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February 2013

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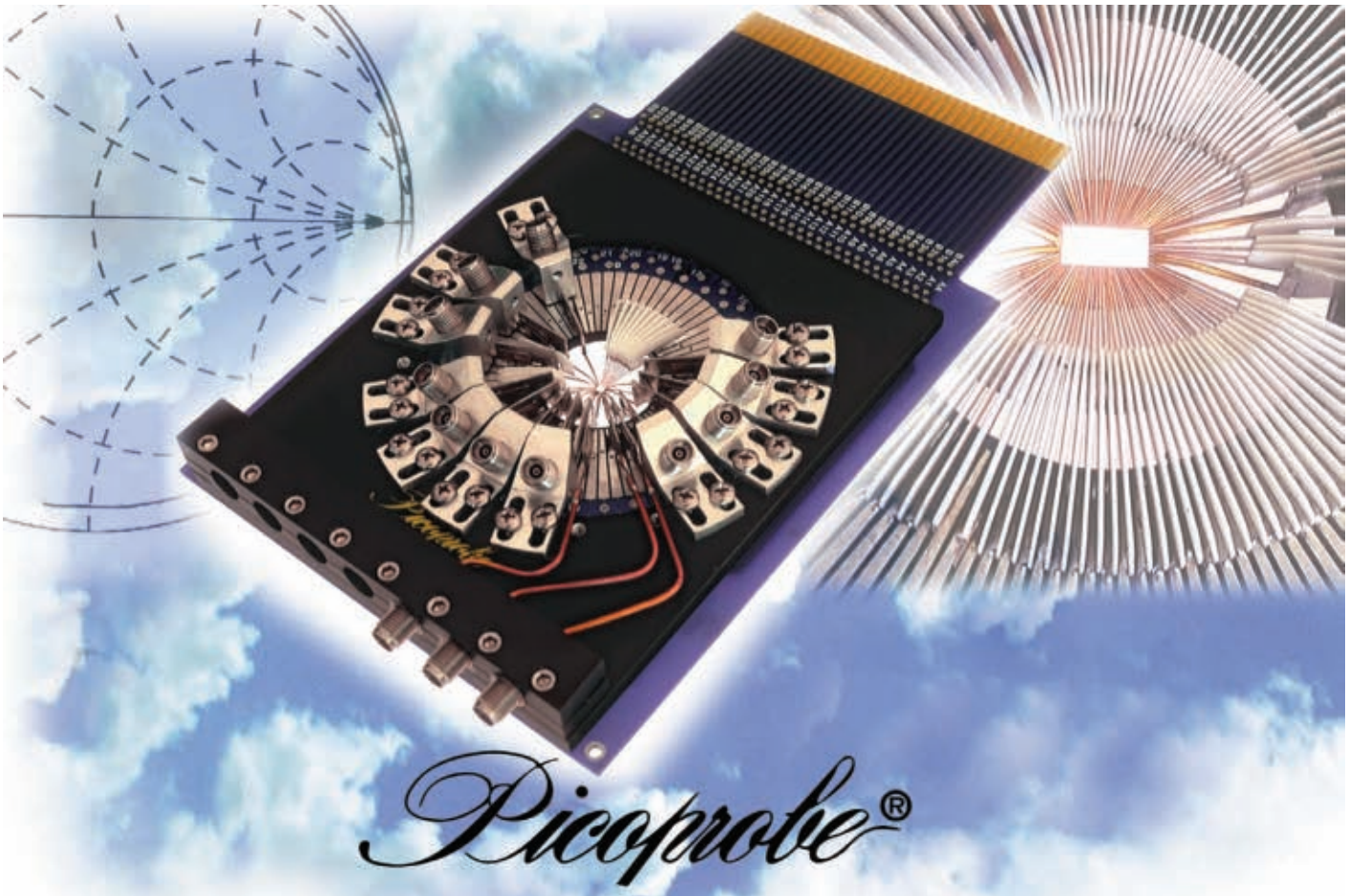

