedance control at baseband (below 50 MHz for most modulated signals) is an important part of being able to accurately predict the memory behavior.

With DC to more than 5 GHz of bandwidth, the open-loop architecture can be used at baseband, fundamental and higher harmonic frequencies. The use of a sampling scope as the nonlinear receiver opens this up for lower frequencies. At higher power levels, it is often more cost efficient to implement the amplification over the required number of harmonics through use of a narrowband PA with center frequencies located around the fundamental and harmonic frequencies. The separation of the harmonic frequencies can be obtained by means of a multiplexer. The same multiplexer can then be used re-combine the harmonic signals.

The fact that the active load pull system is positioned further away than an impedance network within a real circuit design can be readily compensated by controlling the phase and magnitude of each frequency component within the signal generated by the AWG. As the active load pull system is placed outside the calibrated path (comprised of couplers and their connection to the sampling scope) the load pull can be reconfigured without the need to re-calibrate the measurement system.

ACCURATE, FAST LARGE-SIGNAL SIMULATIONS

Designers have been challenged over the years from the discrepancies observed between simulations and measured performance. This can result in the need for multiple design cycles that increase development costs and often add months in development cycle time. Traditionally, characterizing nonlinear device behavior has involved the use of measurements and modeling to achieve optimum results. On the measurement side, existing products have been expanded with application software and hardware in



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an attempt to address this market and assist with the creation of behavioral models. However, these PA measurement techniques often lack a coherent integration with a harmonic source/load pull system resulting in devices and amplifiers being characterized at impedances that are different from their final application. This makes it challenging to translate the measured device performance into a PA design or achieve the potential performance

available from the device or the employed PA architecture.

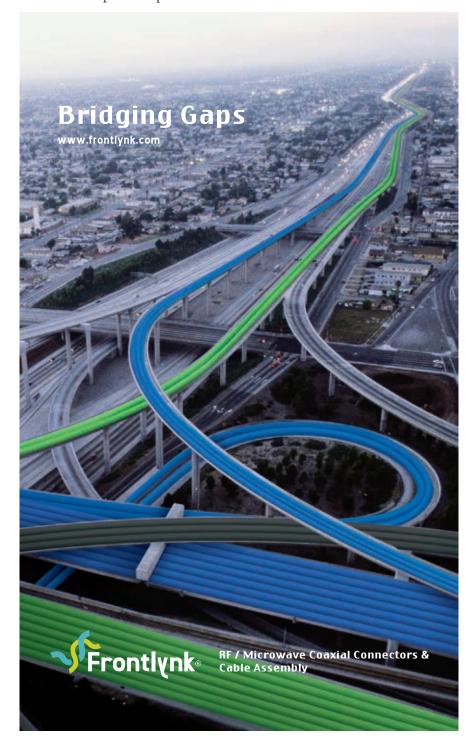
Active load pull-based systems allow for accurate and fast large-signal simulations, including both high power and non-50 Ω applications and data sets beyond the Smith Chart for complex multi-stage amplifier design optimization. Because the system can measure basic voltage and current waveform data, it provides the information needed for harmonic balance

and envelope simulations. The time domain data collected by the sampling scope can be transformed into the frequency domain and stored in a format that can be imported into EDA tools. As shown in **Figure 3**, this technique provides excellent replication of measurement data within nonlinear simulations. Once the data is imported, it can be used for spot-analysis and the authentic recreation of the device behavior with the look and feel of a behavioral model. This allows for complete characterization of nonlinear devices and amplifiers and their use in common nonlinear simulation engines. These behavioral models can be used by designers in complex component or system-level simulations.

CONCLUSION

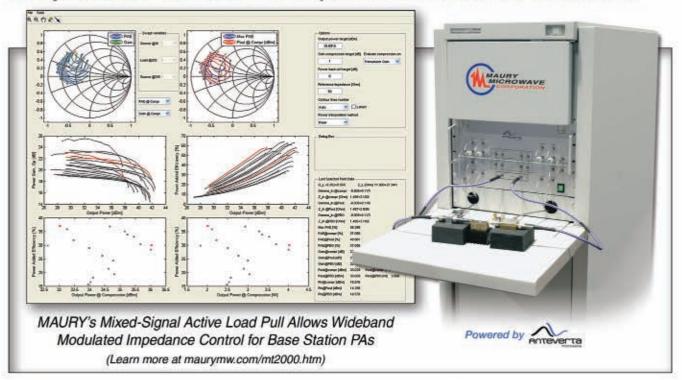
New applications and technologies are being developed at UHF frequency bands for commercial, aerospace and defense uses. When used to help optimize power amplifier designs, traditional passive load pull solutions have both limitations as well as challenges at these low frequencies. Designers need next generation tools to optimize their RF device and PA designs. Active load pull technology not only simplifies UHF testing, but also removes several of the limitations common to passive load pull measurements. Active load pull and waveform engineering enable the designer to more accurately understand the higher order source/load harmonics and thus achieve near theoretical performance. Improving the correlation between design tools and measured results has the potential to reduce design cycles and enable more efficient designs.

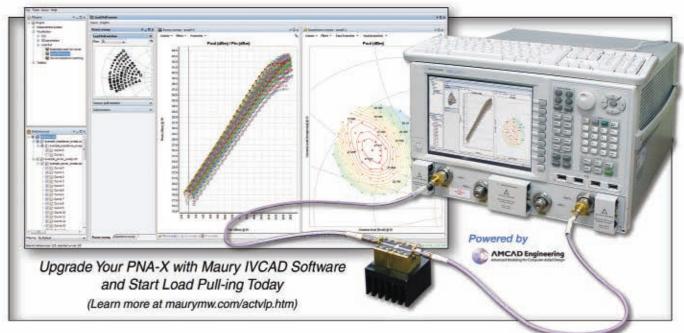
Northwestern University in Evanston, IL. He is the RF technical marketing manager for Tektronix. He has worked extensively in various test and measurement positions for more than 25 years, including R₺D engineer and project manager, product planning, business and market development. He has worked, designed or developed solutions for a wide variety of industries, including radio communication and satellite payload test, radar and direction finding, and EMC and surveillance systems.



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A MULTIBAND BANDSTOP FILTER USING A SINGLE RING RESONATOR FOR A WIRELESS ACCESS COMMUNICATION SYSTEM

A novel multiple bandstop filter (MBSF) with compact size and low insertion loss is proposed and fabricated. This filter is composed of a cell of a spurline and a section of coupled lines with a rectangular ring resonator. The center frequencies of the three stopbands are at 2.4, 3.6 and 5.2 GHz, with bandwidths of 60, 60 and 100 MHz, respectively, and three rejections greater than 20 dB. There is good agreement between the simulated and experimental results.

rireless communication systems, such as cellular mobile communication systems, wireless local area networks (WLAN) and short-range communication systems (Bluetooth), provide convenient communication services in modern society. In an airplane, when the onboard wireless communication services are provided, many other systems may be used simultaneously. Compact equipment that supports multimode/multiband wireless systems is very attractive. As a result, a multimode/multiband system is becoming a focus issue for miniaturization and simplicity. Highly integrated multiband components such as antennas and filters are becoming important under this kind of trend. As a key component in the communication system mentioned above, multiple bandstop filters (MBSF) play an important role in weakening the interference among communication systems, due to coexisting narrowband applications.

Various topologies have been proposed and developed to realize filters with multiple stopband responses.¹⁻⁷ Shaman and Hong describe a general configuration for cross-coupled wideband bandstop filters, based on an n-stub optimum bandstop filter with cross-coupling between the I/O feed lines. Microstrip BSFs using shunt open stubs and spurlines have been described.² The concept of integrating bandstop filters into a conventional bandstop or bandpass filter has been proposed.3 K.S. Chin implemented two parallel-connected different-length open stubs for resonating at dual anti-resonance frequencies to realize a dual-band bandstop filter.4 Y.H. Jeng proposed a distributed perturbation scheme of the ring resonator with no need of extra stubs or notches. 11 In this article, a novel structure of a MBSF with compact size is proposed, in order to protect an airplane navigation system from interfering signals generated by wireless access systems. The concept of the proposed filters is

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Cellular Infrastructure LNA	1200–2300	1950	17.5	0.7	34	18.5	4	55	DFN 8L 2 x 2 x 0.75	SKY67100-396LF
Cellular Infrastructure LNA	2300–2700	2500	16.5	0.7	35.5	18	5	75	DFN 8L 2 x 2 x 0.90	SKY65066-360LF
GPS and ISM Band SiGe LNA	400–3000	1575	16.5	0.8	19.5	0	3.3	7	DFN 8L 2 x 2 x 0.90	SKY65047-360LF
Broadband Low Noise FET	450–6000	2400	15.5	0.65	23.5	10.5	3	20	SC-70 4L 2.2 x 1.35 x 1.1	SKY65050-372LF
Broadband High Linearity Low Noise FET	450–6000	2400	16.5	0.8	33.5	15.5	5	55	QFN 4L 2 x 2 x 0.55	SKY65053-377LF
5.8 GHz WLAN and ISM Band LNA	4900–5900	5800	13	1	20	9	3	11	QFN 1.5 x 1.5 x 0.45	SKY65404-21

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Ws Y-AXIS SYMMETRICAL SPURLINE (a) (b)

Fig. 1 MBSF configuration: (a) basic structure and (b) photograph of the fabricated triple-band MBSF.

validated both by simulations and experiments.

DESIGN OF A MULTIBAND BANDSTOP FILTER

Generally, the bandwidth of a wireless access communication system ranges from 2.4 to 2.5 GHz or 5.0 to 5.8 GHz. In order to suppress interference with the aircraft navigation system, multiple stopbands should be available at special frequencies. More resonance cells could be employed, but the size of the circuit would inevitably increase. To overcome the problem, as shown in Figure 1, a novel configuration of a MBSF, with a size of 4×1 mm, is proposed. It consists of a cell of Y-axis symmetrical spurlines and the combination of a section of coupled lines and a rectangular ring resonator. The pair of Y-axis symmetrical spurlines was implemented to define the center frequency of the second stopband of the MBSF, while the ring resonator introduces the other two desired stopbands. Built on a 0.508 mm thick F4BK ($\varepsilon = 2.65$) substrate, three stopbands of the filter are designed within 2.38 to 2.45, 3.64 to 3.71 and 5.15 to 5.40 GHz. The simulation is performed with the commercial full-wave electromagnetic simulator HFSS.11.

Y-AXIS SYMMETRICAL **ASYMMETRICAL SPURLINE**

A basic spurline bandstop filter,

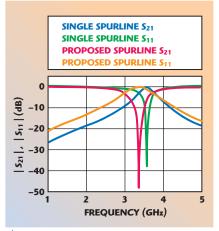
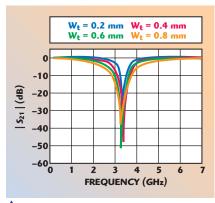


Fig. 2 Simulated frequency responses of Y-axis symmetrical spurlines.



 \triangle Fig. 3 Magnitude of S_{21} as a function of W_t .

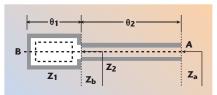
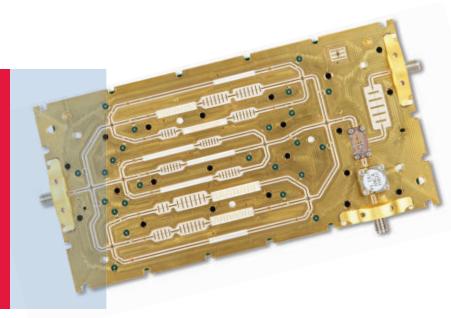


Fig. 4 Diagram of the ring resonator.

consisting of two identical parallel conductors built in stripline configuration, was first introduced by Schiffman and Matthaei. Later, the analysis of spurline filters, using two asymmetrical lines, was proposed by C. Nguyen and K. Chang. 8 In this article, a structure based on two-dimensional (Y-axis symmetrical), two asymmetrical lines was implemented, as shown in the Figure. The principal advantages of the asymmetric two-line filter are its ability to act as a symmetrical two-line filter combined with an impedance transformer, and can be designed to achieve a wider bandwidth by choosing appropriate dimensions for the asymmetric coupled lines.

Figure 2 compares the return loss and the transmission response between a conventional spurline and the

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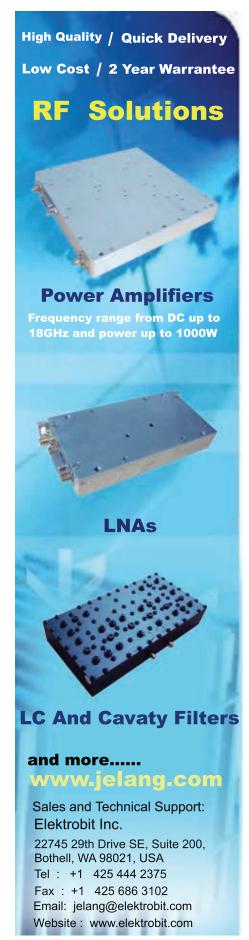
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Y-axis symmetrical spurline. The latter has a deeper rejection level of 48 dB and its bandwidth is twice that of a conventional filter. Furthermore, bandwidth varies with the parameter W_t, while the other parameters are fixed. Figure 3 plots the simulated magnitude of S₂₁ for various W_t. As W_t increases, the bandwidth of the bandstop filter widens.

MODE PERTURBATION

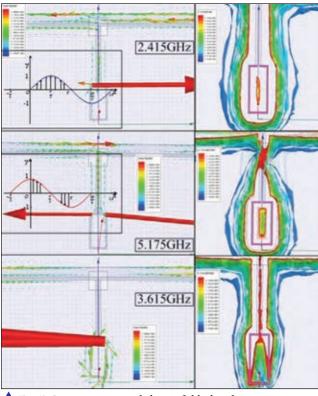
Based on the theory that a uniform ring resonator fed by an asymmetric arrangement of feeding lines or that

the circuit profile is perturbed, the degenerate modes become coupled, resulting in a narrowband bandpass response.⁹ A novel structure of a rectangular ring resonator is adopted to achieve the same effect as adding single or multiple open stubs. Figure 4 shows the schematic diagram of the ring resonator. The characteristic impedances of the coupled line and the rectangular ring resonator are Z_2 and Z_1 , respectively. For odd-mode excitation, the output feed line is coupled to a position of zero electric field along the ring resonator and shows a short circuit. Therefore, no energy is extracted from the ring resonator and the ring circuit provides a stopband. 10 The resonance conditions are determined by one of the following equations; 11 the impedance ratio $\vec{Z_2}$ / $\vec{Z_1}$ is equal to R. There are some solutions for resonance, which are dependent on the combination of R and $\bar{\theta}$

$$\begin{split} Z_{ae} &= jZ_{2e} \, \frac{Z_{2e} \, \tan \theta_{le} \, \tan \theta_{2e} - Z_{le}}{Z_{le} \, \tan \theta_{2e} + Z_{2e} \, \tan \theta_{le}} \, \cdot \\ \tan \theta_{le} \, \tan \theta_{2e} &= R(\text{even mode}) \end{split} \ . \end{split} \label{eq:Zae}$$

$$Y_{ao} = jY_{2o} \frac{Y_{2o} \tan \theta_{1o} \tan \theta_{2o} - Y_{1o}}{Y_{lo} \tan \theta_{2o} + Y_{2o} \tan \theta_{lo}} \cdot$$

$$\tan \theta_{10} \tan \theta_{20} = \frac{1}{R} (\text{odd mode})$$
 (2)



▲ Fig. 5 Current vectors and electric fields distribution.

MULTIBAND BANDSTOP FILTER REALIZATION

CASE 1: R = 1 and $\theta_1 \approx \theta_2$

The optimized dimensions of the parameters are L=32 mm, $W_g=0.2$ mm, $W_t=0.2$ mm, $L_t=6.6$ mm, $W_r=2$ mm, $L_r=4.1$ mm and $W_s=1.4$ mm for a 50 Ω line. L_s is chosen as 4 mm for convenience of measurement. The rectangular ring resonator has three attenuation poles, which are 2.41 GHz with 22 dB rejection, 3.61 GHz with 20 dB rejection and 5.17 GHz with 34 dB rejection. The distribution diagrams of current vectors and electric fields are described in Figure 5, at the center frequencies (f_1, f_2, f_3) of the three stopbands. The total length of the ring is equal to quarter-wavelength, half-wavelength and three quarter-wavelength $\{2 \times (\theta_1)\}$ $+\theta_2$) = $\lambda/4$, $2\lambda/4$, $3\lambda/4$ } separately. θ_1 and θ_2 are the electrical lengths corresponding to the physical lengths l_1 and l_2 . At the center frequency (f_1) of the first stopband, the frequency response exhibits the characteristic of a series resonance and the direction of the current remains unchanged in the range of $[0, \pi]$. At the center frequency (f₂) of the second stopband, the surface currents of the microstrip circuits around the ring resonator and the exciting mode shows the character





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of a direct connection (λ /2 transmission line), while at the frequency (f_3) of the third stopband, the frequency response shows the characteristic of a parallel resonance. The direction reverses as the phase goes through π /2. The simulated and measured amplitude responses of the triple bandstop filter are shown in **Figure 6**. It is concluded that the rejections of the ring resonator filter are greater than 20 dB within 2.38 to 2.46 GHz, 3.63 to 3.72 GHz and 5.17 to 5.41 GHz, respec-

tively. The measured results are even better than the simulated ones.

CASE 2: R<1 and $\theta_1 \approx \theta_2$

As the width of the rectangular ring (b) increases, the degenerate modes, which can be activated as transmission zeros at the frequencies of 3.6 and 5.2 GHz, exhibit a gradually concentrated trend. Investigating the results exhibited in *Figure 7*, the two attenuation poles, starting from the center frequencies, move together and form a wider

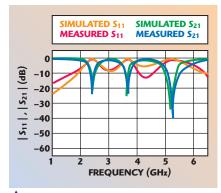
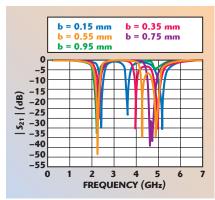


Fig. 6 Simulated and measured Sparameter of the triple bandstop filter.



ightharpoonup Fig. 7 Simulated S_{21} of the ring resonator for various width b.

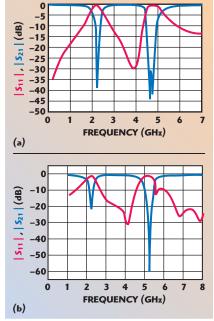


Fig. 8 Return and transmission loss of the dual-band filter: (a) simulated and (b) measured.