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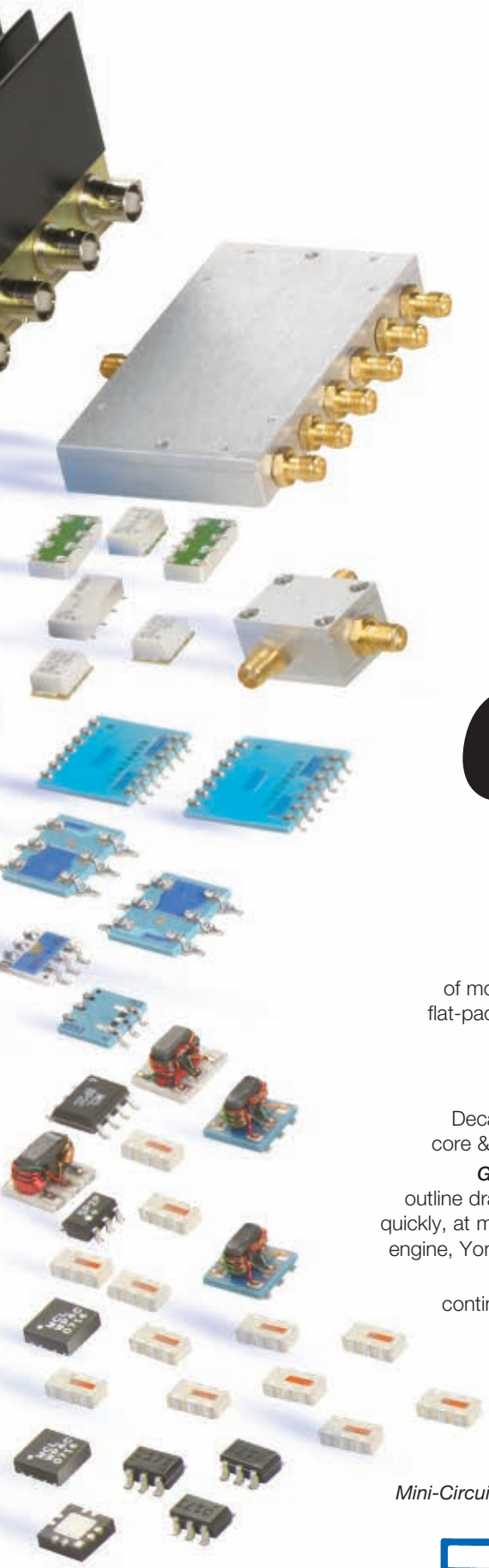

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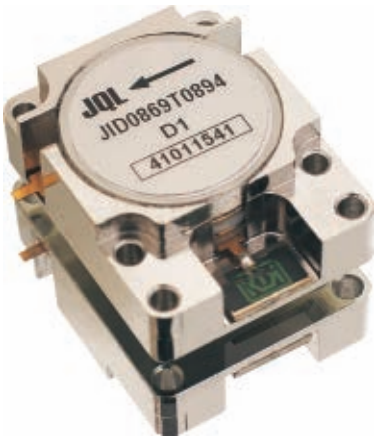

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MLPNC-7103-SMA800	21 @ 800 MHz	23 @ 1300 MHz	> -5 @ 6 GHz	> -15 @ 18 GHz	> -20 @ 30 GHz
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COVER FEATURE

MVP: MOST VALUABLE PRODUCT

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TECHNICAL FEATURES

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Departments

The image of the USS Enterprise (a registered trademark of Paramount Pictures) and the circular waveguide components used in the re-configured starship on this month's cover was rendered in SolidWorks, a 3D CAD design software from Dassault Systèmes.

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December Survey

What was the biggest industry news in 2012?

Freescale introduces its first GaN RF product for cellular infrastructure applications [16 votes] (13%)

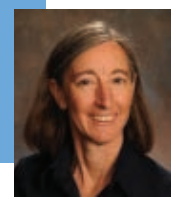
Samsung Galaxy Appeal indicates shift from GaAs to CMOS PAs [34 votes] (28%)

Underwriter: M/A-COM Technology prices IPO at $19/share [12 votes] (10%)

Teledyne Technologies completes acquisition of LeCroy Corp. [14 votes] (12%)

Peregrine Semiconductor announces pricing of initial public offering [45 votes] (37%)

Executive Interview



Joy Weiss, President of the Dust Networks product group at Linear Technology, talks about opportunities for wireless sensor networks and the emerging M2M market.

White Papers

Complex Modulation with Low Cost Arbitrary Waveform Generators
White Paper, Agilent Technologies

Overcoming High Speed Interconnect Challenges
White Paper, Anritsu

Overview of Tests on Radar Systems and Components
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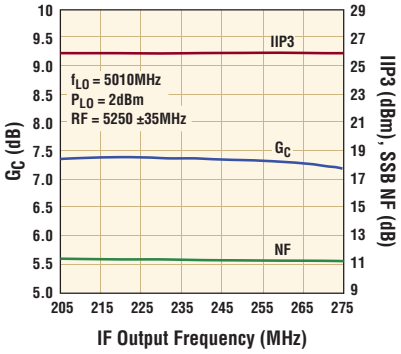