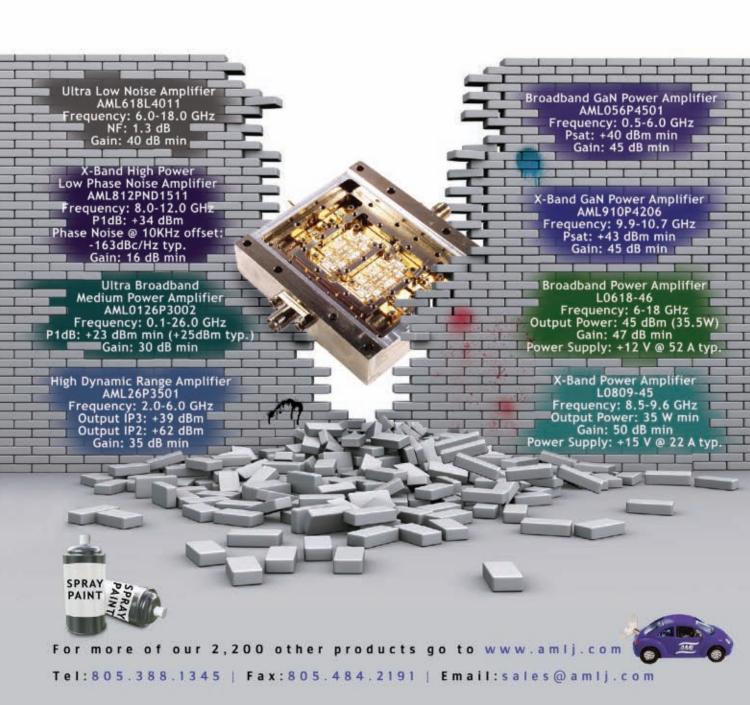
stopband. When b is equal to 0.75 mm, the corresponding impedance ratio R is equal to 0.56. *Figure 8* shows the simulated and measured results of this filter. The proposed filter has two stopbands at 2.14 to 2.24 GHz with 15 dB





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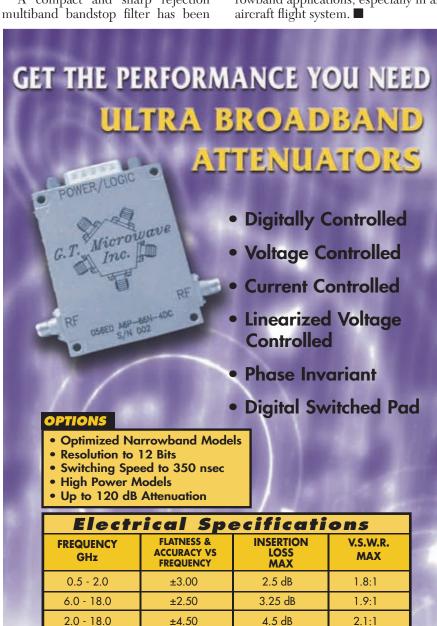


rejection, and 4.60 to 4.78 GHz with 30 dB rejection, an insertion loss lower than 0.4 dB and an attenuation rate for the sharp cut-off frequency responses of 175 dB/GHz (calculated from 4.35 GHz with -1 dB to 4.63 GHz with -50 dB) and 131.3 dB/GHz (calculated from 1.88 GHz with -1.88 dB to 2.19 GHz with -42.6 dB).

CONCLUSION

A compact and sharp rejection

proposed, which is composed of a cell of a spurline bandstop filter and a single ring resonator to achieve multiple stopbands. The measured results match the simulated prediction. The proposed MBSF shows a much deeper rejection and wider stopband without increasing the circuit size. The new filters were designed to weaken the interference among communication systems due to coexisting narrowband applications, especially in an



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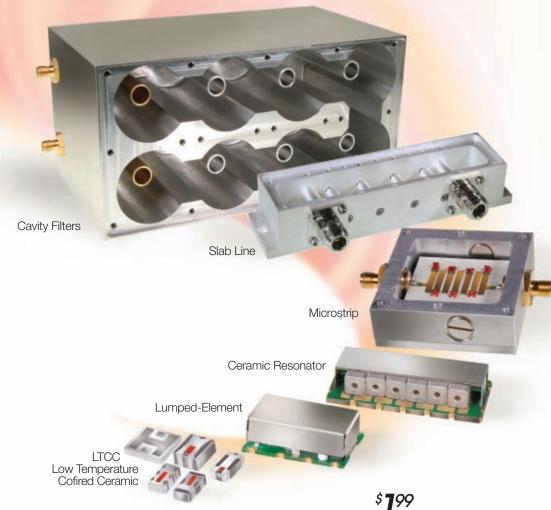
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A WIDEBAND MILLIMETER-WAVE COAXIAL TO RECTANGULAR WAVEGUIDE TRANSITION STRUCTURE

Most current adapters use additional fixtures such as tuning screws to achieve the desired transmission response. These tuning components often present challenges in design. In this article, dielectric photonic band gap (PBG) structures are introduced to the dielectric of a waveguide-to-coax adapter. As a result, the transverse electromagnetic loss is reduced and the transmission characteristics are improved. Both simulation and measurement results show that the proposed structure achieves a VSWR less than 1.25 within the frequency range of 26.3 to 40.6 GHz, while the size is decreased to 75 percent of the traditional design.

The coaxial to rectangular waveguide transition is one of the most important devices used in microwave and millimeter-wave circuits. Especially at millimeterwaves, a waveguide-to-coaxial adapter is one of the most often used components for efficient electromagnetic wave transmission and high power handling. Although many types of adapters are available commercially for frequency below 15 GHz, not many of them with simple structures and easy integration with other circuits have been reported for millimeter-waves. For instance, one of the 8 mm waveguide-tocoax adapters provided by Wiltron is reported to have a VSWR ≤ 1.25 in the frequency range of 26.6 to 40 GHz. However, the device needs additional attached fixtures, such as a tuning screw or pin, without which the performance is poor. Figure 1 shows the simulation model and the calculated VSWR of the adapter without the tuning screw. It can be seen that the VSWR changes dramatically within the frequency band and is generally larger than four. In other words, the performance of the device is sensitive to, or very much dependent on, the tuning screws and pin. It not only presents challenges in the design and fabrication process, but also makes the adapter difficult to

integrate with other circuit structures such as active integrated antennas.

Moreover, quite a number of challenges still remain for the design. For instance, little improvement has been made to extend the adapter's bandwidth without sacrificing the performance. A relatively larger transverse electromagnetic wave loss still exists due to the control of the characteristics of the dielectric used to support the inner conductor. In addition, to carry out the impedance match between a waveguide to a coaxial line (that is from 377 to 50 Ω) has not always been easy within a compact volume. Investigations along this line have been reported in the literature. ¹⁻⁵

In order to circumvent the above problems, a new concept needs to be developed. In this article, a novel structure for an 8 mm coaxial to rectangular waveguide transition in Ka-band is presented that can be easily integrated with antenna waveguide feeding circuit structures. A periodic, two-dimensional photonic band gap (PBG) structure is applied to a dielectric in the coaxial line to mitigate the transverse electromagnetic wave loss, and a step imped-

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DZR50024C	10 MHz-50 GHz		+ 0.8 (to 40 GHz) + 1.0 (to 50 GHz)	0.5	

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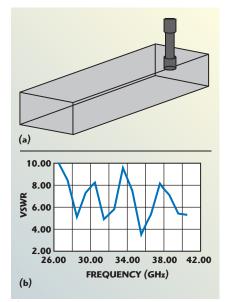
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▲ Fig. 1 (a) Simulation model of a common waveguide to coax adapter structure and (b) simulated VSWR of the adapter without tuning screws.

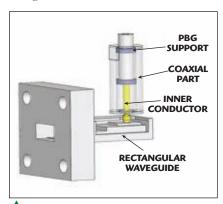
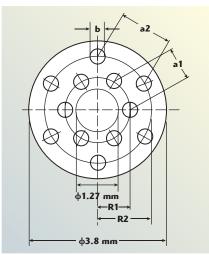


Fig. 3 Overall structure used in simulation.

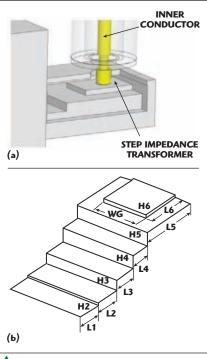
ance structure is used to realize an efficient energy transmission. Numerical simulations were performed on the proposed structure to show the performance obtained. Experiments have been conducted to validate the new design.

THE PROPOSED STRUCTURE AND ITS DESIGN

PBG structures have recently gained great attention in both theoretical studies and practical applications. They are periodical structures that are designed to affect electromagnetic wave propagation in the same way as the periodic electrostatic potentials in a crystal structure affect the electron motion, by defining allowed and forbidden (the gap) electronic energy bands. Such structures create the possibility of effective manipulations of



▲ Fig. 2 Circular dielectric column in a PBG structure.



▲ Fig. 4 (a) Transition assembly between the coaxial line and the step transformer and (b) step impedance structure.

electromagnetic wave emission and propagation processes.

Periodic structures for electromagnetic waves were proposed during the early days of microwave radars. Photonic band gap (PBG) structures are one type of the typical periodic structures. They originated from the work of E. Yablonovitch at UCLA, where one-dimensional periodic slots were cut along a metallic waveguide. Later, they were extended to one-, two- and three-dimensions and are generally known as the "Electromagnetic Band Gap (EBG)" structures. Electrically,

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they form a type of structure that prevents the propagation of the electromagnetic waves in a specified band of frequency. The main factors affecting characteristics of PBG have been found to be the number of periodic units, the geometry configuration, dimensions, array mode and dielectric constants.2,5-8

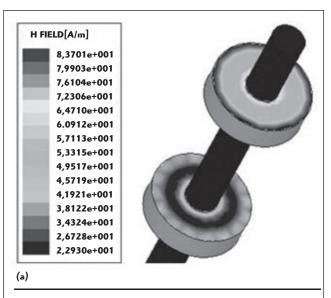
There are two types of two-dimensional (2D) PBG dielectric column structures: solid column and vacuum column array (see Figure 2). In the present case, the latter has been chosen and applied to the dielectric of the coaxial line. Its use not only improves the electrical performance, but also provides support for the inner conductor. More specifically, these vacuum columns help reduce transverse wave loss and serve electrically as a filter, while mechanically it still

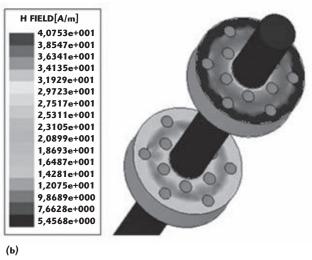
works as a support. The conducting loss will not be increased because the PBG is constructed in the dielectric support, where the electromagnetic field density is still concentrated around the inner conductor.

In the implementation, a double layer 2D PBG configuration was adopted. Given the specifications, the thickness and period of the PBG structure can be computed by using electromagnetic simulators; the central cut-off frequency can be estimated with the following classical formula

$$f_{\text{stop}} = c / \left(2a \frac{\beta}{\beta_0} \right) \tag{1}$$

where c is the speed of light in vacuum, β stands for the propagation constant in the dielectric, β_0 is the





▲ Fig. 5 Simulated field distribution, electric top, magnetic bottom; (a) non PBG structure and (b) PBG structure.

propagation constant in vacuum, a is the period of PBG and f_{stop} is the central cut-off frequency.

In the present case, the central pass band frequency is $f_0 = 37.5~\mathrm{GHz}$ and the design bandwidth is 26.5 to 42.5 GHz. The filling ratio of the PBG structure has a major impact on the performance of the structure. Using HFSS, different filling ratios R_fi were tested

$$R_{fi} = b/a_i$$
 (I = 1,2,...) (2)

According to the size of the dielectric support, two circular PBG structures were chosen. Using simulation and optimization, the best PBG arrangement for this device was obtained. The distance between the two PBG supports is 6 mm. The dimen-

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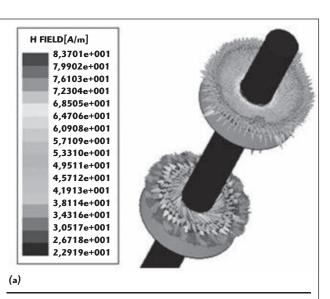
sions of each circular PBG unit is b = 0.5 mm. Numerous simulations were made for $R_{\rm fi}$ varying between 0.15 and 0.65. For the inner circle, the best combination for the two filling ratios are $R_{f1} = 0.55$ and $R_{f2} = 0.19$. However, if 0.55 is chosen as the inner circle filling ratio, the strength of the dielectric will be weakened and will lead to trouble in the fabrication the structure. Consequently, filling factors the outer and inner circles were chosen as 0.19 and 0.46, respectively. Finally, the dimensions of the structures were obtained: $\alpha_1 = 0.99$ mm, $\alpha_2 = 1.5$ mm, $r_1 = 0.\overline{9} \text{ mm and } r_2$ = 1.5 mm.

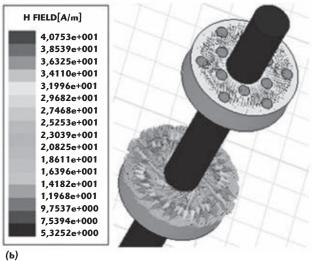
The step impedance transformer structures have been studied and are used in this design. *Figure 3* shows the overall structure used in

the HFSS simulation. In the proposed design, the bottom of the coaxial inner conductor is in contact with the top of the step impedance transformer, as shown in *Figure 4*. The impedance of each section of the transformer is made equal to the geometrical average of the preceding and following segments. The length of each impedance step is approximately $\lambda/4$, equal to the electronic length $\theta=\frac{\pi}{2}$. However, the length of this segment is not equivalent because the impedance depends on the propagation wave length in the waveguide



where λ_{g1} , λ_{g2} are the lower and upper limits of the bandpass frequency, respectively. Naturally, there are





design. Figure 3 \blacktriangle Fig. 6 Electric (top) and magnetic (bottom) line of force: (a) non shows the overall PBG structure and (b) PBG structure.

n + 1 discontinuous points of impedance conversion for n rank impedance conversion. According to the dimensions of the 8 mm rectangular waveguide $(3.556 \times 7.112 \text{ mm})$, the length and height for each step impedance and of the actual device obtained by this method will be shorter by approximately 5/32 of a wavelength. Additionally, the fact that it is well matched with a wide range of frequency can be explained by the relatively constant characteristic impedance.

SIMULATION AND EXPERIMENTAL RESULTS

The whole waveguide-to-coaxial transition structure was simulated using the available HFSS. The outer conductor is made of copper (σ = 5.8 \times 10⁷ Ω /m), while the inner conductor is made of MnCu alloy. The dielector

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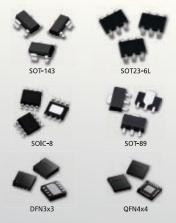


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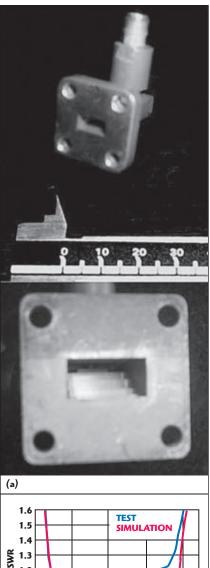
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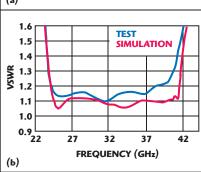


Fig. 7 Final test device (a) and VSWR curves (b).

tric material is PTFE (ϵ_r = 2.07), with a thickness of 1 mm.

Figure 5 shows the electric and magnetic field distributions and Figure 6 the electric and magnetic line forces on the PGB structure in the inner conductor support within the coaxial line, as well as without PGB. The electric and magnetic fields are concentrated around the inner conductor, leading to improved transmission efficiency and less loss from the surface of the inner conductor support.

The structure was fabricated and tested. The vector network analyzer

used for testing is Anritsu 37369B. Figure 7 shows the fabricated device and its simulated and measured VSWR. The simulation and measurement results agree quite well. The simulation shows that the VSWR is below 1.13 within the 26.2 to 40.6 GHz range with a VSWR of 1.102 at 37.5 GHz. while the measurements indicate that the VSWR is below 1.13 in the band of 24.2 to 37.9 GHz and is below 1.25 in the 37.9 to 40.6 GHz range. As mentioned before, such good performance is attributed to the use of the dielectric PBG structure that mitigates the transverse electromagnetic wave loss as well as improves the matching of impedances from waveguide to coax without additional parts.

CONCLUSION

In this article, an 8 mm coaxial to rectangular waveguide transition is proposed. It uses a dielectric PBG structure and a step impedance transformer and does not require additional parts such as tuning screws. Both simulation and measurement reveal that the designed adapter shows a VSWR result better than 1.2 within the frequency range of 26.2 to 40.6 GHz. Without additional screws, the whole structure is simple and stable, a perfect feature for use in the industry.

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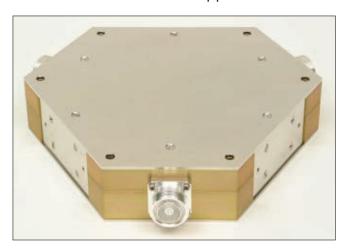
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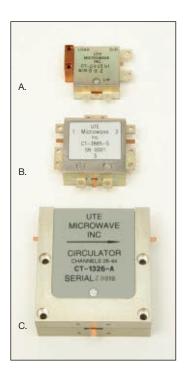
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3500 Sunset Ave., Asbury Park, NJ 07712 Tel: 732-922-1009 Fax: 732-922-1848 E-mail: info@utemicrowaye.com engineers making RF measurements, PXI's use of a high-performance CPU was particularly attractive, especially as new wireless standards were making RF measurements some of the most processor-intensive measurements in the industry.

At its core, PXI combines the computer industry standard PCI bus with timing and synchronization designed specifically for measurement and automation. Over the years, various extensions to the standard were developed and published by the PXISA. A key new PXI specification was introduced in 2005, the PXI Express Hardware Specification. This made use of a flexible new interconnect, PCI Express (PCIe), for communication to a host PC at very high data rates, with very low latency and high scalability.

Today, recent innovations in PXI instrumentation have not only made measurements faster, but have also enabled PXI instruments to push the boundaries of RF measurement performance. In fact, modern PXI RF instruments deliver measurement accuracy competitive with the best rackand-stack test equipment in the industry. For example, instruments such as the National Instruments (NI) PXIe-5665 3.6 GHz vector signal analyzer achieve typical phase noise of -129 dBc/Hz (1 GHz carrier, 10 kHz offset), among the lowest of all RF signal analyzers (see *Figure 1*). In addition, the 6.6 GHz RF vector signal analyzer can measure W-CDMA EVM within

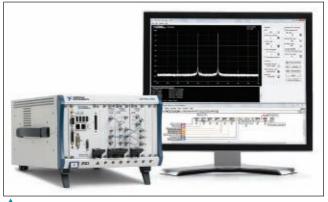
TABLE I NATIONAL INSTRUMENTS KEY PXI RF PRODUCT HIGHLIGHTS				
PXIe-5665 Signal Analyzer	PXIe-5663E Signal Analyzer	PXIe-5673E Signal Generator	PXIe-5630 Network Analyzer	
Up to 3.6 GHz	Up to 6.6 GHz	Up to 6.6 GHz	Up to 6.0 GHz	
Up to 8 Phase Coherent Channels	Up to 8 Phase Coherent Channels	100 MHz BW	Up to 8 per Chassis	
Phase Noise (1 GHz) -129 dBc/Hz	Noise Floor (1 GHz) -158 dBm/Hz	W-CDMA Uplink ACLR < 72 dBe	Dynamic Range > 100 dB	
TOI > +24 dBm Tuning Speed < 500 µs		W-CDMA Uplink EVM < 0.5%	Measurement Speed < 400 μs/point	

^{*}All values above are typical

0.5 percent accuracy, again rivaling the best in the industry. Table 1 shows a brief overview of some key PXI RF performance metrics. What is most impressive is that these performance results are achieved in the remarkably small footprint of PXI. One notable example is the NI PXIe-5630, a two-

port vector network analyzer (VNA) that boasts a front panel that is less than seven square inches in size.

While today's newest PXI RF instruments now offer best-in-class accuracy, two of the most compelling reasons for engineers to adopt PXI



📤 Fig. 1 NI PXIe-5665 with low phase noise.

continue to be measurement speed and flexibility. In PXI, the combination of a high-speed data bus (PCI Express) and high-performance CPU (currently the Intel i7) enable most measurements to be performed five to 20 times faster than traditional

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			FR-27-0035-66	2.67	0.0015		
			FR-27-0045-35	2.73	0.0014	2.70	0.0017
Speedboard® C	PTFE, Thermoset	None		2.56	0.0038	2.67	0.0053

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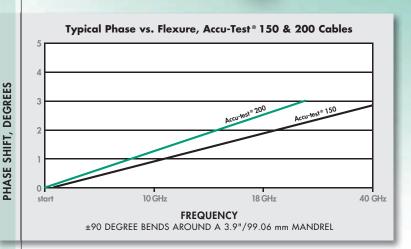
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rack-and-stack instrumentation. Over the last decade, faster measurement speed has been one of the primary drivers of PXI adoption in applications in which engineers are automating test equipment, where test time is a key factor.

Agilent's large PXI product introduction in September of 2010 was enabled by this new level of performance available in PXI, improving speed performance over existing parallel bus architectures and addressing scalability to large systems while making use of existing PXI modules. Modular instruments are a way to provide costeffective solutions by allowing test engineers to purchase exactly what they need, and easily increase (scale) channel count as an application grows.

With system integration in mind, all of Agilent's modules are either PXIe modules or hybrid-compatible PXI modules and therefore work in PXI hybrid slots. Agilent's chassis was developed with 16 hybrid slots, and any 32-bit cPCI, PXIe, or PXI hybrid-compatible modules can be placed into any slot, eliminating the need to choose modules according to the connectors in the chassis. Innovative cooling concepts require only 4U mounting without the need of additional space above or below ensuring that rack space is optimized.

MEASUREMENTS AND APPLICATIONS

The inherently flexible nature of

PXI instruments has also enabled their use in many unique applications that are difficult to solve with rackand-stack instrumentation. One such application is MIMO design and prototyping. With PXI, modularity is one of the chief product design features. As a result, several PXI RF instruments are capable of sharing signals such as reference clocks, ADC/DAC sample clocks, and even local oscillators. Using multiple up-converters, down-converters, or baseband modules, one can configure PXI RF signal generators and analyzers to have two, four, or even eight channels. Not only do PXI multichannel signal generators and analyzers have the benefit of a smaller footprint, they can be configured phase-coherently, unlike many traditional rack-and-stack instruments.

PXI instruments' flexibility offer significant benefits for applications that require real-time signal processing of IQ samples. Using the PCI Express backplane, today's PXI RF signal analyzers are capable of streaming IQ samples directly from onboard memory to other PXI modules at rates of up to 800 MB/s. Common targets for these samples include RAID volumes for data storage or even userprogrammable PXI FPGA modules. Using this technology, engineers can now program their RF signal analyzer as an FPGA target, using the real-time processing capabilities of the FPGA to perform onboard analysis routines such as FFTs, custom filtering and real-time demodulation. While many of these applications would have required engineers to design custom hardware in the past, today's FPGA technology saves both time and money by enabling the use of off-the-shelf instrumentation.

Basic measurements are covered by some of the broad application modules introduced. Test engineers can now utilize Agilent's measurement expertise when developing a PXI-based test and measurement solution. These new modules include a 6.5 digit digital multi-meter, an isolated voltage/ current source, a digital I/O module, several high-speed digitizers and high-precision, wideband arbitrary waveform generators. A large number of switching modules have also been introduced covering the range of DC to 26 GHz, filling the needs of almost any test and measurement system.

A new PXI vector signal analyzer from Agilent, with frequency coverage from 50 MHz to 26.5 GHz and with 250 MHz of instantaneous bandwidth, provides very high performance in a small package that was previously thought possible only in larger "box" instruments. This new device leverages Agilent's current VSA software packages, supporting industry standard software with the newest hardware on the market. Finally, the vector signal analyzer itself is a modular instrument as it is composed of five independent modules, allowing fu-

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ture upward (or downward) scalability as customers may use individual components as they see fit.

The PXI software specification defines standard frameworks for PXI systems. The specification stipulates that the module device driver software must run within a given framework, where the framework is based on the 32-bit Microsoft Windows® operating systems, covering Windows® 2000, XP and Vista. A recommendation of the PXI software specification is for PXI module compatibility with well-established development environments including National Instruments' LabVIEW and LabWindows/ CVI, Microsoft Visual C/C++ and Visual Basic.

The PXI modular hardware is configured and controlled by a device driver implemented using the Virtual Instrument Software Architecture (VISA). The VISA architecture is an I/O software standard, defined by the VXI plug & play specification, and adopted for PXI as well as GPIB, VXI, VME and serial instrumentation. National Instruments' NI-VISA is the

version of VISA used in the Aeroflex PXI 3000. Using VISA promotes interoperability of the software. All Agilent PXI instruments provide IVI and LabView interfaces and a soft front panel, allowing customers the flexibility of using different programming environments including Visual Studio, LabView, LabWindows CVI, MATLAB and VEE.

ADVANCED MEASUREMENT SYSTEMS

As part of its strategy to provide flexible and cost-effective test systems, Aeroflex launched the 3000 Series, a PXI-based modular test suite for mobile phone and general-purpose wireless test in October 2003. Today, the Aeroflex 3000 Series of RF Modular Instruments utilizes the speed and modularity of PXI for wireless communications testing, supporting wide bandwidth RF signal generation, RF signal analysis and RF signal conditioning for signals up to 6 GHz with a broad selection of PXI chassis and modular PXI instruments.

The Aeroflex PXI RF signal gen-

erator and PXI RF digitizer families offer multiple test system configurations that are entirely customizable to serve many different applications. By combining the appropriate Aeroflex PXI digitizers and signal generators, the overall system bandwidth and frequency range can be set to fit the needs of engineers while allowing for future expansion.

The 3000 series is also supported by the PXI Studio application software for waveform generation and vector signal analysis of complex wireless communications systems. A portfolio of libraries that is continually expanding is now capable of supporting multiple wireless standards including GSM/EDGE, UMTS/HSUPA, LTE FDD, CDMA 2000 and 1xEVDO, TD-SCDMA, WiMAX, WLAN and Bluetooth® wireless technology. The 3000 Series modules harness this speed by incorporating List Mode and Fast Sequence Tuning features to accelerate hardware setup times. Implementation of application-specific multi-threaded algorithms enables the concurrent test of multiple devices transferring speed advantages to the production line.

THE FUTURE

Key new PXI infrastructure products provide high speed and robust capabilities to the PXI community. Taking advantage of PCI Express Gen2 signaling and protocol capabilities, the new chassis and remote cabling solutions will allow up to four times the currently available data transfer rates for modules as well as remote hosts via cabled PCI Express. Also included with these infrastructure innovations are advances in backplane architecture allowing efficient and transparent peer-to-peer communication across the entire chassis. This transparency enables the emerging technologies of direct module-to-module communication allowing multiple modules to quickly and efficiently communicate without the overhead of software intervention. With underlying innovations to the modular framework, module designers and test engineers alike are now able to create even more powerful test systems than ever before.

Agilent's introduction of 48 new instruments in September of 2010 reflects how well suited PXI module

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development is to the test and measurement products, form-factors and software strategies already in place. Along with other instrumentation platforms such as rack-and-stack, test engineers will have available a widening variety of instrument modules to address a variety of test and measurement needs.

One of those other platforms is AXIe (for more information, see www.axiestandard.org), which can

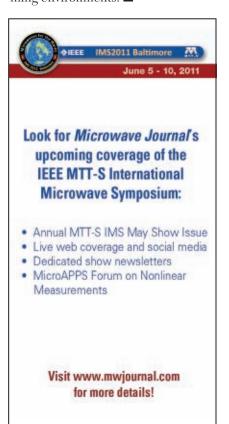
be thought of as a "big brother" to PXI. This new test and measurement standard enables modular applications that require more board space and power than PXI. AXIe modules provide about six times more of each attribute while retaining the identical programming model of PXI. In the future, the AXIe platform might even be a platform for expanding PXI functionality; the AXIe module space could allow for a carrier module with

space for two PXI modules, further expanding the integration and interoperability of the PXI standard.

Looking forward, the industry will see widespread adoption of PXI as the standard for automated RF measurement systems. In addition, future products from PXI vendors will continue to introduce measurement performance improvements in microwave RF test equipment, especially at higher frequencies. Finally, the next two to three years are likely to bring user-programmable FPGA technology to the forefront of instrument design, with RF signal analyzers using FPGAs to perform an increasing number of computationally-intensive measurements—like EVM—in essentially real-time.

In summary, test instrumentation based on open modular standards such as PXI and AXIe provides instrument designers with a vehicle to deliver new measurement technologies more rapidly, with a broad selection of test tools enabling customer specific test scenarios. Test engineers' unique measurement needs will be met faster. The software will continue to advance over time to allow test programmers freedom of choice for their programming environments.





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SIMPLIFYING AND IMPROVING ADVANCEDTECHNOLOGY MIMO RECEIVER TESTING

ultiple-In, Multiple-Out (MIMO) antenna techniques promise to de-Lliver exceptionally high data rates over new wireless technologies such as LTE and LTE-Advanced. However, the increase in attainable data rates brought about by MIMO technology is based on taking advantage of several channel characteristics that were inconsequential to legacy technologies. These new receiver designs necessitate changes in the way base stations and devices are tested, specifically a new test technique called MIMO Overthe-Air (MIMO-OTA) testing. Spirent's new MIMO-OTA Environment Builder was designed to take the uncertainty and guesswork out of this otherwise intricate field of testing (see **Figure 1**).

MIMO OTA: WHAT AND WHY?

MIMO operation is based on the idea that a set of receiving antennas can distinguish between separate data streams transmitted in the same frequency band as long as there is some spatial (directional) difference in the routes taken from transmitting antennas to receiving antennas. The simplest way to ensure that these differences are significant would be to separate the receiving antennas by large distances and ensure that the device antennas were arranged in a linear array that remains parallel to the linear array of transmitting antennas.

Of course, neither is feasible in a pocketsized mobile device, requiring some clever work on the part of the antenna designer. Conducted-signal testing is still quite useful, but it fails to account for MIMO's dependence on the physical antenna design. This is why radiated OTA testing has become critical with the increased reliance on MIMO techniques.

A typical MIMO OTA test consists of a shielded chamber, a signal source, a channel

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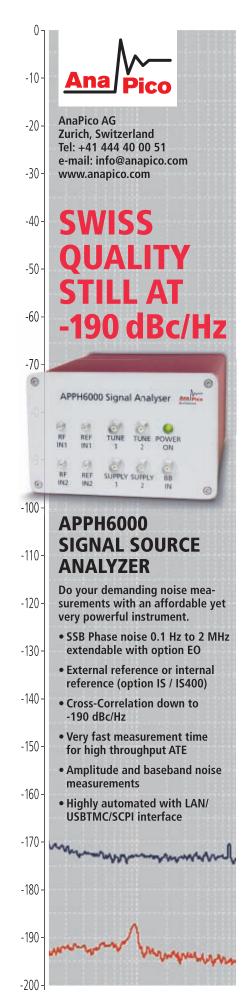
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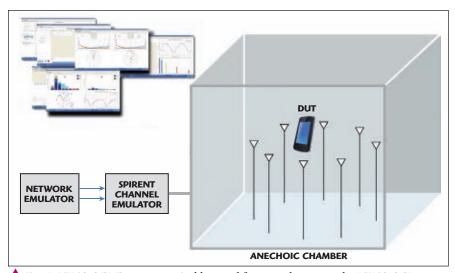
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lacktriangle Fig. 1 MIMO OTA Environment Builder simplifies control over complex MIMO OTA testing.

emulator and a number of transmitting antennas installed within the chamber. The chamber itself is one of two types:

- An anechoic chamber, which takes the chamber out of the equation by ensuring that RF energy from the antennas are not reflected into the field seen by the DUT.
- A reverb chamber, which not only uses reflections from the chamber walls, but augments and affects them with mechanically controlled reflective "stirrers" or "paddles".

The two chamber-based methods each have pros and cons, and have driven intense study and discussion within the industry's standards bodies. The Third Generation Partnership Project (3GPP), a group chartered to define wireless technologies and ensure their effectiveness, has devoted countless hours to the consideration of these methods. Discussions so far seem to indicate that while the anechoic chamber method offers greater resolution of the many variables that affect reception, the reverb chamber method is an acceptable, more costeffective solution.

MIMO OTA: HOW?

To understand the effectiveness of the MIMO OTA Environment Builder, it is important to get a feel for the complexity of the channel models that need to be created for MIMO-OTA testing. Taking the anechoic-chamber case as an example, one set of channel models that are appropriate for MIMO OTA are the 3GPP's Spatial Channel Models (SCM) (3GPP TR 25.996, "Spatial Channel Model For MIMO Simulations," version 6.1.0, September 2003). In order to recreate the SCM over the air, the radiated signals to the device must maintain a number of properly matched statistical properties.

First, it is important to match the spatial correlation properties of the channel. The SCM is defined in terms of 20 specular components. One obvious approach to matching the SCM model is to reproduce these components using 20 separate antennas. This is not practical considering that the SCM actually contains many reflecting clusters, each consisting of 20 specular components. In addition, a fully realistic model needs to accurately represent the angle spread of the transmitted signal as well as the angles of arrival (AoA) seen by the device being tested.

Spirent research (3GPP R4-"Evaluating 094673, Channel Models for MIMO OTA," Spirent Communications, November 2009) has indicated that it is possible to fully match these spatial correlation properties of the SCM model with as few as three antennas per reflecting cluster. Remarkably, careful control of the powers transmitted can accurately reproduce all the correlation properties as well as the angular spread and angles of arrival of the SCM modeled signals. Additionally, Spirent research has shown that each transmit antenna in the chamber can be used to contribute

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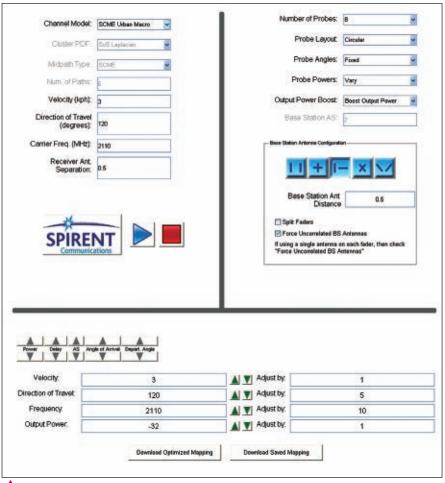


Fig. 2 Control interfaces to MIMO OTA Environment Builder: Receiver control (upper left), transmitter control (upper right) and real-time in-test editing (bottom).

signal content for the multiple reflecting clusters that make up the SCM model. The result of this work is a patent application regarding how a few antennas can accurately replicate a full field for MIMO OTA testing (International Patent Application no. PCT/US2010/024204, Publication no. WO/2010/094000). While this simplification dramatically reduces the number of antennas required in the chamber, making the anechoic chamber OTA method feasible, it also creates other complications.

The time-domain characteristics of the signal must also match the SCM. In particular, the signal received by the mobile must have the same levelcrossing rate or "fading rate" as the SCM model. This becomes challenging because of the limited number of antennas used in the chamber. However, by using Spirent's SR5500 Wireless Channel Emulator to create well-controlled faded signals into each transmit antenna, Spirent's solution simultaneously matches both the correlation properties and the timedomain statistics of the Spatial Channel Model.

Another critical aspect of the channel model is the Doppler spectrum. Since the chamber approach is based on a reduced number of antennas, the combination of generated signals must be considered in composite and shown to have a Doppler spectrum resembling the target model.

Finally, many devices have particularly good polarization diversity. In order to generate an accurate radiated SCM for these devices, both the vertical and horizontal aspects of polarization must be modeled and matched to the SCM reference model. While accounting for the addition of multiple vertically polarized antennas is straightforward, combining horizontally polarized signals is much more complex.

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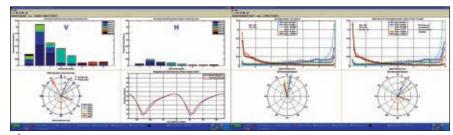
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▲ Fig. 3 Graphical feedback from MIMO OTA Environment Builder.

MIMO OTA ENVIRONMENT BUILDER

Spirent's MIMO OTA Environment Builder offers an efficient interface designed to shield the user from the labor-intensive mathematical exercises required to create valid radiated models in an anechoic chamber (see *Figure 2*). Controlling the radiated environment requires three steps:

- Setting up the channel model parameters setup can be as simple as selecting a standard channel model from a drop-down box, then entering mobility and other parameters. Customized channel models are also possible.
- Describing the in-chamber transmitting hardware probe-specific parameters are selected here. Greater accuracy is achieved by a one-time chamber calibration that tells the software how to account for radiated path loss, etc.
- In-test editing during test execution, screen-oriented controls can dynamically adjust parameters in order to quickly see the effects of realistic variations in the environment. For example, angles of departure and arrival can be edited, as can the total signal power seen by the device under test. On-screen graphics offer immediate feedback, helping minimize the potential for user error.

The feedback mechanism designed into the tool offers comprehensive graphical summaries of the effects of the modeled channel. *Figure 3* includes two of the tab views available from the tool. The left side of the figure shows per-probe values of power distribution related to both the vertical and horizontal polarizations. It also contains (on the bottom left) a polar summary of the power angle profile for the given model overlaid on a representation of the actual antenna probes as configured in the chamber. The graphic to the right of this polar

plot is a map of the generated channel correlation as compared to the ideal narrow-band model. The two plots on the upper right-hand side of Figure 3 depict the ideal and generated Doppler spectra, while the two on the bottom show the power azimuth spectra at both the base station and the device under test.

The MIMO OTA Environment Builder is the latest manifestation of Spirent's continuing strategic initiative to bring simplified control over complex wireless testing. This powerful tool offers straightforward, graphical control and feedback over the extremely useful but complex processing required to perform MIMO OTA testing with confidence. The implementation of MIMO-based 4G technologies promises great benefits. This potential underscores the importance of validating the entire MIMO channel, especially those elements that take on new significance with MIMO. When properly implemented, MIMO OTA testing can have a direct effect on the ability of operators and device manufacturers to deliver the data speeds promised by these advanced technologies.

Spirent Communications, Sunnyvale, CA (408) 752-7100, www.spirent.com.

"With the onset of multi-antenna, multi-band devices in evershrinking form factors, optimizing OTA performance is critical to the success of LTE," said Rob Van Brunt, Vice President of Spirent's Wireless group. "Spirent's test experts are leading the industry in developing a range of new MIMO OTA test methodologies, including techniques that use anechoic and reverberation chambers."