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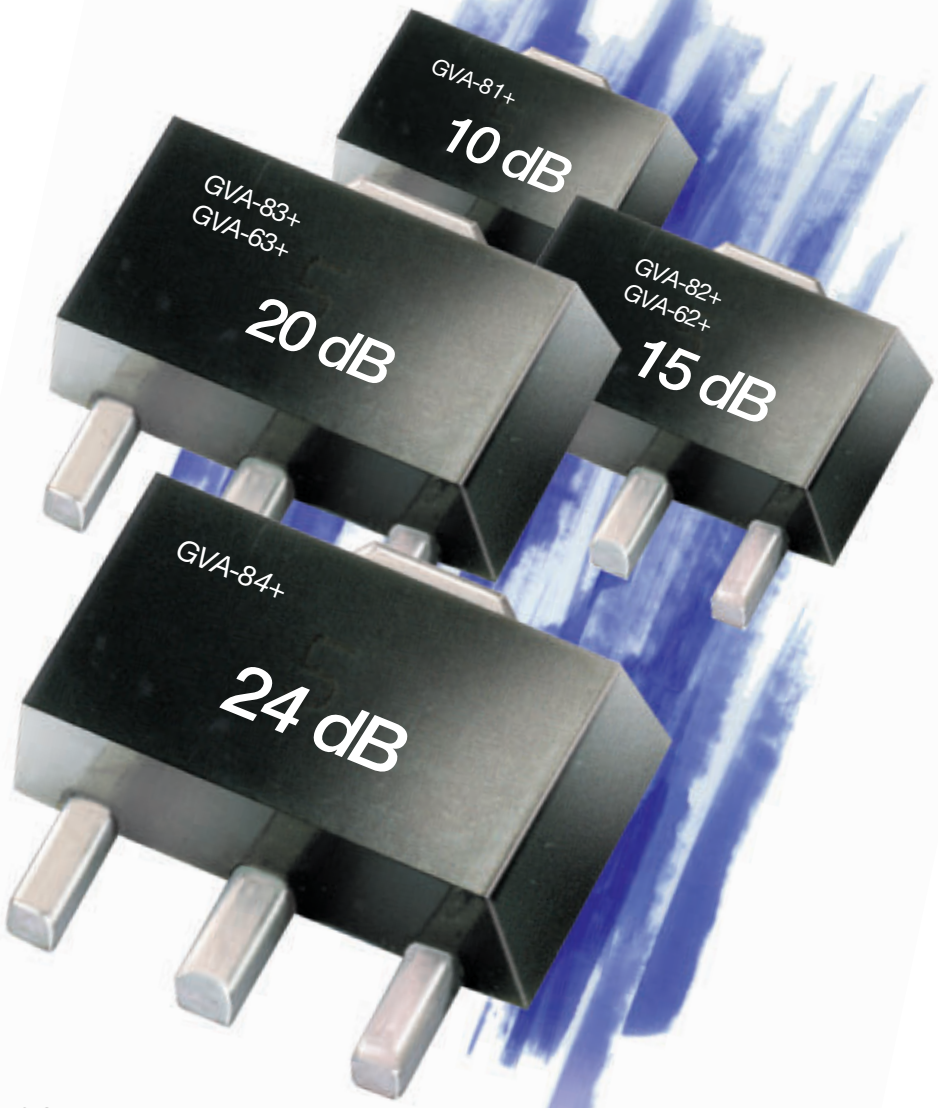

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3	4	5	6	7	8	9
		isQED Symposium 2013 Santa Clara, CA	**Webinar: GPS Interference & Spoofing** Sponsored by ROHDE & SCHWARZ	**Webinar: GaN on SiC** Sponsored by Agilent Technologies		
10	11	12	13	14	15	16
	IWCE International Wireless Communications Expo — Conference: March 11-15, 2013; Exhibits: March 13-14, 2013; Las Vegas Convention Center, Halls C1-3	EDICON Electronic Design Innovation Conference 电子设计创新会议 2013 Beijing, China	**Webinar: Signal Analyzer Fundamentals** Sponsored by Agilent Technologies			
17	18	19	20	21	22	23
		SATELLITE 2013 Washington D.C.	**Webinar: Linearizing GaN Amplifiers** Sponsored by Scintera, Sumitomo Electric	**Webinar: Understanding Probability of Intercept** Sponsored by Agilent Technologies		
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24	25	26	27	28	29	30
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31	1	2	3	4	5	6

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http://natehome.com/annual-conference

MWC 2013
Mobile World Congress
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www.mobileworldcongress.com

MARCH

ISQED 2013
International Symposium on Quality Electronic Design
March 4–6, 2013 • Santa Clara, CA
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IWCE 2013
International Wireless Communications Expo
March 11–15, 2013 • Las Vegas, NV
www.iwceexpo.com

EDI CON 2013
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PSATS 2013
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www.psats.eu