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SIGNAL GENERATOR SIMULATES GPS, GALILEO AND DIGITAL **COMMUNICATIONS STANDARDS**

o characterize Global Navigation Satellite System (GNSS) receivers, a number of typical tests are used. These tests check how quickly a receiver can fix its position after it is switched on, or how accurately the calculated position matches its actual position. Users normally perform a complete series of tests under various scenarios in order to make statistically sound statements about the characteristics of a receiver. A satellite simulator that can simulate various scenarios is ideal for this task and the GNSS solution provided by the R&S SMBV100A signal generator features the required flexibility.

Only a few keystrokes are needed to generate complex scenarios that are unlimited in time with up to 12 satellites. The user can select the almanac file, the number of visible satellites and the receiver's geographical position. It is possible to simulate stationary positions and moving scenarios that simulate the movement of a receiver along any chosen route.

The user can also simulate restricted sight conditions to the satellites, such as when driving through a tunnel. In addition, the simulation of multipath propagation and atmospheric effects produce very realistic transmission conditions. For full GNSS functionality, the R&S SMBV100A also provides hybrid GPS and Galileo scenarios for testing multi-standard receivers.

The R&S SMBV100A GNSS solution also comes with flexible customization options that allow users to change the configuration of the signal generator to keep pace with additional testing requirements. The user invests in new features on an as-needed basis. Additional functions can be activated with a license key so there is no downtime such as would be needed for hardware in-

Today, GNSS receivers are a standard feature in numerous mobile phones and car entertainment systems. Even chipsets in pure navigation devices are increasingly multi-standardcapable. In addition to generating GNSS signals, the R&S SMBV100A comes with options for generating standard-compliant signals for all major digital communications standards (LTE, HSPA+, W-CDMA, WiMAX, GSM, WLAN) and radio standards (DAB, Sirius/XM radio, HD radio). Manufacturers of products with integrated GNSS receivers benefit from this versatility as they only need one R&S SMBV100A to test GNSS and other functions.

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Solutions for Verifying LTE Signals - Quickly and Accurately Decode LTE Downlink Signal Data

White Paper, Agilent Technologies



Harmonic Measurement for IEC 61000-4-3 and other Radiated Immunity Standards

Jason Smith and Pat Malloy, AR Worldwide



Using COMSOL to Solve for Currents along a Thin-Wire Antenna Excited by a Lumped Source $\ensuremath{\mathbb{R}}$

3D EM Field Simulation: A Tool to Control Thermal Runaway

Presented by COMSOL



Microwave Power Amplifier Fundamentals

Carlos Fuente, Giga-tronics, Inc.

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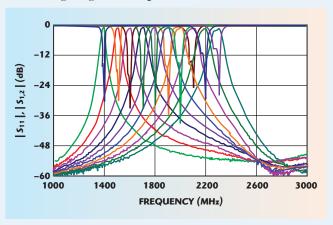


Frequency Matters.



Breakthrough Highpower Microwave Filter Technology

ctive Spectrum has introduced low-loss, tunable filter modules in the 225 to 6000 MHz bands, using a proprietary tunable resonator to implement a filter with wideband tuning, low insertion loss (1.0 dB typical) and high RF power handling capability (> 20 W). The tunable filters show significantly improved insertion loss, linearity and static power consumption compared to conventional varactor or PIN diode tuned filter modules. These miniature tunable filters show industry leading performance in terms of low insertion loss, high RF power handling capability and very wide tuning range (octave plus).



These products are ideal solutions for difficult co-site interference problems in next generation communication systems for commercial and military applications. Active Spectrum offers standard tunable filter models covering the frequency bands from 700 MHz to 4 GHz, and custom designs up to 18 GHz.

Active Spectrum, Foster City, CA (650) 212-2625, www.asimicrowave.com.



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LTE Videos VENDORVIEW

Gain greater insight into LTE design and test with the new 24/7 Agilent LTE Videos page. The site is designed to give information about LTE test for greater understanding, more rapid development and design into this complex technology. To view the videos, visit www.agilent.com/find/LTEvideos, or go to YouTube and search for "AgilentLTE".

Agilent Technologies Inc., 5301 Stevens Creek Blvd., Santa Clara, CA 95051

www.agilent.com



Interference Solution Provider

ARC Technologies has revamped its website for smoother navigation and easier document download. The site features a fresh design and the addition of flash animation on its homepage. For customers looking for the latest information on ARC Technologies' microwave absorber products and electrically tuned composite materials, the new site provides streamlined navigation for easier site browsing and easy access to download brochure-catalog PDFs. Markets served by ARC's products – electronics, military, medical, antenna and automotive – are listed.

ARC Technologies Inc.,

11 Chestnut Street, Amesbury, MA 01913

www.arc-tech.com



RF and Microwave Filters VENDORVIEW

Visit the company's website for high performance RF and microwave filters and related products for commercial, aerospace and defense, and industrial applications. Products include low pass, bandpass, high pass, and bandstop filters in lumped element, ceramic, cavity, crystal, SAW and helical configurations. AEI also manufactures duplexers and triplexers, power dividers, directional couplers, circulators, terminations, cable assemblies and antennas.

Anatech Electronics Inc. (AEI), 70 Outwater Lane, Garfield, NJ 07026

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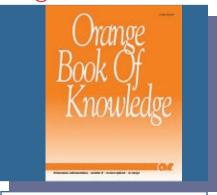
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4th Edition – AR's Orange Book of Knowledge

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A digital edition of AR's "Orange Book of Knowledge" is now available on AR's website. The book contains articles and application notes on a wide range of topics and applications including a reference guide for coaxial connectors and cables and harmonic measurement for IEC 61000-4-3. Visit www. ar-worldwide.com to download your copy today.

AR RF/Microwave Instrumentation, 160 School House Road, Souderton, PA 18964

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Video Tutorials

In order to get acquainted with the software, a new and convenient learning tool has been introduced in the download section of the EMPIRE XCcel website. Video tutorials demonstrate, step-by-step, how to use the software for typical applications. Mouse movements and clicks are indicated and the video can be stopped and rewound at any time. Videos offer guidance via audio comments, which explain all steps in detail. The videos can be displayed online by using the latest Acrobat reader or downloaded as an executable.

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TM1-0	0,3 - 1000	1:1	ĴĖ
TM1-1	0.4 - 500	1:1	JE
TM1.5-2	0.5 - 550	1.5:1	ĴĔ
TM2-1	1 - 600	2:1	JE
TM1-6	5 - 3000	1.1	0-ww-0
TM2-GT	5 - 1500	2:1	<u> </u>
TM4-GT	5 - 1000	4:1	ŢŢ
TM8-GT	5 - 1000	8:1	ŢŢ
TM4-1	10 - 1000	1:4	
TM4-4	10 - 2500	1:4	
TM1-2	20 - 1200	13	ĨE
TM1-9	100 - 5000	1:1	0_mm_0
TM1-8	800 - 4000	1.1	مسسو









Product Tutorials VENDORVIEW

The 50BA-series is an all-new line of variable attenuator systems. These modules come complete with Ethernet/RS-232 interfaces as well as manual control (via Momentary Lever Actuator Switches with 7-segment digital display). Designed to be easy to use, compact and affordable, the 50BAs are available with one or two channels of attenuation (0 to 63 dB or 0 to 95 dB in 1 dB steps) and operate from 0.2 to 6 GHz.

JFW Industries, 5134 Commerce Square Drive, Indianapolis, IN 46237

www.jfwindustries.com



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YONI2® Search Engine VENDORVIEW

Mini-Circuits offers more than 10,000 RF/IF and microwave components on its website. To help customers take full advantage of their product range, the company developed YONI2, a patented search engine. YONI2 references millions of actual test data points to meet almost any customer request. If an exact match is not currently available, YONI goes even further. It helps customers reprioritize, to identify any items that meet key criteria, or easily adaptable close matches.

Mini-Circuits, PO Box 350166, Brooklyn, NY 11235

www.minicircuits.com



Product Tool Finder VENDORVIEW

San-tron has redesigned its website to offer clients, representatives and engineers the opportunity to search its extensive product inventory and knowledge base. The website navigation has been intuitively reorganized, making it easy to browse the main product lines of connectors, adapters, cable assemblies and turned components. Scrolling features on the homepage deliver the most pertinent information directly to visitors, while links to the latest news are plainly visible.

San-tron Inc.,

4 Turnpike Road, Ipswich, MA 01938

www.santron.com



Filters, Diplexers and Sub-assemblies VENDORVIEW

Reactel Inc. has revamped its website offering a new look and much more information. Accessing information of issuing an RFQ for the company's products has never been easier, and is now just a click away. Reactel's full line of RF and microwave filters, multiplexers and multifunction assemblies catalog is available for download in support of its worldwide customer base.

Reactel Inc., 8031 Cessna Avenue, Gaithersburg, MD 20879

www.reactel.com



Product Training Modules VENDORVIEW

This new product training module showcases Skyworks' comprehensive diode product portfolio, which is now available and can be found at www.skyworksinc.com/Products_Diodes.aspx. Skyworks' diode product offering includes PIN, Schottky, varactor and limiter diodes. The company's discrete silicon and GaAs semiconductors are available as die, plastic packaged, surface-mount and ceramic hermetic packaged devices.

Skyworks Solutions Inc., 20 Sylvan Road, Woburn, MA 01801

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T-Tech Inc. announced the launch of the company's new website www.t-tech.com. The updated design and interface have been developed to provide an excellent online prototyping tool, and material ordering experience. Improvements include order history, permanent cart, multiple address book and product reviews.

T-Tech Inc., 510 Guthridge Court. Norcross, GA 30092

www.t-tech.com



RF and Microwave Filters to

EWT has launched a redesigned website with a new look and improved content and navigation. The site features RF and microwave filters and filter-based products for military, commercial, wireless and space applications. Visitors can download EWT's catalog and will find product information on its cavity and waveguide filters to 50 GHz and lumped element filters up to 10 GHz.

Eastern Wireless TeleComm Inc. (EWT), 2040 Shipley Drive, Suite 5, Salisbury, MD 21801

www.ewtfilters.com



RF and Microwave Components

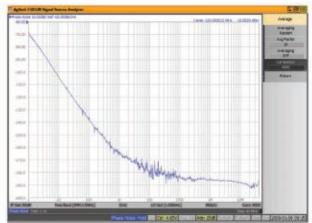
Technical Research and Manufacturing Inc. announced the changing of its name to TRM Microwave and the launch of its new website. TRM's dramatically redesigned site demonstrates its forward-thinking vision and commitment to the growing needs of its customers. Based on extensive research and interviews with customers, it offers: clearer messaging on TRM's mission; direct access to TRM's product catalog from every page; more intuitive navigation and streamlined searching; and streamlined online quoting.

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Plainview, NY (516) 694-6700, www.aeroflex.com.

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Analog Devices Inc., Norwood, MA (781) 329-4700, www.analog.com.

DC Blocks



Crystek's line of CBLK DC blocks are designed to block DC voltage while passing frequencies from 300 kHz to 3 GHz. These DC blocks are ideal for use in broadband coupling and test and measurement applications. Crystek DC blocks produce a flat frequency response, they offer low insertion loss (0.02 dB at 300 kHz; 0.20 dB at 3 GHz) and excellent return loss through 3 GHz (14 dB male and 15 dB female). DC input voltage is rated at 16 W VDC (maximum); operating temperature range is -55° to +90°C. Crystek DC blocks are available immediately from Crystek's stocking distributors.

Crystek Corp., Fort Myers, FL (239) 561-3311, www.crystek.com.

MMIC Phase Shifters



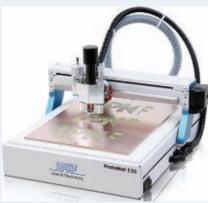


The HMC931LP4E, HMC932LP4E and HMC933LP4E are SMT packaged MMIC phase shifters ideal for phased array, as well as sensor and subsystem applications in fiber optic, military, test, and industrial/medical equipment from 8 to 24 GHz. The three MMIC analog phase shifters provide continuous phase shift of up to 470 degrees and accept an analog control voltage from 0 to 13 V. The HMC931LP4E phase shifter covers 8 to 12 GHz, while the HMC932LP4E and HMC933LP4E phase shifters cover 12 to 18 and 18 to 24 GHz, respectively. The HMC931LP4E, HMC932LP4E and HMC933LP4E exhibit consistent insertion loss as low as 3.5 dB, with excellent phase accuracy of ±10 degrees across the band.

Hittite Microwave Corp., Chelmsford, MA (978) 250-3343, www.hittite.com.

Prototyping System

LPKF introduces the new ProtoMat® E33 circuit board plotter, an entry-level milling machine for in-house rapid PCB prototyping. This compact system is a great introduction to



PCB structuring and comes with powerful software to effectively support the user during the milling process. It does not require the necessity of external vendors and encourages those with limited budgets a more practical use such as exercises, experiments and educational purposes. The LPKF ProtoMat E33 has the ability to create single or double-sided circuit board prototypes without the use of chemicals, drills holes for plated vias, mills individual units from base material and also engraves front panels of housings. Its compact $16.5" \times 11.7"$ size comes equipped with a 30,000 RPM milling motor, 0.8 µm resolution, ±0.005 mm repeatability, and an easy-touse tool holder.

LPKF Laser and Electronics, Tualatin, OR (503) 454-4212, www.lpkfusa.com.

Precision 7-16 DIN Adapters



7-16 DIN adapters are highly desired in test applications such as base station passive intermodulation (PIM) testing. These low loss, low VSWR "rugged" adapters are designed to be used with portable antenna and cable analyzers. Anritsu's Site MasterTM, Summitek's SITM series and Boonton's PIM testers are examples where high grade DIN adapters are used. Some features include stainless steel coupling nuts, white bronze plated bodies for tarnish free service, superior electrical performance and low PIM. White bronze plating offers a non-magnetic solution while retaining high conductivity in the conductor paths.

RF Precision Products, San Diego, CA (858) 571-5400, www.rfp2.com.

300 kHz to 20 GHz

AMPLIFIERS



Mini-Circuits ZX60 family of compact coaxial amplifiers serve a broad range of applications from 300 kHz to 20 GHz. ZX60 models offer many combinations of gain (as high as 38 dB), noise figure, output power, and linearity (IP3 performance) over wide bandwidths, allowing designers, for example, to optimize system dynamic range through a wide choice of noise-figure performance levels (as low as 0.4 dB at 1.4 GHz) and high IP3 performance (as high as +45 dBm at 2.4 GHz). ZX60 amplifiers are small in size and low in cost, and still deliver excellent active directivity (isolation-gain) and outstanding unit-to-unit performance repeatability. All models feature Mini-Circuits exclusive Unibody housing (protected by US Patent No. 6,790,049) for reliability. And when these ready-to-ship standard models won't do, Mini-Circuits technical team is ready to quickly meet your most demanding requirements with effective custom solutions.

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Model	Freq. (GHz)	Gain (dB) Typ.	NF (dB) Typ.	IP3 (dBm) Typ.	P _{out} @ 1dB Comp. (dBm) Typ.	DC Volts (V)	Current (mA) Max.	Price \$ ea. (1-9)
Lengti	h: 0.74" x (W)	1.18" x (H) 0.46	3"				
ZX60-2510M ZX60-2514M ZX60-2522M ZX60-3011	0.5-2.5 0.5-2.5 0.5-2.5 0.4-3.0	12.9 16.4 23.5 12.5	5.4 4.8 3.0 1.7	+28.8 +30.3 +30.6 +31.0	17.1 16.5 18.0 21.0	5.0 5.0 5.0 12.0	95 90 95 120	59.95 59.95 59.95 139.95
ZX60-3018G ZX60-4016E ZX60-5916M ZX60-6013E ZX60-8008E ZX60-14012L ZX60-33LN	0.02-3.0 0.02-4.0 1.5-5.9 0.02-6.0 0.02-8.0 0.0003-14.0 0.05-3.0	20.0 18.0 17.0 14.0 9.0 12.0 17.6	2.7 3.9 6.4 3.3 4.1 5.5	+25.0 +30.0 +28.3 +28.7 +24.0 +20.0 +30.0	11.8 16.5 14.4 10.3 9.3 11.0 17.5	12.0 12.0 5.0 12.0 12.0 12.0 5.0	45 75 96 50 50 68 80	49.95 49.95 59.95 49.95 49.95 172.95 79.95
ZX60-183+ ZX60-24+	6-18 5-20	24.0 24.0	6.9 6.8	27.3 27.0	18.0 18.0	5.0 5.0	290 290	169.95 199.95
ZX60-1215LN	g th: 1.20" x (W 0.8-1.4) 1.18" x 15.5	0.4	+27.5	12.5	12.0	50	149.95
ZX60-1614LN ZX60-2411BM ZX60-2531M ZX60-2534M ZX60-3800LN	1.217-1.620 0.8-2.4 0.5-2.5 0.5-2.5 3.3-3.8	14.0 11.5 35.0 38.0 23.0	0.5 3.5 3.5 3.1 0.9	+30.0 45.0 +26.1 +30.0 +36.0	13.5 24.0 16.1 17.2 18.0	12.0 5.0 5.0 5.0 5.0	50 360 130 185 110	149.95 149.95 119.95 64.95 64.95 119.95

U.S.Patent # 6,790,049



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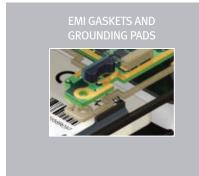


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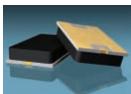
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NEW PRODUCTS

Components

Surface-mount Limiters



The LM Series of surfacemount limiters is designed for receiver protection applications through 8 GHz. These RoHS-

compliant devices provide high power protection at levels to 100 W CW and 2 kW peak power in surface-mount-technology (SMT) packages measuring only $8\times5\times2.5$ cubic mm. Ideal for receiver protection applications at L-band (1 to 2 GHz), S-band (2 to 4 GHz) and C-band (4 to 8 GHz) frequencies. LM Series limiters provide considerably higher thermal capacity than silicon and GaAs MMIC solutions. Their small size and excellent thermal conductivity supports low-profile circuit designs without sacrificing protection for sensitive receiver front-end components.

Aeroflex/Metelics, Londonderry, NH (888) 641-7364, www.aeroflex.com/metelics.

Two-way Power Divider



KRYTAR announced a twoway power divider that offers high performance over the broadband frequency range of

3 to 45 GHz in a single compact package. This new power divider offers the widest frequency coverage in a single package on the market and provides superior performance. Targeting broadband electronic warfare (EW) systems and complex switch-matrix applications, for example, KRYTAR used its proprietary design to produce a matched-line directional divider (MLDD) with ultra-high performance over the broadband frequency range of 3 to 45 GHz. Model 6030450 offers high pass frequency response to attain low insertion loss and high isolation.

KRYTAR Inc., Sunnyvale, CA (408) 734-5999, www.krytar.com.

Ultra Broadband Bias-tee





MITEQ introduced an ultra broadband high current Bias-tee to its Bias-tee family. Model BT 2 6 5 0 - H C covers 100 MHz

to 26.5 GHz with an insertion loss of ≤ 2.5 dB, input voltage of up to +15 V and for a maximum of 1 amp current handling. It can be used in general-purpose test and measurement systems or OC768 transmitters and receivers. This model is available from stock.

MITEQ Inc., Hauppauge, NY (631) 439-9220, www.miteq.com.

SPST Thru SP32T Switches



PMI offers a line of solidstate switches that operate up to 40 GHz. Many standard models are available. Many

new models are in development so please contact PMI if you do not see exactly what you require. Standard features include: ultra-high isolation, low insertion loss, fast switching speeds, low power consumption and small packages.

Planar Monolithics Industries Înc., Frederick, MD (301) 662-5019, www.pmi-rf.com.

Wideband 90 Degrees Hybrid



Pulsar model QS8-13-463-7 is a 90 degree hybrid covering the frequency range of 0.5 to 10 GHz with 2.0

dB insertion loss, ± 0.8 dB amplitude balance and \pm 8 degrees phase balance. Isolation is 16 dB and VSWR is 1.5:1 maximum. The average input power rating is 20 W maximum. Outline dimensions are 6.10" \times 1.00" \times 0.40" and the connectors are SMA female.

Pulsar Microwave Corp., Clifton, NJ (973) 779-6262, www.pulsarmicrowave.com.

Single and Dual Directional Couplers



RLC Electronics' high power directional couplers offer accurate coupling, low insertion

loss and high directivity in a compact package. The standard units are optimized for two octave bandwidths and are available with a choice of coupling values. These units are ideal for sampling forward and reflected power with a negligible effect on the transmission line and very low intermodulation products.

RLC Electronics Inc., Mount Kisco, NY (914) 241-1334, www.rlcelectronics.com.

Radio Link Converters



These next-generation E- and V-band converter platforms, aimed at the telecom industry, can help manufacturers

of point-to-point and multipoint microwave radio systems running at transfer rates up to 10 Gb/s. The company can provide complete or partial assemblies, including various combinations of converter, diplexer and LO. This allows radio link suppliers to select custom solutions for their outdoor unit applications. E- and V-band technology will help meet the demand for higher speeds and provide more available bandwidth to datahungry users, especially in dense urban areas.

Sivers IMA AB, Kista, Sweden +46-8-703 68 00, www.siversima.com.

New Products

Four-port Circulator



The model FMP146 Circulator-Detector provides up to 40 dB of isolation (dual-junction signal path) with insertion

loss typically less than 0.4 dB. The device has both forward and reverse power detection with a tunable DC power output detection circuit operational to 75 W CW. The FMP146 was designed for harsh naval radar operations with an integrated BeO load termination and light weight aluminum chassis.

TRAK Microwave Corp., Tampa, FL (813) 901-7200, www.trak.com.

Amplifiers

GaN Power Amplifier



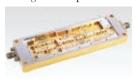
The model SSPA 2.0-4.0-100 is a high power, GaN amplifier that operates from 2000 to 4000 MHz minimum and is packaged in a

rugged enclosure. This amplifier is designed for operation in harsh environments. Typical output power is 100 W across the band at P3dB. Small-signal gain is 54 dB \pm 3.0 dB across the band typically. Input and output VSWR is 2.0:1 maximum. This unit is equipped with DC switching circuitry that enables and disables the RF devices inside the amplifier in 540 nSec typical for turn on and 230 nSec typical for turn off time. Standard features include reverse polarity protection, output short and open circuit protection, and over/under voltage protection.

Aethercomm Inc., Carlsbad, CA (760) 208-6002, www.aethercomm.com.

X-band AGC Amplifier

The AMLSW3011 is a GaAs X-band switched gain selectable amplifier with excellent state-to-state gain and phase tracking. The amplifier



offers selectable gain steps of 0/10/20 and 30 dB. A minimum OIP3 of +35 dBm is provided in any of the

in any of the gain states. This amplifier is also available with an input detector option that limits the output power to +30 dBm maximum under conditions of high input drive. This feature protects components that follow the amplifier in the system cascade. DC voltage is 12 to 18 VDC.

AML Communications Inc., Camarillo, CA (805) 388-1345, www.amlj.com.

Coaxial Wideband Microwave Amplifier

VENDORVIEW



The ZX60-24+ is a coaxial wideband microwave amplifier that operates in a frequency range from 5 to 20

GHz. This 50 Ω amplifier features gain of 24 dB typical and flatness of ±1.3 dB typical, output power at 1 dB compression, 18.0 dBm typical and excellent isolation of 62 dB typical. This amplifier is unconditionally stable and protected by US patent 6,790,049. Applications include: military and radar, DBS, wideband isolation amplifier, microwave point to point radio and satellite systems. These amplifiers are RoHS compliant in accordance with EU Directive (2002/95/EC). Price: \$199.95 each (1 to 9).

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.

Antenna

Patch Antennas



Spectrum Advanced Specialty Products announced that its patch antenna elements have successfully ful-

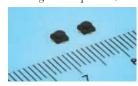
filled Iridium Satellite Communications' "Iridium Compatible Equipment (ICE) Certification" requirements. This certification offers Spectrum's customers the ability to save time when using Iridium-certified antennas in their applications by eliminating the need for re-certifying equipment when using the patch antennas according to Iridium's guidelines. This new partnership with Iridium Satellite demonstrates Spectrum's continuing dedication to manufacturing high quality, high performance products. Currently, the PA25-1621-025SA and PA45-1621-1575SA patch antennas have achieved ICE Certification; ĥowever, several of Spectrum's antennas and assemblies are in the approval process and certification is expected in 2011.

Spectrum Advanced Specialty Products, Fairview, PA (814) 474-1571, www.specemc.com.

Semiconductor/IC

Ultra-low-noise Heterojunction FET

The NE3520S03 ultra-low-noise heterojunction field effect transistor is claimed to feature industry-leading low noise characteristics for 20 GHz satellite broadcast reception. To reduce noise at ultra-high frequencies, the NE3520S03



employs a new epitaxial wafer structure that leverages high electron density, thin-layer technology. This in-

creases the velocity at which the electrons move through the channels and lowers the source resistance, making possible a noise figure of 0.65 dB,

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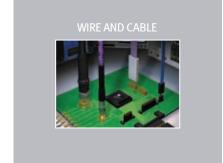




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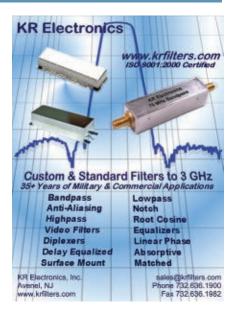
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Technology www.astswitch.com





Modco offers a low-noise general purpose amplifier. Model Number WB100-6000DJ covers a frequency range of 100MHz through 6000MHz. The amplifier is housed in an Iridite Gold finished aluminum housing measuring 1.25" x 1.25" x 0.60". It is supplied with three SMA F Connectors. The device operates from a single +5V supply and consumes 60mA

www.modcoinc.com



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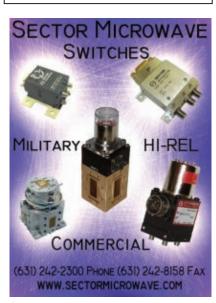


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which is among the lowest in a mass produced product for the 20 GHz band, and an associated gain of 13.5 dB.

Renesas Electronics Europe GmbH, Munich, Germany +49 89 380 7000, www.renesas.eu.

Source

GPS-Disciplined Oscillator

The MXO-100 is a GPS-Disciplined oscillator, which accepts a 1 PPS reference input from a GPS receiver, with simultaneous outputs of 10, 20, 70 and 100 MHz with extremely low phase noise characteristics. Features include optional two alarm outputs (loss of lock and holdover),



low phase noise, > 45 dB channel isolation, low gsensitivity, ruggedized for shock and vibration holdover mode, serial in-

terface, warm-up time of two minutes at +25°C typical and up to four outputs at various frequencies. Ideal for use in radio base stations, synchronization source applications, digital video broadcast equipment, 3G and WiMAX base stations and more, the MXO-100-01 is packaged in a small $(3.5" \times 2.5" \times 0.6")$ connectorized housing, accepts +5, +8 or +12 VDC power supplies, and operates over the -30° to +70°C temperature range.

EM Research Inc., Reno, NV (775) 345-2411, www.emresearch.com.

Power Amplifier Design Engineer

AR RF/Microwave Instrumentation, located in Souderton, PA, is seeking an engineer responsible for the development of new & existing broadband microwave power amplifier products in the frequency range 10kHz to 40GHz. Direct, design & establish specs & standards. May oversee task groups to develop new applications & designs of products. Conduct research & perform simulations, including 3D EM simulations & non-linear analyses, on electronic systems. BS + 8 years related RF and microwave power amplifier design experience required, including power devices, power combining techniques and hybrid technology. Competitive salary & benefit packages make AR a great place to work! Resumes with salary requirements to HR@amplifiers.com, fax (866) 743-3838. EOE. See www.amplifiers.com/careers for more details.



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Understanding MIMO OTA Testing: Simple Solution to a Complex Test

The MIMO Expert Forum at CTIA Wireless 2011 Thursday, March 24th 10:30 – 12:30

MIMO Over-the-Air (OTA) testing is an accurate and cost-effective solution for complex MIMO device testing. This MIMO Expert Forum explains the fundamentals of MIMO OTA testing, providing an understanding of system performance and the core elements that facilitate systematic and repeatable performance measurement of MIMO devices. The Forum highlights the technical features of the test system, including the chamber, software and instrumentation. A panel discussion with the speakers concludes the Forum.

Speakers include:

Moderator - Bryan Sayler, Vice President and General Manager, ETS-Lindgren

- Moray Rumney, Lead Technologist, Agilent Technologies
- Jukka-Pekka Nuutinen, Research Manager, Elektrobit
- Michael Foegelle, Director of Technology Development, ETS-Lindgren
- Doug Reed, Solutions Architect, Spirent Communications

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An Engineer's Guide to Automated Testing of High-speed Interfaces

> Jose Moreira and **Hubert Werkmann**

roviding a complete introduction to the state-of-the-art in high-speed digital testing with automated test equipment (ATE), An Engineer's Guide to Automated Testing of High-speed Interfaces focuses exclusively on this increasingly important topic. The book covers all critical aspects of the subject, from highspeed digital basics, ATE instrumentation for digital applications, and test and measurement, to production testing, support instrumentation and text fixture design. It also discusses advanced ATE topics, such as multiplexing of ATE pin channels and testing of high-speed bi-directional interfaces with fly-by approaches.

After an introduction and coverage of the basics, the book explores highspeed interface standards and ATE instrumentation. The middle of the book covers in-depth tests and measurements, production testing and support instrumentation. Test fixture design and advanced ATE topics wrap up the remaining content, but there are many appendices covering additional topics that are not directly related to the test of high-speed devices. However, these topics are helpful in understanding the background of some of the test requirements and test implementations that are presented in the main book. Many of the topics that would interest the microwave engineer include bit error rate (BER), TDR/TDT, S-parameters, CAD tools, test fixture evaluation and jitter.

The target audience of this book is mainly test engineers working on design verification, characterization and production testing of multi-gigabit I/O interfaces. It does, however, provide a general overview of the challenges these test engineers face that can be helpful to

chip designers and product engineers to understand how to minimize challenges using appropriate test strategies.

This book is very comprehensive and timely as high-speed interfaces are at the forefront of many of the new test systems and products under development. It is a recommended book for those involved in this area or those looking for information on the topic to learn more about how they affect systems and test equipment.

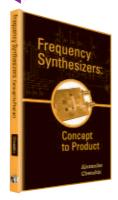
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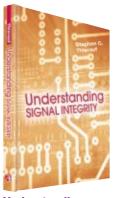
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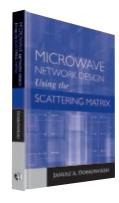


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Technical Education Series

Presented by Rohde & Schwarz

New Insights Into the Dynamic Behavior of RF Systems Using Real-time Spectrum Analysis: This webcast will provide designers of synthesizers, radar systems and other transmitters with a look at the new measurements needed for their development and optimization tasks. The techniques apply not only to spectrum analyzers, but also to instruments with real-time signal processing capability, or a spectrum signal analyzer combined with a real-time spectrum analyzer. Live webcast: 3/17/11, 11:00 AM EDT

Presented by AWR Corp. and Rohde & Schwarz

LNA Design and Test Verification: In this webcast, the design of a low-noise amplifier is demonstrated. Design software and a Vector Network Analyzer are integrated to bring the measured and simulated results together for instantaneous comparison and virtual model verification. Live webcast: 3/8/11, 12:00 PM EST

Presented by Agilent Technologies

See the Future of Arbitrary Waveform Generators: This webcast presents the next generation of arbitrary waveform generators. See how engineers can push their design to the limit and bring new insights into their analysis with technology featured in this month's MVP product feature. Available for on demand viewing after 3/1/11

RF/Microwave Training Series

Presented by Besser Associates

RF Oscillators: This presentation provides an overview of oscillator design, specifications, and the topologies used to meet these performance challenges.

Live webcast: 3/15/11, 11:00 AM EDT

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Innovations in EDA Series

Presented by Aailent Technologies

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2011: This webcast will detail recent advances and breakthrough capabilities for multi-technology co-design, inherent in RF modules and system-in-package (SiP) designs using EM analysis and a fully integrated design platform.

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Special MWJ Webcast: MIMO OTA Expert Forum at CTIA Wireless

Presented by Agilent, ETS-Lindgren, Elektrobit and Spirent

Understanding MIMO OTA Testing: Simple Solution to a Complex Test: This Forum highlights the technical features of systems for MIMO Over-The-Air testing of mobile devices and networks. Simulcast web panel: 3/24/11, 10:30 AM EDT

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RF/Microwave Training Series

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- RF Power Amplifier Linearization Techniques
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- Passive Component Modeling

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Presented by Agilent EESof EDA

- Memory Effects in RF Circuits: Manifestations and Simulation
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- Accurate Modeling of Packages and Interconnects
- Applying the Latest Technologies to MMIC Design

Innovations in Signal Analysis

Presented by Agilent Technologies

• Three Steps to Successful Modulation Analysis

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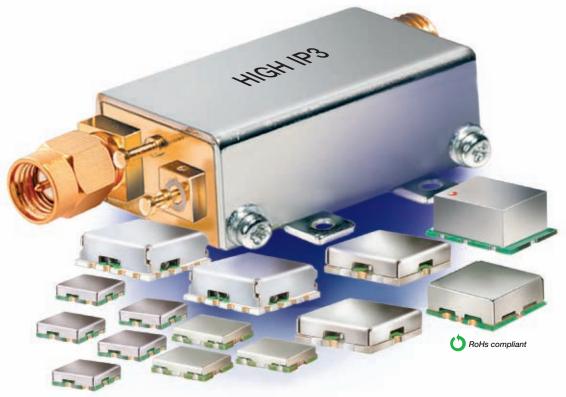
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China Michael Tsui ACT International Tel: 86-755-25988571 Tel: 86-21-62511200 FAX: 86-10-58607751 michaelT@actintl.com.hk

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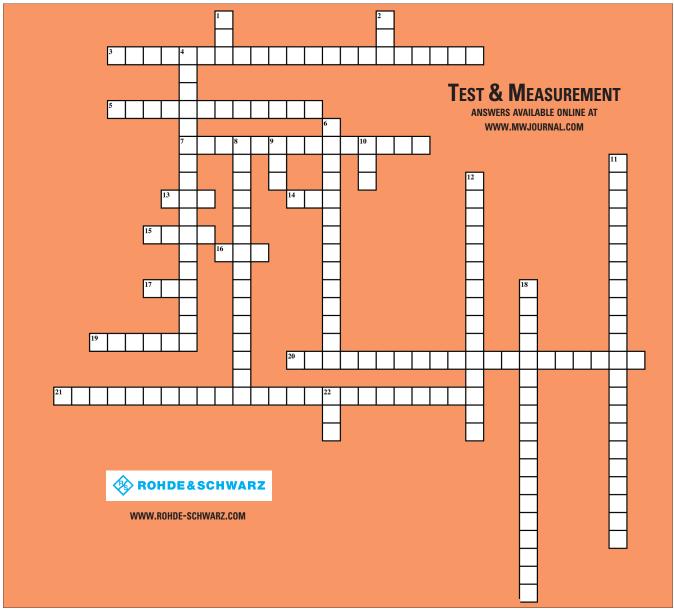
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Across

- 3 ENOB (4 words)
- ${\bf 5}$ A technique used with oscilloscopes and spectrum analyzers to reduce noise and effectively increase resolution and dynamic range
- 7 A load-pull technique that uses a separate coherent signal source to stimulate the source or load side of the DUT, thus removing any uncontrolled interaction between the DUT and load-pull system (3 words)
- 13 Vector signal analyzer
- 14 Short for Digital Storage Oscilloscope
- 15 Bigger brother of PXI
- 16 Tektronix has developed a high performance display technology called _____
- 17 Vector Network Analyzer
- 19 Time variation of a periodic signal
- 20 FTT (3 words)
- 21 A key figure of merit for an oscilloscope that needs to be specified by fractional bandwidth and at the frequency of interest (4 words)

Down

- 1 Short for PCI extensions for instrumentation
- 2 Short for Mixed Signal Oscilloscope
- 4 XCO (2 words)
- ${\bf 6}$ Passive tuners with multiple slugs/sliding shorts that allow some control of harmonic impedances (2 words)
- 8 While most high performance oscilloscopes use SiGe-based ICs, Agilent has implemented high speed ICs using this material (2 words)
- 9 Error Vector Magnitude
- 10 Power Added Efficiency
- 11 PIM (2 words)
- 12 DUT (3 words)
- **18** SNR (4 words)
- 22 Arbitrary Waveform Generator

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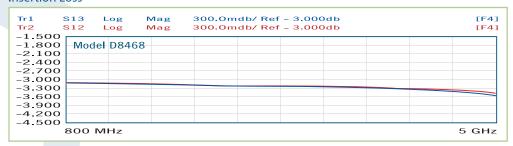
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Insertion Loss



Isolation



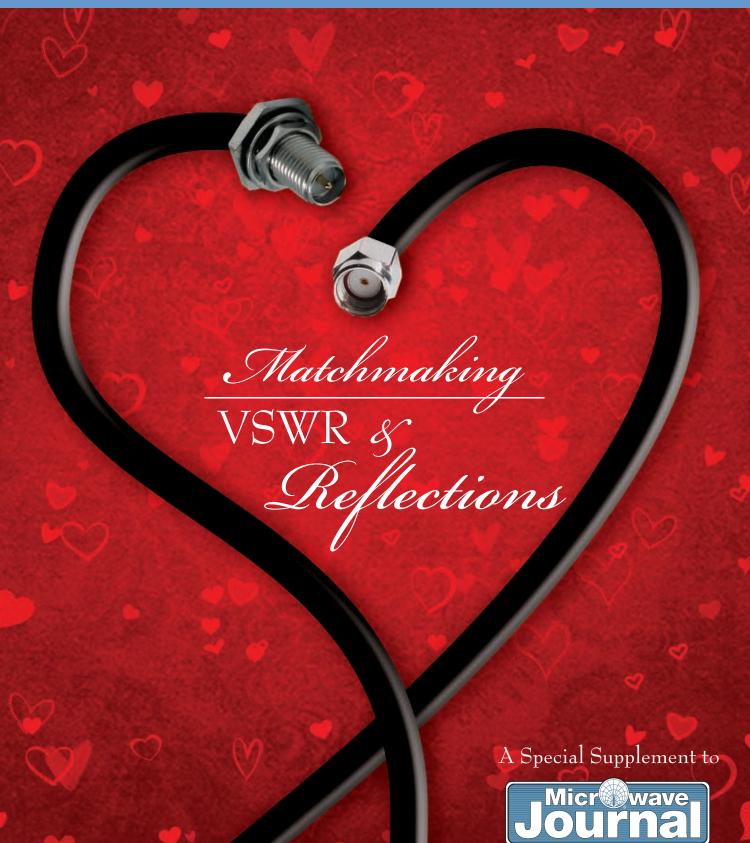
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D8414	2-Way	600-3000	200	0.5	1:35:1	15	4.0 x 1.9 x 1.0
D8378	2-Way	500-2000	800	0.4	1:35:1	15	4.0 x 1.9 x 1.37
D8468	2-Way	800-5000	150	0.6	1:35:1	15	3.4 x 1.4 x 0.87
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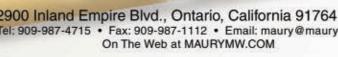
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RF ABLATION: TECHNICAL TRENDS FOR A HOPEFUL FUTURE

promising new method for the treatment of cancer tumors and metastases is microwave or RF ablation. This minimally invasive treatment makes it possible to operate in areas of the body that are inaccessible using conventional means and alleviates post-traumatic complaints, as well as offering significant cost savings. Such minimally invasive interventions are complemented by constantly improving imaging techniques that make it possible to localize even the tiniest tumors or metastases. All of these advantages mean that this new surgical technique offers excellent potential for growth.