APRIL

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www.wamicon.org

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www.microwave-rf.com

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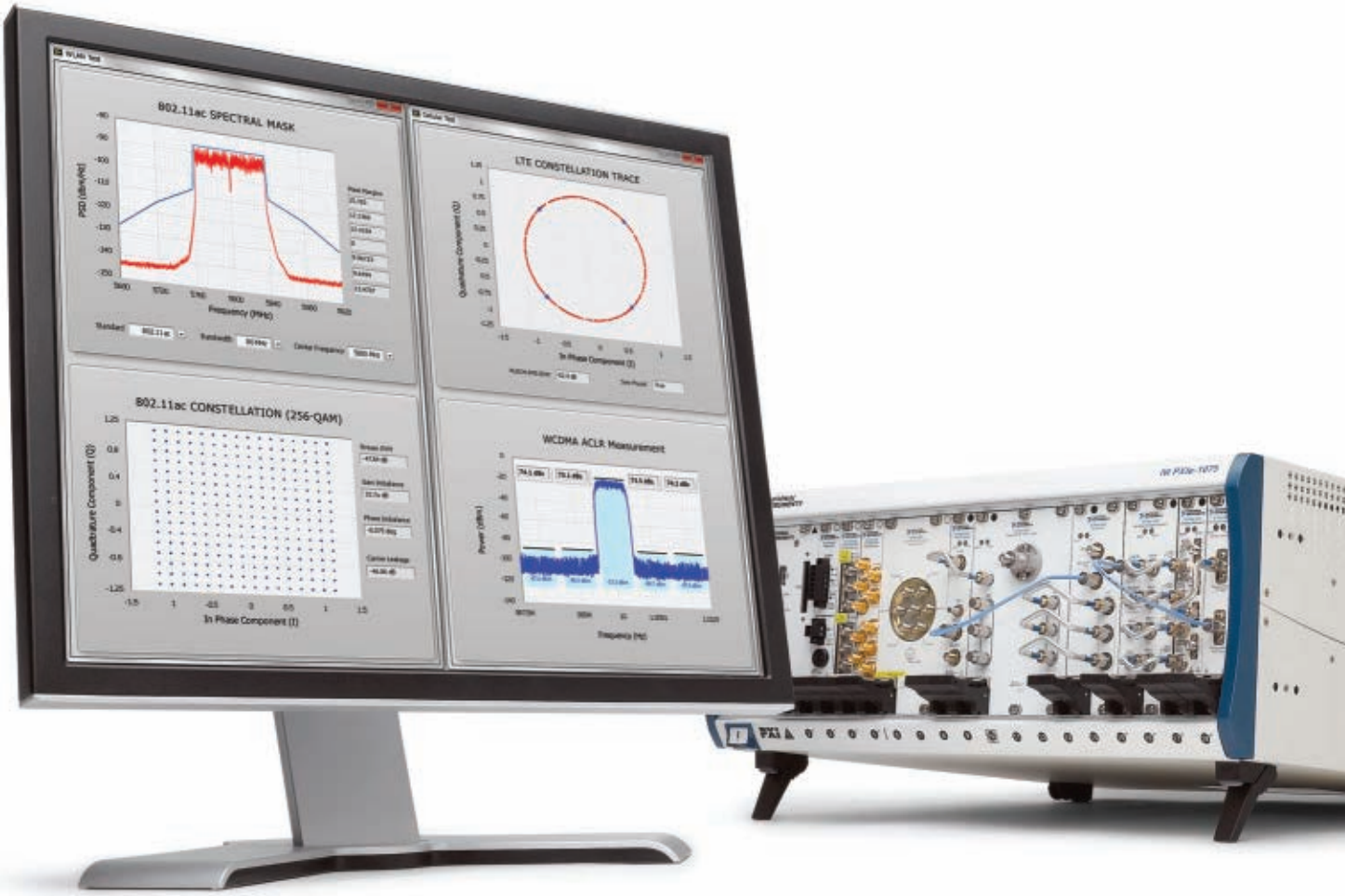

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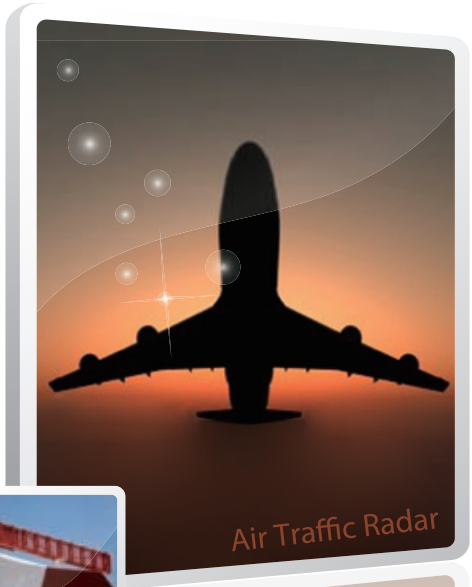

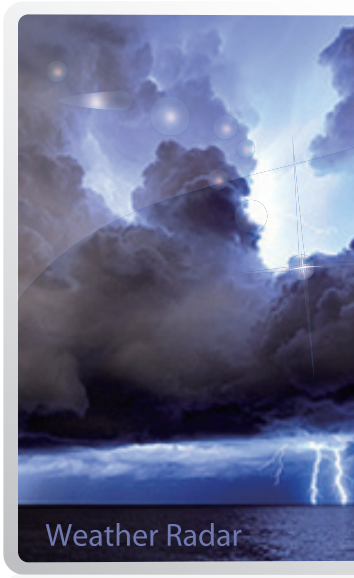

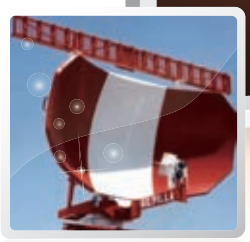

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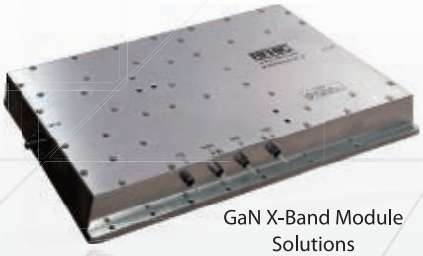

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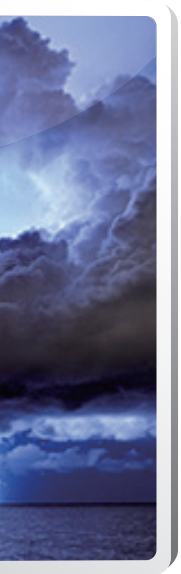