MINIATURE PROBE DISOLATES TUMOURS

The way that ablation works is by releasing electromagnetic energy inside the tumor. This causes water molecules to vibrate, generating heat and destroying the diseased tissue, which is simple but effective. The great challenge, however, is to channel the microwave power required from the generator into the diseased

tissue, adding as little loss as possible while keeping flexibility at an optimum, i.e. the cables, connectors, etc. The type of connectivity required is dictated by the specific application.

Although RF ablation is currently used to treat primary tumors and metastases in the lungs, liver, kidneys and bones, the technique is also increasingly being used for treating other organs. As a result, the system frequencies, the ablation time and the applied electromagnetic power vary considerably. These parameters, along with the ergonomic considerations of the operating environment need to be taken into account when deciding what cables/connectors to use.

ATTENUATION IN COAXIAL STRUCTURES

The transmission loss (attenuation), which indicates how much lower the outgoing power is in comparison with the incoming power in a

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cable, is a major consideration. In the equation:

this value is negative; however, to avoid confusion, attenuation is often stated as a positive number. **Figure 1** shows the attenuation loss components of a cable, σ_a = conductivity of the inner conductor, σ_b = conductivity of the outer conductor, ε_r = dielectric constant and tangent δ = characteristic of insulator material. The total transmission loss is $\alpha_{total} = \alpha_{conductors} + \alpha_{dielectric}$.

sion loss is $\alpha_{total} = \alpha_{conductors} + \alpha_{dielectric}$. The cable attenuation loss is the sum of the conductor losses (e.g. copper losses) and the dielectric losses. In Equations 2 and 3:

$$\alpha_{\text{Conductor}} = \alpha_{\text{C}} = \frac{11.39}{\text{Z}} \sqrt{f} \left| \frac{\sqrt{\rho_{\text{rd}}}}{\text{d}} + \frac{\sqrt{\rho_{\text{rD}}}}{\text{D}} \right| \left[\text{dB/m} \right]$$
 (2)

$$\alpha_{Dielectric} = \alpha_d = 90.96 f \sqrt{\epsilon_r} \tan \delta \left[\ dB/m \ \right] \eqno(3)$$

f = frequency (GHz) and the diameters d and D are in mm. Z is the characteristic impedance in Ohms $[\Omega],$ and ρ_{rd} and ρ_{rD} represent the material resistivities of the conductor in comparison to copper. That is: ρ_{rd} = 1 for a copper inner conductor and $\rho_{rD}\approx 10$ for a steel outer conductor. δ is the loss angle of the insulating material.

Figure 2 shows the attenuation loss as a function of the three cable components. A lower attenuation loss can be achieved by the following:

- Large cable diameter
- High conductivity of the materials
- Low dielectric constant
- Small loss angle

Because the conductor losses increase proportionally to \sqrt{f} , whereas the dielectric losses increase directly proportionally to f, the losses from the polymer structures used in applications such as RF ablation are considerable (Equation 2 + Equation 3). The two parameters that need to be influenced are ϵ_r and $\tan \delta$.

Both values are directly linked physically to the pres-

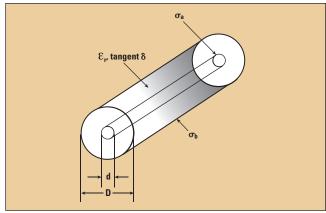


Fig. 1 Attenuation loss components.

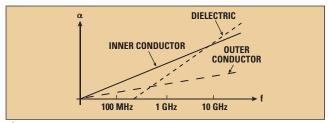


Fig. 2 Attenuation loss as a function of the three cable components.

ence of material and assume minimum values in a vacuum ($\varepsilon_r = 1$ and tan $\delta = 0$). Furthermore, the polymers used must provide excellent stability in terms of mechanical and thermal loading, dielectric strength and, most importantly, process capability. The values for typical materials are shown in **Table 1**.

ERGONOMIC DESIGN

With regards to the surgical environment, many diverse requirements have to be met. For example, if a robust or even crush-resistant connection is required for a cable that is fed to the operating table, then it is desirable to have a cable with the smallest possible dimensions in the operating area. Also, the supply cable to a probe (see *Figure 3*) for liver tumor ablation should be as flexible as a cord and should remain positioned on the patient without losing its shape, whereas a cable used for intestinal operations should exhibit

	TABLE I								
	PROPERTIES OF DIFFERENT CABLE MATERIALS								
Material	$\epsilon_{ m r}$	tan δ	Glass Temperature (°C)	Operating Temperature (°C)	Density (g/m³)	Dielectric Strength (kV/mm)			
Air	1.0	<10-5			0.0013	<1.0			
PE	≥2.28	0.0003	<-125	-40+85	0.910.97	>28			
SPE	1.252.05	< 0.0003		-40+80	0.210.75				
XLPE	>2.28	>0.0003		-20+10	0.910.97	>25			
FEP	2.1	< 0.0007	-100	-100+200	2.15	>50			
PFA	2.06	0.0001	<-80	-200+250	2.14	>50			
PTFE _{sat}	< 2.05	< 0.0001	-100	-200+250	2.2	2550			
PTFE _{unsat}	1.41.7	< 0.0001		-200+250	0.81.5				
PP	2.25	< 0.0005	-20	-10+100	0.9	>25			
PEEK	3.2	0.003	143	-250+250	1.32	20			









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a 'memory effect' and should return to its original position in a controlled manner.

Surface properties regarding sterilization and 'coolability' as well as the choice of color in order to ensure visibility in the operating area and system matching are further examples of parameters that have to be considered when selecting the most suitable cable.

SELECTIVITY

A bent coaxial cable may, depending on the structure and material, develop forces and become deformed over time. Although in most cases this effect should be completely avoided, it can be desirable in certain special catheter applications. For such individual circumstances it is vital for the cable and connector manufacturer to work closely with the end user to se-

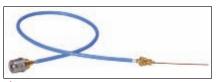


Fig. 3 Supply cable and probe.

lect the right choice of connectivity products and develop test procedures to simulate the end-user applications.

INTERDISCIPLINARY APPROACH

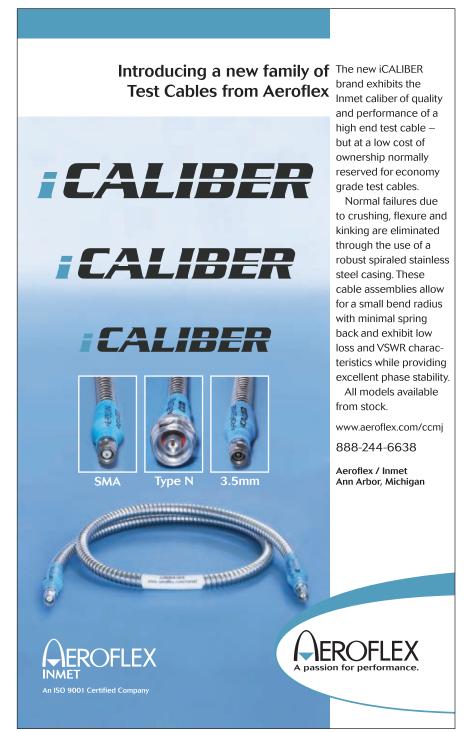
Just as today's doctors are expected to be familiar with the use of state-of-the-art equipment, in order to supply and fit the right cables and connectors, engineers must have an understanding of how medical practitioners work and the environment in which they have to function. It is essential to select RF connectors that provide true and easily achievable connection.

This is a major consideration, for example, with the microwave-compatible connectors that an operating team would use, as partial or insecure mating could have serious consequences given the high power levels used in these applications. In such circumstances a push-pull connector that clicks audibly into place, reliably remains connected even when subjected to radial movements and is waterproof, would be the type of connector that should be considered.

CONCLUSION

RF ablation is a technique being increasingly used in the medical field. These applications are diverse, requiring a variety of cables and connectors to deliver the high power demanded. In order to provide effective, efficient and safe systems, engineers must calculate the attenuation loss of the cable and be aware of the specific characteristics of the cable/connector options on the market in order to be able to meet the specific demands of the medical environment.

Following a four-year apprenticeship as an electrician, **Reto Germann** gained an engineering degree in mechatronics from FHS St Gallen, Switzerland, and a management diploma from the Chinese-European International Business School (CEIBS), Shanghai, China. He joined HUBER+SUHNER as an Applications Engineer in 2000, became Application Engineering Manager, China, in 2005, and Distribution Manager, APAC a year later. Since 2008 he has been Market Manager Medical, Radio Frequency Division.





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REDUCING COSTS WITH FLEXIBLE CABLES AND IMPROVED CONNECTORS

emi-rigid cables have long been the backbone of the US Military interconnection technology for RF and microwave applications. These cables provide a robust means of interconnection supporting high power, low loss and high frequency applications with extremly good shielding characteristics. With no fear of sand and abrasion, these cables provide armor to military electronics on land, sea and air. Today, however, is semi-rigid really the best solution for high reliability?

San-tron believes that Times Microwave has developed an ideal alternative to semi-rigid cables that should be seriously considered for system integrations. Below is a discussion of the apparent differentials that Times TFLEX-402 and TFLEX-405 provide to technical performance, costs of design-in, cost of manufactur-

ing, and to the logistics chain and maintenance operations. This is followed by a discussion of the connector designs that fully leverage the capabilities of flexible cables.

TABLE I COMPARISON OF ATTRIBUTES OF TFLEX AND SEMI-RIGID CABLES

Parameter	TFLEX-402	RG-402
jacket	FEP	n/a
shield	Ag/Cu	Cu
core	PTFE	PTFE
conductor	Ag/Cu	Ag/Cu/Steel
mass (kg/m)	0.049	0.051
Vo (kVrms)	1.9	1.9
Temp max C	125	125
Temp min C	-65	-40
Min Bend Radius (mm)	12.7	6.4
S21 k1	0.330	0.318
S21 k2	0.0012	0.0012
S21 @ 18 GHz (1 meter)	-2.16 dB	-2.11 dB
P (watts) @ 18 GHz	48	65

TECHNICAL ATTRIBUTES & DIFFERENTIALS

The technical performance semi-rigid cables TFLEX are extremely similar. A brief decision matrix is helpful in identifying the major characteristics. Due to the solid copper outer shield of semirigid cable, these assemblies are superior at diffusing heat, insuring low attenuation and thus providing higher power handling abilities. The TFLEX series provides better support for corrosive environments due to its FEP jacket and silver clad metals. TFLEX also supports low attenuation, full shielding and further offers multiple cable bending. *Table 1* provides a close look at some of these differentials in attributes.

The standard semi-rigid RG-402 cable is composed of a solid copper shield and a silver clad steel center conductor. Thus, the operating environment needs to be considered in choosing these materials. Will the assembly be exposed to corrosive agents that will attack the copper shield? Will the steel center conductor generate PIM products within frequencies of interest? This cable does support tight bend radii of 6.4 mm; however, the cable can only be bent once. Repeated bending will fracture the solid copper shield.

TFLEX cables are composed of a FEP jacket and silver clad copper metals. The FEP jacket provides excellent protection from corrosive environments. This TFLEX shielding is a composite of a helical wrap and braid, and like semi-rigid, the RF leakage is beyond the range of measurable limits. The silver clad helical wrap further provides temperature phase stability, loss stability and low insertion loss. A one meter length of the two cables perform within 0.05 dB of each other at 18 GHz. From the technical profile of these cables, the only parameter that favors semi-rigid cable is power handling; at 18 GHz the semi-rigid nudges out TFLEX at 65 versus 48 W.

COSTS OF DESIGN-IN

Within system integration, each semi-rigid cable requires predetermined geometries. Just as a civil engineer designs bridges, entrance ramps and clover leafs into our highways, a mechanical engineer takes on the task of designing bend radii, segment lengths, over and under locations, etc. Each cable becomes a customized part number with exacting requirements to rigidly lie within the constraints of various barri-

FRED HULL San-tron Inc., Ipswich, MA





«RF Ablation - lowest loss for minimal invasive surgeries»



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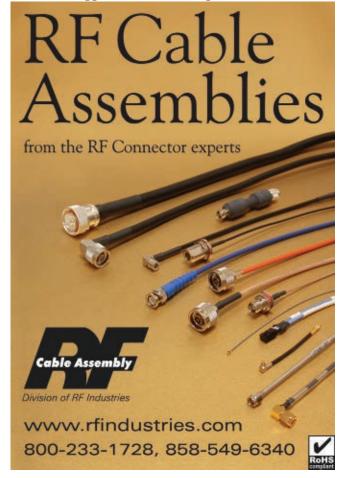
ers: amplifiers, filters, mixers and other cables. When subsystems are modified and upgraded, so too are the cable assemblies, which effects fit, form and function between new versus legacy deployments. With the typical semirigid cable being composed of ~5 bends and total lengths of 8 to 30 inches, a simple problem just became a documentation dilemma. All of these custom cables can be supported with standard TFLEX assemblies supplied in incremental lengths. One can simplify the documentation and focus on engineering creativity and solving technical issues.

COSTS OF MANUFACTURING

The manufacturing processes for semi-rigid is a bit more involved than the TFLEX methodology. Below is a cost comparison just in the required capital equipment for both processes (see *Table 2*).

To manufacture semi-rigid cables there is a common process requiring \$77,300 in estimated costs:

- Cable is supplied in straight 8-foot lengths
- Cut the cable to developed length
- Process the cable through a bending machine
- Verify position of bends within tolerances via a quadaxis machine
- Thermal cycle the cable to relieve stresses within the PTFE core
- Strip the cable ends for connector termination
- Solder both the center contacts and bodies to the cab Comparatively, the process for TFLEX only requires \$18,400 of costs:
- Cable is supplied in continuous spools



- Cut the cable to developed length
- Strip the cable ends for connector termination
- Solder bodies to the cable

EFFECTS ON LOGISTICS & MAINTENANCE

Imagine all the costs associated with producing these unique semi-rigid cable assemblies and every dimension is within specification; every segment length, every bend radius, and even the tolerance stack-up from connector end to connector end has been minimized. These cables are not simply going into a plastic bag and shipped to the customer. Each cable assembly part number will have unique cut foam inserts and these cables will be carefully placed into expensive custom boxes. Then a set of these boxes will be placed into a larger shipping box. If the customer requires five different cables for a deployment then the manufacturer will provide five different sets of cut foam inserts. Each assembly will be custom packaged to prevent dimensional changes during shipping and handling.

The customer will receive different crates of semi-rigid cable assemblies with each assembly packaged in a box that measures $12" \times 18" \times 6"$. How do they place these crates within your work flow? And how quickly can they remove the empty boxes from the production floor and store or dispose of them?

The alternative could be as simple as a couple of cable lengths of TFLEX supporting all of the semi-rigid applications. Then just a couple of part numbers of flexible TFLEX cables are needed. These are bulk package as 20 pieces into a plain plastic bag and dropped into the mail. No need for foam inserts, pallets, specialized work flow and packaging removal.

For maintenance operations this advantage is greatly multiplied. Consider TFLEX to be the "duck tape" of the 21st century for microwave applications. Regardless of the OEM, the frequency range and the performance parameters, standard lengths of TFLEX cable assemblies can be stocked for a full array of upkeep and retrofits. The concern

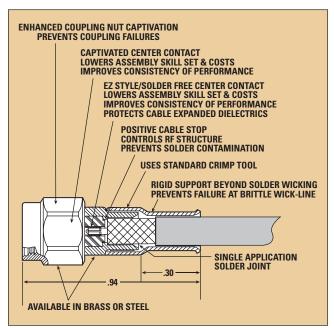


Fig. 1 e Series improvements made to SMA connector.

Field SMA Replaceable SMA



2 Hole, .625", with Ground Plane



4 Hole, .500", with Ground plane



2 Hole Diamond with Ground Plane



2 Hole, .550" with EMI Gasket



4 Hole, .500" x .375" with EMI Gasket



2 Hole, .625", Male, with EMI Gasket



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Male Thread Mount

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Materials

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 Center Contacts:
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 Bodies:
 \$\$303

 EMI gaskets:
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Plating

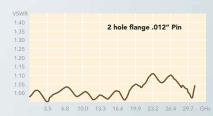
Center Contacts:GoldBodies:Passivated



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is shifted from exacting geometries to only the need for minimum length assemblies. And with the minimum of tooling required it is even possible to produce retrofit cable assemblies on site.

eSERIES: CONNECTOR DESIGNS THAT LEVERAGE FLEXIBILITY

Now that TFLEX cable has been offered as a drop-in substitute for semi-rigid cables, there is a need to take a look at connectorization. What attributes can the connector bring to the overall reliability and performance of these assemblies?

The San-tron eSERIES product line was initiated with the SMA interface as this is the most prevalent connector for intra-system integrations, the connection of sub-systems within an OEM package. The company wanted to design advance features into the connector to remedy issues that were common with conformable cable assemblies. By combining experiences of both semirigid and conformable cable assemblies, the new eSERIES is a positive step in the enhancement of performance and survivability in the field. The following features were implemented into the eSMA series (see $\hat{F}igure 1$):

- Enhanced coupling nuts that will not "walk-off" brass bodied connectors
- Captivated factory-set center contacts for no worry interface dimensions
- EZ style, solder free center contacts
- Integral positive cable stops that control RF structure and limits solder contamination
- Rigid cable support beyond the solder wick line
- Cable assembly performance with VSWR < 1.22 (DC-20 GHz)
- PIM performance < -150 dBc

The enhanced coupling nut is a far reaching improvement beyond the e-SERIES product line. It is a natural occurrence that brass bodied SMAs coin with each successive torque application of the coupling nut. As this coining continues to progress, the retaining ring eventually fails to capture both the body and the coupling nut. The brass SMA connectors have implemented a feature that prevents this failure mode. All of these SMA connectors exceed the military specification of 15 in-lbs of coupling proof torque. It typically requires ~80 in-lbs of torque to cause

fracture. The captivated, factory-set center contacts provide controlled interface dimensions that reduce the opportunity for mechanical collisions within mating connectors.