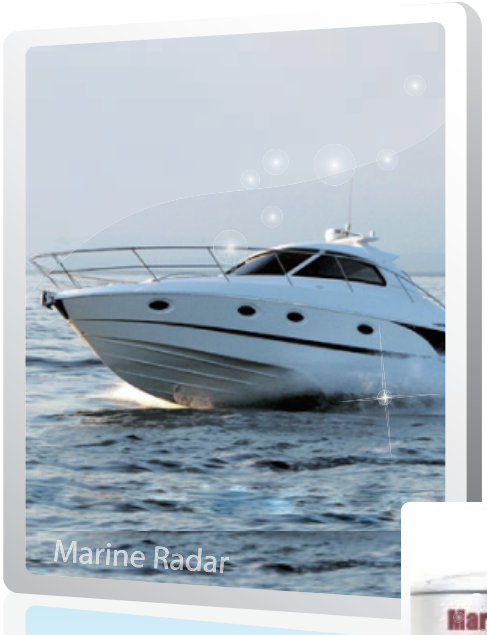

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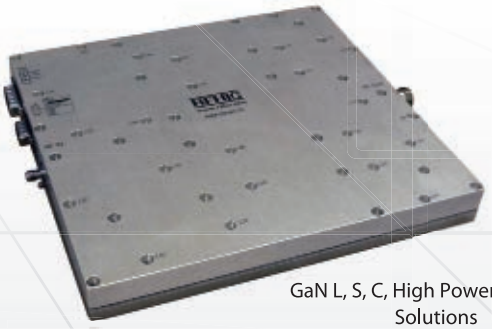

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COVER FEATURE
INVITED PAPER

Making Connections Beyond 110 GHz

Research pioneers are exploring the vast spectrum resources above 110 GHz, which is commonly referred to as the millimeter-wave (mm-wave) frontier that spans from 30 GHz to 1 THz. These pioneers already have demonstrated the feasibility of mm-wave technology for solving emerging problems in advanced wireless communication, astronomy, imaging, biomedical and homeland security fields. In the next phase, these pioneers will stake their claim with the development of new mm-wave products. It is this mm-wave trend from research toward global commercial viability that drives the technology covered in this article.

Preparation for this exploration begins with background information on why the mm-wave spectrum is attractive for exploration. The journey continues with practical lessons learned from the ALMA Project (the gigantic antenna array in Chile), which is the first global success story on the mm-wave frontier. This retrospective will ensure we do not duplicate the mistakes of previous pioneers by revealing what is important to know for our upcoming journey. Finally, the foundation is being set today for the mm-wave ecosystem with standards that address metrology concerns in the physical layer. This framework is how engineers will achieve faster time-to-market and lower cost through competitive forces, instead of manufacturer dependent efforts. At the completion of this article, future pioneers and entrepreneurs can also stake their own claim by developing exciting new mm-wave products to accelerate the deployment of mm-wave solutions.

SPECTRUM RESOURCES BEYOND 110 GHz

The excitement of commercializing mm-wave technology is motivating research beyond 110 GHz as the data rates are faster with more available spectrum. These applications include fixed wireless links, THz nano cells, WLAN/WPAN, kiosk downloading, short range device connections and board-to-board communication. There are two new expedition teams that are forming to further delve into these applications. The first group is IEEE 802.15 WPAN™ Terahertz Interest Group (IGthz).[1] The second group is IWPC Mobile Multi Gigabit (MoGIG) Wireless Networks and Terminals.[2] The IGthz is primarily pursuing THz communications and related network applications operating in the THz frequency bands between 275 GHz and 3 THz. The mission of MoGIG is to answer the question of what will happen to mobile wireless networks in the coming years when they run out of spectrum to support the massive increases in data demand.

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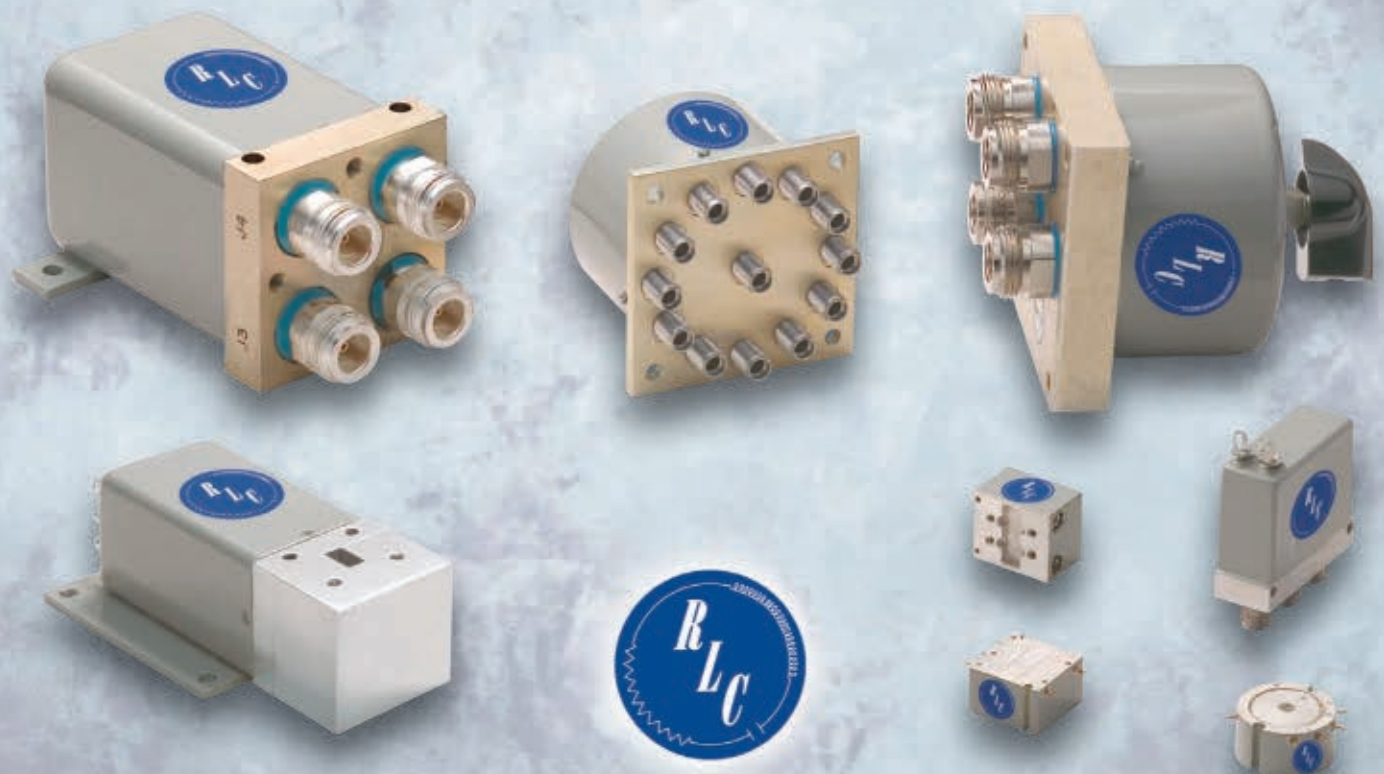

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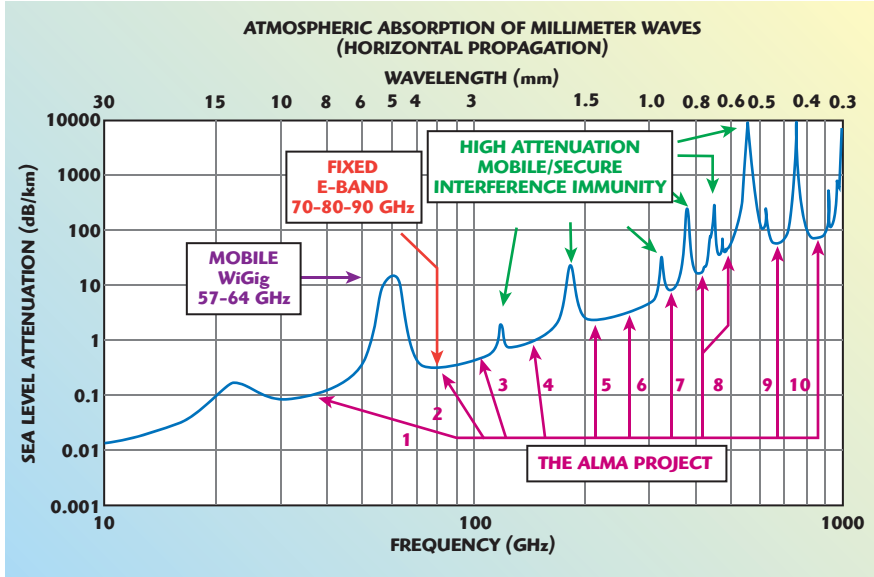

Fig. 1 Atmospheric absorption properties of mm-wave signals vs. frequency and wavelength.

GHz of bandwidth in the 60 GHz band.[3] This performance currently represents a ten times faster improvement over RF WLAN technologies using 80+ MHz of bandwidth. By further exploring beyond 110 GHz, engineers are planning the next decade in data transfer technology. In addition, smaller antenna sizes and emerging beam steering technology are enabling development efforts toward more commercially attractive mobile solutions with smaller size and less weight. Operating on the mm-wave frontier will also simplify deployments and hopefully reduce costs. Generally speaking, more bandwidth and shorter wavelengths in the largely untapped mm-wave spectrum are the key ingredients in achieving the next tier in multi-gigabit transfer rates. One regulatory hurdle to keep in mind is that transmissions must coexist with existing spectrum usage from radio astronomy, Earth exploration and space research applications. These regulatory applications span the 275 to 600 GHz spectrum. Coexistence places a burden on development efforts to demonstrate compliance and risk mitigation of interference concerns.