The EZ style, solder free contacts prevent heat disruption of the core dielectric helping to maintain the 50 ohm structure. It is the combination of heat disruption and controlled solder spacing of the center contact that contributes most to variation in RF performance. These EZ style contacts negate these limitations.

Integral positive cable stops control the resultant geometry of the prepared cable into the connector. The cable stop also limits the flow of solder to the braided cable zone preventing solder flow forward into the connector cavity. This helps give the cable assembly technician a repeatable process to support the higher 20 GHz performance.

As solder is applied to the cable it naturally wicks up the cable braid. The further it wicks, the more problems that will ensue. The wick line is a very distinct characteristic in that the braid is solid on one side of the line and is flexible on the other. Thus, this wick line becomes a fulcrum plane at which cable failure is prone. By controlling heat and dwell time it is easy to limit this solder wicking to 0.33 inches. Then the application of the optional crimp ferrule provides mechanical support to 0.49 inches. This extended ferrule provides the mechanical support that prevents braid failure under multiple cable flexing. Additional support can then be augmented with heat shrink strain relief.

The ultimate goal of these enhancements is to provide a consistent, reproducible process to fabricate low cost SMA cable assemblies with strong RF performance through 20 GHz. As a result, the required skill set of the cable assembly technician has been simplified. These features with 20 GHz performance were implemented into SMA plugs, jacks, panel mounted jacks and weather sealed bulkhead mounted jacks. Recently the SMA right angle plug was added to this product line with performance to 12.4 GHz.

The next series of solutions focused on inter-system integrations—how to get the signals to the outside world. The type N and 7/16 connectors have a

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TABLE II COST COMPARISON TO PROCESS TFLEX VERSUS SEMI-RIGID CABLES Equipment TFLEX-402 RG-402

Equipment	TFLEX-402	RG-402
Bending Fixture: #HB1	N/A	\$700
Q/C Orthogonal	N/A	\$100,000
Thermal Cycling: Blue-M	N/A	\$19,000
Cable Strip: #CS5400	\$18,000	N/A
Cable Strip: #SR1000	N/A	\$57,000
Soldering	\$400	\$600
Total Capitalization	\$18,400	\$177,300

TABLE III eSERIES CONNECTORS FOR TFLEX-402

631/112/ 60/ 112/ 101				
Frequency	PIM	Part Number	Part Description	
18 GHz	no	0401-257-AH	N Plug	
18 GHz	yes	0401-257-AS	N Plug	
18 GHz	no	0405-72-AH	N Bulkhead Jack	
18 GHz	yes	0405-72-AS	N Bulkhead Jack	
6 GHz	no	0501-75-AH	RPTNC Plug	
6 GHz	no	0502-17-AH	RPTNC Right Angle Plug	
20 GHz	no	1201-28 M1-GJP	SMA Plug Quick Mate	
20 GHz	no	1201-28-GJP	SMA Plug	
20 GHz	yes	1201-33-BWA	SMA Plug Solder Contact	
20 GHz	yes	1201-33-GWP	SMA Plug Solder Contact	
20 GHz	no	1201-45-VJP	RPSMA Plug	
12.4 GHz	no	1202-24-VJP	SMA Right Angle Plug	
20 GHz	yes	1203-08-AG	SMA Jack	
20 GHz	no	1203-08-VH	SMA Jack	
20 GHz	no	1204-06-VJ	SMA Panel Jack	
20 GHz	no	1205-06-VJ	SMA Bulkhead Jack	
20 GHz	no	1205-07-VJ	SMA Bulkhead Jack Weather Seal	
8 GHz	yes	1904-05-SS	7/16 Panel Jack	
8 GHz	yes	1905-06-SS	7/16 Bulkhead Jack Weather Seal	

strong market position for external connectivity. Therefore, these features were implemented into an 18 GHz type N bulkhead mounted jack and into an 8 GHz 7/16 panel jack and bulkhead mounted jack. The RPTNC and RPSMA were also added specifically for wireless LAN customers. The product offering of eSERIES for TFLEX-402 is shown in $\it Table~3$.

Re-thinking the use of high performance flexible cable and connector designs shows that semi-rigid cables may not be the best choice in many demanding applications. The traditional semi-rigid cables may actually be increasing manufacturing costs, reducing design flexibility, increasing maintenance costs and impacting operational costs that could be avoided in many cases with flexible cable options.





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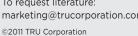
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IEEE P1785: A New Standard for Waveguide Above 110 GHz

The Microwave Theory and Techniques Society (MTT-S) of the IEEE has recently launched an activity to develop an international standard to define waveguides used at frequencies of 110 GHz and above—specifically, rectangular metallic waveguides. The standard's Working Group (P1785) has already met several times and is looking to define both the dimensions of the waveguides (and associated frequency bands) and their interfaces (that is flanges).

here are many applications that are presently being researched in the high millimeter-wave/low terahertz frequency range. These applications are supporting many areas, including astronomy, remote sensing, communications, radar systems and homeland security. This standard is being developed to make sure that all of these applications have a commonality and can interface easily with other technologies that are being developed.

FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS

To date, much of the work of the Working Group has concentrated on establishing the frequency bands and waveguide dimensions. It was agreed early on that, for the waveguide aperture, the ratio of the width to height of the waveguide would be 2:1. The waveguide sizes and frequency bands that have been chosen to be included in the standard are shown in **Table 1**. The waveguides in the shaded region of Table 1 correspond closely to waveguides given in existing standards (References 2 and

3, for example). The main difference is that the IEEE waveguide sizes are being specified using metric units (that is micrometers, rather than mils that were used, for example in Reference 2). The waveguides will also be named according to their metric size: the letters WM indicate that the size refers to waveguide using metric dimensions, followed by a number indicating the size (in micrometers) of the broad wall dimension of the waveguide. For example, WM-570 refers to a waveguide with a broad wall dimension of 570 µm. Another difference with the IEEE standard is that it will use tighter tolerances for specifying the critical dimensions of the waveguide (that is those dimensions that directly affect electrical performance).

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TABLE I PROPOSED FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS FOR THE IEEE STANDARD

Waveguide Name	Aperture Width (μm)	Aperture Height (μm)	Cut-off Frequency (GHz)	Minimum Frequency (GHz)	Maximum Frequency (GHz)
WM-2540	2540	1270	59.014	75	110
WM-2032	2032	1016	73.767	90	140
WM-1651	1651	825.5	90.790	110	170
WM-1295	1295	647.5	115.75	140	220
WM-1092	1092	546	137.27	170	260
WM-864	864	432	173.49	220	330
WM-710	710	355	211.12	260	400
WM-570	570	285	262.97	330	500
WM-470	470	235	318.93	400	600
WM-380	380	190	394.46	500	750
WM-310	310	155	483.53	600	900
WM-250	250	125	599.58	750	1100
WM-200	200	100	749.48	900	1400
WM-164	164	82	913.99	1100	1700
WM-130	130	65	1153.0	1400	2200
WM-106	106	53	1414.1	1700	2600
WM-86	86	43	1743.0	2200	3300

For information, *Table 2* gives a comparison between the new IEEE waveguide names¹ and the names of related waveguides in the existing MIL standard,² and the nearest waveguides that have been proposed previously to extend the MIL series of waveguides.⁴

The series of waveguides shown in Table 1 have been chosen so that they can be easily extended, when necessary, to cover higher frequencies. The following procedure should be followed to extend the waveguide series:

- Select a waveguide size from the unshaded region of Table 1;
- Divide the mechanical dimensions by 10:
- Multiply the frequency values by 10.
- Rename the waveguide accordingly.

For example, the next two sizes in this series (derived from WM-710 and WM-570) are shown in *Table 3*.

The part of the standard covering frequency bands and waveguide dimensions has now been drafted and is likely to be circulated for public comment in the coming few months.

WAVEGUIDE INTERFACES

The attention of the standard's Working Group is now turning to the waveguide interfaces, often called

TABLE II COMPARING THE IEEE[1], MIL[2] AND 'EXTENDED' MIL[4] WAVEGUIDE NAMES				
MIL name	New IEEE Name	fmin (GHz)	fmax (GHz)	
WR-10	WM-2540	75	110	
WR-08	WM-2032	90	140	
WR-06	WM-1651	110	170	
WR-05	WM-1295	140	220	
WR-04	WM-1092	170	260	
WR-03	WM-864	220	330	
`Extended MIL' name	New IEEE Name	fmin (GHz)	fmax (GHz)	
WR-2.8	WM-710	260	400	
WR-2.2	WM-570	330	500	
WR-1.9	WM-470	400	600	
WR-1.5	WM-380	500	750	
WR-1.2	WM-310	600	900	
WR-1.0	WM-250	750	1100	

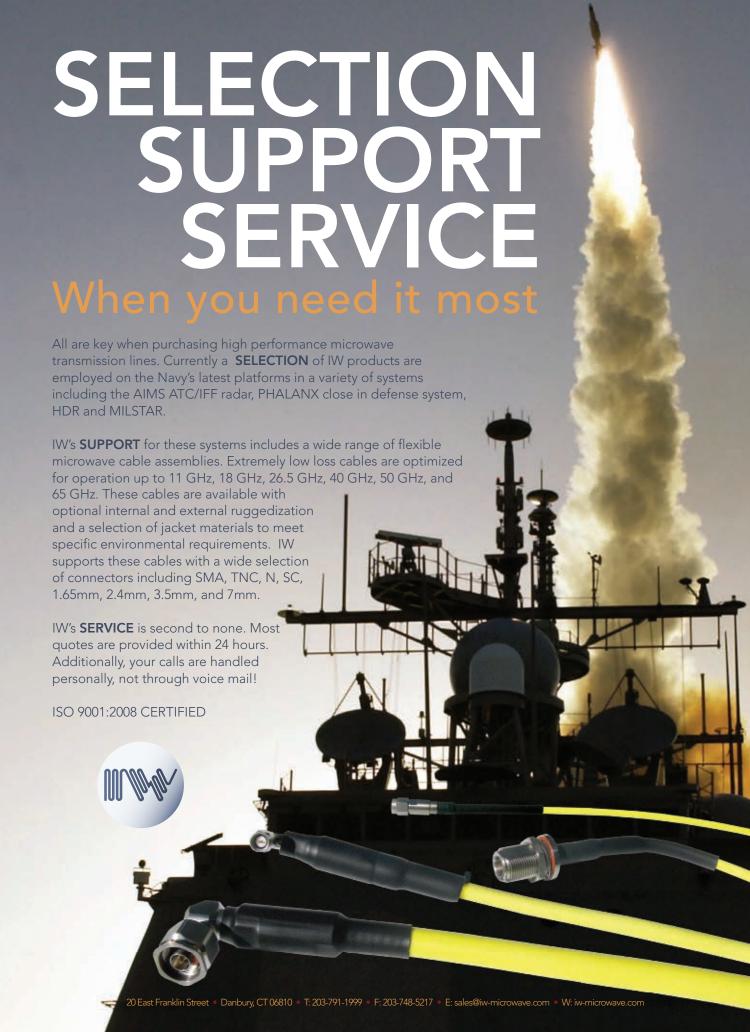


TABLE III					
EXTENDED FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS FOR THE IEEE STANDARD					
Waveguide Name	Aperture Width (µm)	Aperture Height (μm)	Cut-off Frequency (GHz)	Minimum Frequency (GHz)	Maximum Frequency (GHz)
WM-71	71	35.5	2111.2	2600	4000
WM-57	57	28.5	2629.7	3300	5000



Fig. 1 A precision version of the so-called "UG-387" flange, showing the two additional dowel holes, immediately above and below the rectangular waveguide aperture.

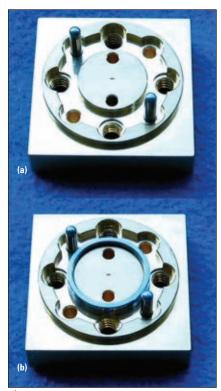


Fig. 2 Ring-centered waveguide flange: (a) with dowel holes and pins and (b) with the coupling ring in place.

"flanges". The Working Group is keen to ensure that it considered all flange designs that are used regularly at these frequencies (that is at 110 GHz and above). Therefore, a subgroup is being set up to investigate this matter further. Advice is also being sought from the entire millimeter- and sub-millimeter-wave communities to help identify any such candidate flange designs. If you are aware of any flange design that you consider should be included in this standard, please contact the authors of this article. The plan is that the standard, when published, will contain all appropriate flanges that will be used routinely in this frequency region.

For example, one such flange that is likely to be considered for inclusion in the standard is a precision version of the MIL-F-3922-67D flange (often called UG-387) that has been described⁵ and is shown in *Figure* 1. Compared to the conventional UG-387 flange,⁶ this precision version contains two additional alignment dowel holes immediately above and below the waveguide aperture. These additional holes (and the associated dowel pins) are specified to a tighter dimensional tolerance than the dowel holes and pins found on the conventional UG-387 flange. This leads to better mechanical alignment of the waveguide interfaces and hence lower electrical reflection from a mated pair of flanges.

Another type of flange that is likely to be considered for inclusion in the standard is a newer design—a ring-centered flange,⁷ as shown in *Figure 2*. This design is compatible with both the UG-387 and precision UG-387 flange designs, but also uses a coupling ring to significantly improve the alignment of the flange interfaces.

It is expected that the IEEE standard, when published, will contain several flange designs, allowing endusers (such as customers, suppliers, etc.) to chose a design that best meets their given requirements. The role of the standard, in this context, is to provide the information needed for this choice to be made reliably.

CONCLUSION

The IEEE is well on its way to publishing a standard for defining rectangular metallic waveguides for use at frequencies above 110 GHz. Already, there are many applications emerging for the use of this part of the electromagnetic spectrum—millimetre-wave, submillimeter-wave, terahertz, etc.⁸ Therefore, the publication of this standard is timely, and should serve our industry well for many years to come. ■

Nick Ridler and Ron Ginley are chair and vice-chair, respectively, of the EEE P1785 working group (http://grouper.ieee.org/group/1785).

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NEW HYBRID JUMPER FOR REMOTE RADIO HEADS

gainst a background of expansion of the LTE network, worldwide operators are increasingly relying on amplifiers installed close to the antenna, known as remote radio heads (RRH), especially for smaller antenna systems mounted in towers or on roofs. Previously, the transmission distance between the RRH and the antenna was usually bridged by ½ inch jumpers. However, operators have met with increased difficulties due to the maximum allowable insertion loss of such links, which is why the ½ inch jumpers have been deemed to be unsuitable for certain cable lengths. This is why the larger 7/8 inch feeder cables, which have better attenuation properties, often need to be used.

The downside is that their diameter is almost twice as large. This makes them rigid in comparison to ½ inch jumpers and their relatively large bending radius and high bending torque are obstacles to easy installation, particularly on the last meter before the antenna or the RRH. In reality, for installation purposes, users have often had to resort to the far more

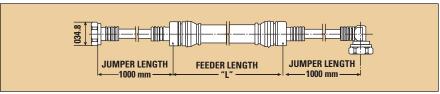
flexible ½ inch jumpers again, at least where close-coupled connections need to be made. However, this approach requires quite a lot of effort to cut the ½ inch feeder cables to length on site, strip them and attach the necessary connectors. Furthermore, assembling the cables on site is critical, given that conditions are not always ideal and that the RF parameters and durable resistance to environmental influence are essential.

COMBINED BENEFITS

SPINNER has addressed these issues by offering the market a product that combines the benefits of both cable types, thus ensuring easy assembly. The Hybrid Jumper features the good attenuation performance of the feeder cable as well as the desirable flexibility of the jumper cable. The specifications for the Hybrid Jumper are shown in *Table 1*.

SPINNER GMBH München, Germany

TABLE I SPECIFICATIONS OF THE HYBRID JUMPER **Electrical Specification** 380 ... 470 1710 ... 1990 2000 ... 2200 2200 ... 2700 698 ... Frequency range (MHz) 960 **VSWR** 1.07 max. 1.09 max 1.11 max 1.13 max 1.16 max. 1.05 typ. 1.06 typ. 1.08 typ. 1.08 typ. 1.10 typ. IM3 ≤ -160 dBc max./-165 dBc typ. (@ 2 × 43 dBm) Environmental Specification IP 68 (0.1 bar/24 hours/unmated) Ingress protection IP 68 (1 bar/1 hour/mated) -70°C to +85°C | -94°F to+185°F Storage Recommended -40°C to +60°C | -40°F to+140°F Installation temperature range -55° C to $+85^{\circ}$ C | -67° F to $+185^{\circ}$ F Operation Types (Extracted Examples) LF 7/8" Nominal insertion loss @ Article Assemply Feeder weight 800 MHz 1800 MHz 2700 MHz length "L' Cable Sizes: SF 1/2" /LF 7/8" Connectors: both ends 7-16 male JFJ-S12L78-7M7M-6 2.9 kg | $0.36 \mathrm{dB}$ $0.56~\mathrm{dB}$ $0.72~\mathrm{dB}$ 4000 mm 6.4 lb 6000 mm JFJ-S12L78-7M7M-8 3.9 kg | 0.42 dB $0.68~\mathrm{dB}$ 0.86 dB 8.6 lb JFJ-S12L78-7M7M-10 $8000 \; \mathrm{mm}$ 4.9 kg | $0.50~\mathrm{dB}$ $0.80~\mathrm{dB}$ 1.00 dB 10.8 lb JFJ-S12L78-7M7M-12 1.16 dB 10000 mm 5.9 kg | $0.58 \mathrm{dB}$ 0.92 dB13.0 lb



▲ Fig. 1 Cross-section of the make-up of SPINNER's Hybrid Jumper.

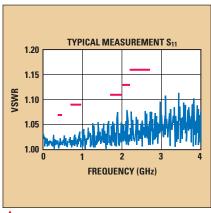


Fig. 2 Typical VSWR measurement graph.

The newly designed Hybrid Jumper includes a $\frac{7}{8}$ inch feeder cable as the main line, the length of which can be freely determined. On each end, it has a one meter long ½ inch jumper that is assembled on the main line with specially developed and optimized connection elements. *Figure I* shows the configuration. These connection elements are tightly soldered on the outer conductors of the cables, thus ensuring high stability and excellent intermodulation properties over the whole service life and under any environmental conditions.

COMPLETE ASSEMBLED UNITS

The traditional approach has been to join the feeder cable and jumper with a combination of connector and coupler, with at least one of them (usually the connector of the feeder cable) being assembled on site. Instead, the Hybrid Jumper is delivered as one completely assembled unit that is ready for use. The transition points are exactly matched and ensure superior VSWR values under repeatable manufacturing conditions. Typical measurements are shown in **Figure 2**.