ATMOSPHERIC ABSORPTION

An important design consideration in spectrum allocation is the atmospheric absorption properties of mm-wave signals. As shown in ***Figure 1***, there are natural molecular resonances that create operating windows for either minimum or maximum signal propagation characteristics.[4] Selection of a "valley" corresponds to minimum attenuation that is conducive to applications requiring relatively longer transmit/receive paths. One notable valley example is point-to-point radios where E-Band is a popular deployment. Conversely, selecting a "peak" will shorten transmission paths, which may be a desirable attribute for minimizing interference in a dense signal environment. One notable peak example is for mobile applications: WiGig (802.11ad). Across the entire mm-wave spectrum, it is important to note that moisture content (e.g., relative humidity, fog, rain) degrades the propagation characteristics. These characteristics will influence the line-of-site (LOS) transmission path and, subsequently, whether the application is fixed or mobile.

LESSONS FROM THE ALMA PROJECT

The Atacama Large Millimeter/sub-millimeter Array (ALMA) is an array of 66 high-precision radio telescopes in the Atacama Desert of northern Chile. An international partnership of Europe, North America and Japan in cooperation with the Republic of Chile have successfully deployed this mm-wave system with spectrum coverage from 30 to 950 GHz.[5] The spectrum allocation of the ten bands are shown in both Figure 1 and ***Table 1***. The purpose of this antenna system is to empower scientists from around the world to unravel longstanding and

important astronomical mysteries. These discoveries are now possible by gathering data in mm-wave frequency ranges previously not exploited.

On the mm-wave frontier, the ALMA Project is arguably the first international success story. Given this success, future mm-wave endeavors can leverage this initial industry experience. In addition to the underlying mm-wave technology, the lack of standards was a primary cause of confusion and delay in the deployment. These standards span the full gamut of the application from band designators to waveguide interfaces. Equally painful was the absence of traceable standards for independently verifying critical system performance criteria. It was easy to grant a sole-source justification due to lack of standards, but the trickle-down effect of products without standards initiated a painful era of incompatibility issues across the globe. In terms of electrical performance, waveguide irregularities were shown to cause undesirable degradations; subsequently, the needs for anti-cocking and further flange alignment features were documented. These are the primary mm-wave lessons from the ALMA Project that require addressing before further exploration and commercialization can happen.

TABLE I

THE 10 FREQUENCY BANDS OF THE ALMA ANTENNAS

ALMA Band	Frequency Range (GHz)
1	31 to 45
2	67 to 90
3	84 to 116
4	125 to 163
5	162 to 211
6	211 to 275
7	275 to 373
8	385 to 500
9	602 to 720
10	787 to 950

BACKGROUND ON COAXIAL/ WAVEGUIDE INTERFACES

In the overlap spectrum from 50 to 110 GHz, engineers today can choose between coaxial or waveguide interfaces; however, above 110 GHz is almost exclusively the domain of waveguide (primarily related to the short wavelengths). Engineers are most familiar with the popular coaxial interface for device characterization tasks where broadband sweeps are necessary, including DC for biasing active devices. The well-known cut-off frequency of the coaxial lines (for TE waveguide mode) is calculated from the difference between the inner and outer diameter dimensions. It is important to choose dimensions that will not support waveguide modes in the coax line since coaxial transmission depends on the TEM mode.

Beyond 110 GHz though, engineers will instead implement a banded waveguide interface where the aperture propagates the transmission without a center conductor. Similar to coaxial calculations, the narrow and broad wall dimensions set the boundaries for lower and upper cut-off frequencies (for TE_{10} operation). For any given waveguide dimension, the dominant TE_{10} mode is limited to approximately a 50 percent bandwidth.

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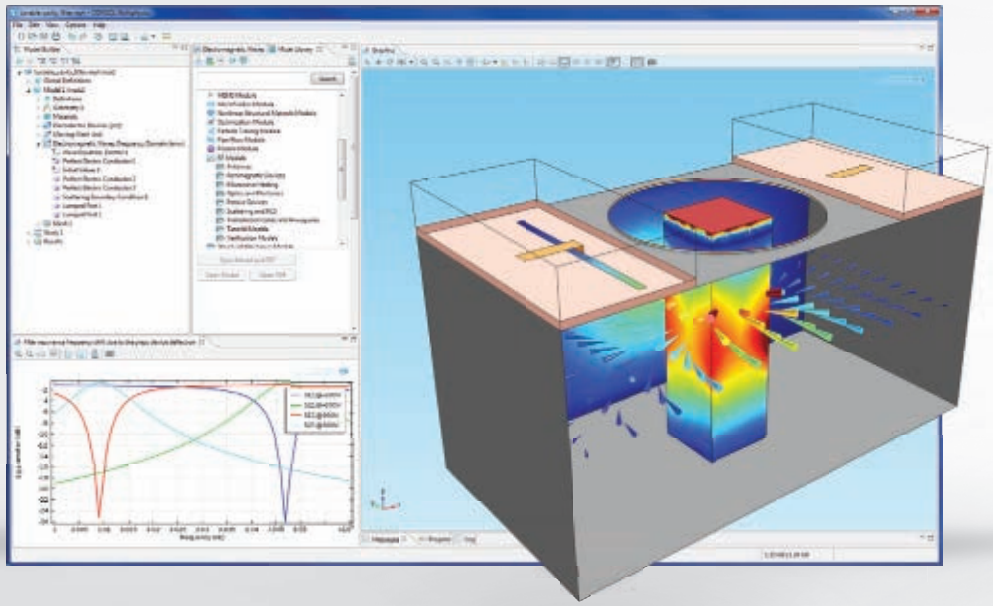