The Hybrid Jumper, as a complete line, has an IM3 ≤ -160 dBc, which meets the stringent intermodulation requirements of individual pre-assembled ½ inch jumpers over the whole service life. Furthermore, the cables go through a 100 percent test before dispatch; upon request the test log is available to the customer. The product also fully meets the requirements of the IP68 protection rating, thus ensuring resistance against environmental effects.

By harnessing the company's technical competence and long-standing experience in order to find the optimum solutions for its customers, SPINNER's new Hybrid Jumper is a cable that is flexible where flexibility is needed, while also featuring low insertion loss. Repeatable manufacturing conditions and 100 percent testing of all relevant technical parameters guarantee high operational reliability. An additional benefit is that complete pre-assembly makes the Hybrid Jumper very easy to install and ready for immediate use. It is currently available in standard lengths from 6 to 12 m and special lengths can be manufactured and supplied upon request. Besides the most common connector combination with $2 \times 7-16$ connectors, the Hybrid Jumper is also available in the standard version 7-16 connector/7-16 angled connector.

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BRAIDED OUTER-CONDUCTOR LOW PIM TEST LEADS

ompetition in the cellular industry continues to drive the need to not only attract but keep subscribers. However, subscribers increasingly view cell service as a commodity driven in part by laws requiring cell phone numbers to be portable. Providers attempt to differentiate themselves with new services, but poor call reception remains a major reason subscribers change providers so the race to eliminate dropped calls remains a very high priority.

Passive Intermodulation Distortion (PIM) has been identified as a leading source of dropped calls in cell systems; therefore, it is understandable that providers view eliminating PIM sources as a high priority. PIM concerns have been raised for years, but are a relatively recent cell test criteria and still not completely understood by test technicians. Passive Intermodulation Distortion is caused by the presence of multiple transmit signals in a single transmission line or other components. The RF signals interact with each other at nonlinear junctions and create unwanted signals at frequencies that are the sum or difference of the transmit frequencies. If these signals fall in the receive band and are at high enough levels they can interfere with call quality and cause dropped calls. The levels that can cause problems in the receive band are more than 130 dB below the level of the carrier signal meaning that they can be generated by very small nonlinearities created by loose connections, the presence of non-ferrous metals or other reasons. They are difficult to measure and difficult to find and fix.

Independent contractors report finding the source of PIM frustratingly elusive and time consuming. Identifying the root cause is many times trial and error with a body of knowledge being generated from individual experiences. However, predicting the source in unique situations remains a challenge. For example, multiple systems now compete for space on the same or nearby towers and high PIM levels may only show up sporadically. The nearby landscape may have changed. Metal grates or large pieces of metal-encased equipment may have been added to a rooftop generating unacceptable PIM levels where none existed when the system was deployed. Tower vibrations can loosen any number of hundreds of connections. Individual components that exhibited acceptable PIM levels when first installed sometimes degrade with time, from antennas at the top to lightning protection devices down to internal radio components and jumpers. Even temperature changes may contribute to poor PIM performance.

Accepted practices to reduce PIM levels include using only non-ferrous metals and eliminating nickel under-plating in components used particularly in the transmit paths. Plating finishes must be smooth and are limited to silver or preferably non-tarnishing tri-metal (tin, copper, zinc). Reducing the number of pressure contacts between two pieces of metal within the primary RF path is desirable. When metal-to-metal contact is required (usually in a

TIMES MICROWAVE SYSTEMS Wallingford, CT



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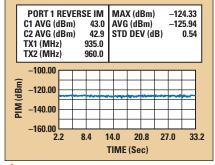
mated pair of connectors), clean, uniform, undamaged interfaces and high contact pressure is crucial. Specific torque values must be maintained. For 7-16 connectors, 21 ft-lbs is required. This brings us to the issue of how to get from the PIM tester to the DUT without introducing additional sources of PIM generated from the test lead itself.

Corrugated cable is typically used to achieve low PIM in the test lead. This eliminates the countless contact points found in the braided outer conductor of flexible coax, but the trade off is the lead can be difficult to handle and tends to kink mid-span or break more easily at the connector attachment area. Flexible coax makers historically have not focused on making low PIM, long flex life cable regardless of the application because of the high barrier to entry in this market.

By paying strict attention to the braiding process and materials, Times Microwave has developed several cable designs that exhibit reasonable flexibility, flex life and PIM performance (see *Figure 1*). PIM performance

mance is better than -160 dBc at full PIM test equipment RF power levels. A three meter assembly exhibits approximately 1.25 dB of attenuation at 1 GHz. Drawing on its extensive experience supplying SilverLine- TG^{TM} (TuffGrip) phase stable test cables for cell site DTF measurements, Times outfits SilverLine-LPTM (Low PIM) products with a large armor and strain relief system that is another industry first. The armor withstands 1500 lbs per inch crush resistance. Connector retention exceeds 500 lbs. All pressure contact areas are eliminated in the assembly design in favor of full induction soldering for both center and outer conductors—not a trivial process when the entire product is heavilv armored. As an added value, Times offers a set of three low PIM adaptors in a heavy duty protective nylon case and a limited-time test lead refurbishment program with every purchase of SilverLine-LP (part number SLS03-76M76M-02.75MK).

SilverLine-LP flexible low PIM test leads are also suitable for high volume production test. Beta site tests of



🛕 Fig. 1 Typical PIM performance.

SilverLine-LP with a maker of cellular antennas show SilverLine-LP lasts for up to six months in regular production use. As with any high performance test lead it is recommended to flex the product as little as possible for the longest life.

PIM testing also requires a PIM load suitable for the application. For tower testing, the most popular load on the market today is designed primarily for weight savings. If left under full power, it burns out quickly. Other designs that can handle full power are extremely heavy and cumbersome. Times portable PIM loads strike the ideal balance between weight (approximately three lbs) and full power handling. Times part number 67019 can handle full test equipment output power continuously for as long as is needed to troubleshoot a system. It comes equipped with both male and female 7-16 connectors eliminating the need for adaptors under certain test conditions or jumper configurations. Metal protective connector caps secured with metal chains, a frame-mounted lanyard loop, heavyduty protective nylon case and wide wrench flats to assure proper torque are standard features not found in competing products.

For production or lab environments, Times also offers part number 67020 bench PIM load. The company's bench model includes similar features to the portable model with the addition of an easy-to-use folding handle. For those more comfortable with traditional corrugated test leads, Times offers part number SLCOR03-76M76M-03.00M, 3/8" super flex corrugated cable test leads.

Times Microwave Systems, Wallingford, CT (800) 867-2629, www.timesmicrowave.com.



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Cables & Connectors Supplement

LIGHTER-WEIGHT RG COAXIAL CABLE



7.L. Gore & Associates has introduced a new, lighter-weight RG coaxial cable for aircraft communication and navigation systems, providing significant weight savings without compromising performance. When compared to standard RG coaxial cables, these new cables reduce operating costs because they are over 25% lighter and the diameter is more than 15% smaller. This smaller and lighter profile coaxial cable still meets the stringent electrical and mechanical requirements of MILT-81790 and EN 3475-503. The cables engineered for electrical impedance of 50 and 75 Ω also exceed the electrical requirements of MIL-C-17G.

Although weight is a crucial factor for the aerospace industry, the performance of cables cannot be compromised to reduce mass. Gore's experience in developing fluoropolymer-based materials for the rugged environments encountered by aircraft has enabled them to consistently deliver high-performance, light-weight cables that meet RG specifications. These new lightweight RG coaxial cables are ideally suited for both newly designed systems and retrofit applications because their standard range of RF connectors can be terminated using standard tooling and processes.

The special cable design of Gore's new RG coaxial cables facilitates easier routing and improved abrasion resistance for the cables. The unique jacketing material used in the cable's construction significantly reduces size while maintaining shielding effectiveness, controlling impedance and withstanding operating temperatures ranging from -65° to 150° C.

W.L. Gore & Associates Inc., Landenberg, PA, www.gore.com/aerospace.



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Type N - 18GHz

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Adapters - 40GHz

TNC - 18GHz

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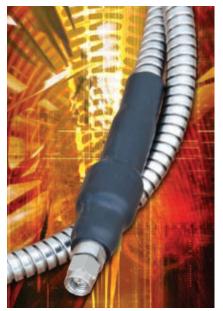


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rystek has ruggedized its LL142 low-loss RF cable assemblies by incorporating a spiraled stainless steel casing, along with extra fortification provided by heavy-duty adhesive strain relief with a Neoprene jacket. This added measure of protection eliminates the failures commonly caused by cable flexion and compres-

ARMORED FAMILY OF 18 GHz Low-loss Cable Assemblies

sion. At 18 GHz, the new Armored LL142 assemblies feature attenuation of 0.36 dB/ft and VSWR characteristics of <1.3.

Crystek's Armored LL142 Series cables offer shielding effectiveness of greater than -110 dB with an operating temperature range of -55° to +85°C (extended range of -55° to +125°C available through special order). The cables feature rugged stainless-steel solder-clamp construction and a minimum bend radius of 1.5 inches with minimal spring-back. The Armored LL142 Series cables are available in four standard lengths—24, 36, 48 and 60 inches—with SMA male to SMA male connectors. Custom lengths

and configurations (Type N and TNC connectors) and electrically matched pairs are also available.

Crystek has been providing frequency products since 1958 and operates two divisions dedicated to frequency control. Crystek Crystals and Crystek Microwave are dedicated to the development and manufacture of frequency products using quartz-based resonators and frequency control products for the microwave industry.

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www.astrolab.com



Product Brochure

Amphenol RF introduced its latest innovation, the Mini Lock 7 (ML7) RF connector for wireless infrastructure markets. The ML7 combines proven advantages of the 7/16 interface with a new, low torque, quick coupling mechanism that speeds installation and reduces connector size up to 25 percent while delivering the same high performance quality and electrical performance users expect from Amphenol RF products. The

ML7: lower costs and improved performance from the leader in RF technology.

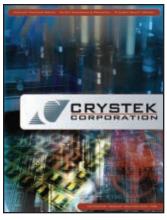
Amphenol RF, Danbury, CT (800) 627-7100, www.amphenolrf.com.



Product Catalog

This brochure features the company's SMPM-T, the smallest threaded open source connector on the market. Its unique and innovative combination of a MIL-STD-348 SMPM Female Interface connector together with a retractable threaded nut provides an integrated solution offering unprecedented electrical and mechanical performance.

Astrolab Inc., Warren, NJ (732) 560-3800, www.astrolab.com.

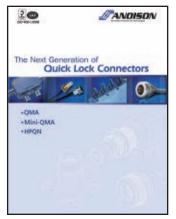


Frequency Control Solutions

Crystek specializes in providing high frequency, low-phase-noise solutions to the microwave and RF wireless industries. Crystek's custom engineering solutions, manufacturing capabilities and quality control have been unmatched in the industry. The Crystek frequency control lineup features VCOs, VCXOs, PLLs, XOs, TCXOs and quartz crystals, along with a full line of

accessories such as RF coax cable assemblies, attenuators and filters.

Crystek, Fort Myers, FL (239) 561-3311, www.crystek.com.



Coaxial Connectors

Anoison Electronics offers a full range of QUICK LOCK coaxial connectors in three series: QMA, Mini-QMA and HPQN. The QMA offers comparable electrical performance to an SMA, DC to 18 GHz, and is inherently waterproof to IP 68. The Mini-QMA offers the same advantages of the QMA in a smaller package. The HPQN is designed to replace N connectors, where a quick connect/disconnect application is desired, DC to 18 GHz.

Anoison Electronics LLC, Portsmouth, NH (603) 431-1414, www.anoison.com.

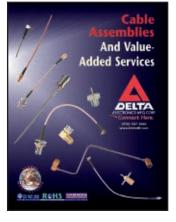


Corporate Capabilities Brochure VENDORVIEW

This Carlisle Interconnect Technologies brochure is a high level overview of all the company offers as a global provider of RF/microwave,

specialty and filtered connectors, cable/cable assemblies, complex harnesses, integrated installation kits and ARINC trays, racks and shelf assemblies, to engineering/certification services with DER, DAR and DMIR personnel on staff.

Carlisle Interconnect Technologies, St. Augustine, FL (800) 458-9960, www.CarlisleIT.com.



Product Brochure

To assist customers who have a need to streamline their supply chain and logistics, Delta Electronics Manufacturing now offers a broad range of coaxial cable assemblies and other connector-related, value-added component subassemblies. Delta's cable assemblies, incorporating flexible, semi-rigid and handformable cables, range in size from micro-miniature to large, high-power types. They cover the spectrum of market needs

from high volume, low cost assemblies to high performance, low volume categories.

Delta Electronics Manufacturing Corp., Beverly, MA (978) 927-1060, www.deltarf.com.

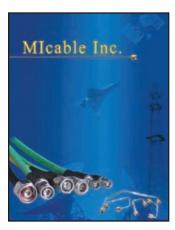




High Speed Digital Testing Solutions

HUBER+SUHNER is offering a broad range of high end RF test components and assemblies developed and optimized for high speed digital testing. These products stand for highest density, lowest loss and highest performance coaxial-to-PCB transitions and cabling solutions. The solutions include extensive technical support, libraries of 3D-files, electrical modelling data and customer specific optimized footprints.

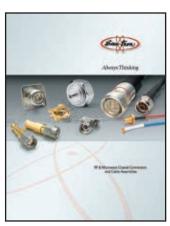
HUBER+SUHNER, Herisau, Switzerland, info@hubersuhner.com.



Product Catalog

MIcable Inc. produces a wide variety of high quality coaxial cable assemblies with flexible, conformable, and semi-rigid cable and customer specified connectors. The company offers prototypes or volume quantities, all fully tested up to 40 GHz and delivered on time. The product brochure highlights a few of the company's products along with providing performance data. For more information, call 86-591-87382855 or e-mail: sales@ micable.cn.

Mlcable Inc., Fuzhou, Fujian, China +86-591-8738 2855, www.micable.cn.



Coaxial Connectors and Cable Assemblies VENDORVIEW

The brochure features several innovative high performance designs, including: S292TM connectors offering VSWR of <1.18 through 40 GHz; solder-free Type N right angle adapters; Type N panel receptacles featuring rugged single piece body construction; eSMATM cable assemblies that replace semi-rigid; field-replaceable SMAs that minimize loss from

DC to 26.5 GHz; and a 7/16 panel receptacle featuring -175 dBc intermodulation.

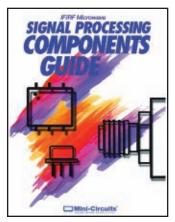
San-tron Inc., Ipswich, MA (978) 356-1585, www.santron.com.



Product Catalog

This 204-page catalog covers the entire Maury Metrology-Grade Precision Calibration Standards product line, including coaxial and waveguide VNA calibration kits, opens, shorts, loads, coaxial adapters, waveguide-to-coaxial adapters, coaxial connectors and cables, connector gage kits, torque wrenches and manual tuners. It is available in the original 2006 printed edition, and as a revised and updated 2010 PDF edition that can be downloaded from the Maury website at: www.maurymw.com.

Maury Microwave Corp., Ontario, CA (909) 987-4715, www.maurymw.com.

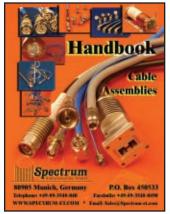


IF/RF Microwave Signal Processing Components Guide VENDORVIEW

Mini-Circuits' new 164-page catalog includes over 750 new products and is the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and over 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB Power

Sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine, which searches actual test data on over thousands of units.

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.



Cable Assembly Handbook

The company's new Cable Assembly Handbook will be available shortly. The company has been designing and manufacturing coaxial cable assemblies for 30 years. Spectrum has a complete RF and microwave design capability, developing and manufacturing 100 percent in-house the wide range of connectors for its cable assemblies and offers customized solutions.

Spectrum Elektrotechnik GmbH, Munich, Germany +49 89 3548 040, www.spectrum-et.org.





Need the performance of a semi-rigid cable, but the versatility of a flexible assembly? Mini-Circuits has the solution: *Hand Flex™ Cables*. Like semi-rigid cables, they are mechanically and electrically stable. But unlike semi-rigid assemblies, Hand Flex cables can be shaped by hand to quickly form the configuration you need in your assembly, system, or test rack. Hand Flex cables are available in popular semi-rigid cable diameters, 0.086 and 0.141", with SMA connectors for applications from DC to 18 GHz. They feature low insertion loss—typically 0.2 dB at 9 GHz for a 3-inch cable—with excellent return loss. Simplify your high-frequency connections. Low-cost Hand Flex cables are available now in standard lengths from 3"to 24", or order the KHFC-1+ Designer's Kit with 10 Hand Flex cable assemblies, five each of 0.141-and 0.086" diameter 3" long cables.

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141-6SM+	6	0.25	39	8.69
141-7SM+	7	0.33	37	8.69
141-8SM+	8	0.30	38	8.69
141-9SM+	9	0.38	38	8.69
141-10SM+	10	0.39	37	8.69
141-12SM+	12	0.46	38	9.70
141-14SM+	14	0.52	37	9.70
141-15SM+	15	0.54	37	9.70
141-18SM+	18	0.62	37	9.70
141-24SM+	24	0.77	37	11.70
.086" Diameter				
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086-4SM+	4	0.23	33	8.95
086-5SM+	5	0.29	33	8.95
086-6SM+	6	0.34	34	8.95
086-7SM+	7	0.42	32	8.95
086-8SM+	8	0.46	36	8.95
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SV Microwave,

Product Catalog

The next generation in miniature connectors and SV Microwave's RFffortless family is the SMPS. The SMPS series is capable of frequencies exceeding 100 GHz. Being 30 percent smaller than the SMPM, the SMPS is ideal for multiport and board to board applications.



Short Form Catalog

This new short form catalog presents an overview of Teledyne Storm Products' microwave cable assembly lines, as well as its manufacturing and test & measurement capabilities for build-to-print assemblies, and its multi-channel microwave harness solutions. This Line Card can be viewed or downloaded at www.teledynestorm.com; click on the Resource Center link.

Teledyne Storm Products, Woodridge, IL (630) 754-3300, www.teledynestorm.com.



Product Brochure

PhaseTrack IITM is a significant breakthrough in coaxial cable technology. PhaseTrack II is based on the unique, thermally stable Times Microwave Systems' proprietary TF5TM dielectric material. A proprietary engineered material and process combine to make TF5 dielectric the most stable dielectric material available, virtually eliminating the changes of phase with temperature characteristic of other high

performance expanded PTFE dielectric flexible RF and microwave coaxial cable assemblies.

West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.

Times Microwave Systems, Wallingford, CT (203) 949-8400, www.timesmicrowave.com.



RF and Microwave Interconnects

TRU Corp. has created a short form capability catalog that outlines a wide variety of RF and microwave interconnect solutions. The catalog utilizes easy to use matrices to specify TRU brand cable and connector interface options for general purpose, commercial wireless and high performance test cable assemblies. A complete outline of RF receptacle design options as well as a full

range of precision test and quick change adapters are included. This capability catalog discusses additional application driven design capabilities available from TRU Corp.

TRU Corp., Peabody, MA (978) 532-0775, www.trucorporation.com.



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