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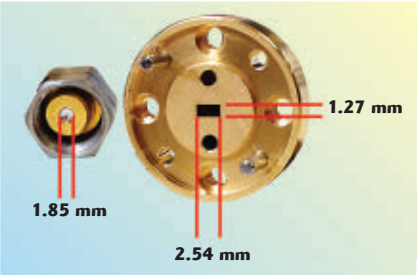


▲ *Fig. 2 Size comparison of 1.85 mm coaxial interface and WR-10 flange.*

This is not normally a handicap since transmission application bands are relatively narrow. As a visual example, ***Figure 2*** shows a side-by-side comparison between 1.85 mm coaxial (70 GHz, maximum) and WR-10 waveguide interfaces (75 to 110 GHz).

WAVEGUIDE FLANGE REFERENCE

Table 2 shows the popular rectangular waveguide bands and their respective cut-off frequencies and aperture dimensions. The table also contains a close-up aperture view for relative comparison purposes. As a rule of thumb, an engineer can quickly identify the WR number with a quick caliper measurement of the broad wall in mils (thousandths of an inch), divided by 10. For example, a broad wall measurement of 100 mils corresponds to WR-10.

WAVEGUIDE FLANGE TERMINOLOGIES

Similar to a coaxial connection, the two mating flanges utilize the outer permanent waveguide alignment pins/holes to align the apertures. The alignment pins cleverly alternate pin/hole match at the mating interface. For vector network analyzer calibration purposes, tightening the #4-40 flange screws with 15 in-oz of torque (± 1.5 in-oz) completes the connection for signal propagation. A damage threshold for deployed systems is a maximum torque of 5.5 in-lb for the #4-40 screw. It is important to note that any misalignment of the apertures, including normal waveguide irregularities, will create a mismatch and degrade the electrical performance.

MIL-DTL-3922/67D

An example waveguide connection is shown in ***Figure 3***. The outer waveguide pins and circular waveguide dimensions are traceable to the MIL-DTL-3922/67D (often called UG-387) standard that was defined in the 1960s to ensure radar interoperability. At that time, the flange technology was defined through 110 GHz (WR-10). In the physical layer sense, the craftsmanship of the flange is truly an amazing engineering and manufacturing achievement. Given no formal standard is in existence today beyond 110 GHz, industry has extrapolated the guiding principles in this venerable standard to flanges beyond 110 GHz with some modifications.

▲ *Fig. 3 Typical waveguide connection showing alignment pins.*

TABLE II

POPULAR MILLIMETER-WAVE RECTANGULAR TE_{10} WAVEGUIDE INTERFACES

Waveguide Spectrum	TE_{10} Cutoff Frequency (GHz)	Rectangular Waveguide Interface View	Internal Dimensions Width × Height (mils)	Internal Dimensions Width × Height (µm)
50-75 GHz WR-15 WM-3760	39.9 GHz		148 × 74	3760 × 1880
60-90 GHz WR-12 WM-3099	48.4 GHz		122 × 61	3099 × 1550
75-110 GHz WR-10 WM-2540	59 GHz		100 × 50	2540 × 1270
90-140 GHz WR-08 WM-2032	73.8 GHz		80 × 40	2032 × 1016
110-170 GHz WR-06 WM-1651	90.8 GHz		65 × 32.5	1651 × 825.5
140-220 GHz WR-05 WM-1295	115.7 GHz		51 × 25.5	1295 × 647.5
170-260 GHz WR-04 WM-1092	137.2 GHz		43 × 21.5	1092 × 546
220-325 GHz WR-03 WM-864	173.5 GHz		34 × 17.0	864 × 432
325-500 GHz WR-02.2 WM-570	263 GHz		22 × 11.0	570 × 285

FLANGE ALIGNMENT LIMITATIONS

More than a decade ago, mm-wave pioneers began sharing test data and analyzing fundamental limitations in the waveguide flanges complying with the MIL-DTL-3922/67D standard.[6] These degradations are still noticeable today starting in WR-08 (90 to 140 GHz). As we approach THz applications, a better solution to accelerate exploration of the mm-wave frontier is necessary.

When the two flat surfaces of a flange make contact, the quality of the connection depends on the precise alignment of the aperture. In general, the ideal alignment creates the least amount of mismatch and undesirable signal reflections. A thorough analysis of alignment quality requires both two and three dimensional mastery of true position and tolerances.

As shown in ***Figure 4***, there is a potential for misalignment in terms of four main mechanisms (assumes flat face alignment): broad wall offset, narrow wall offset, rotational and diagonal. The most significant electrical degradation occurs with broad wall and narrow wall offsets. Furthermore, the electrical degradation in the interface quality is proportional to offset: larger offsets cause more degradation.

To verify flange compliance, engineers will typically use state-of-the-art

mechanical and optical inspection tools. These visual techniques will reveal true dimensions of a single flange; however, actual alignment of two flanges is more difficult to ascertain. Engineers can simulate the possible alignment quality from these visual measurements, but electrical performance is only "viewable" with S-parameter measurements that reveal the true alignment quality. These alignment compliance techniques will become more important as applications approach the THz range.

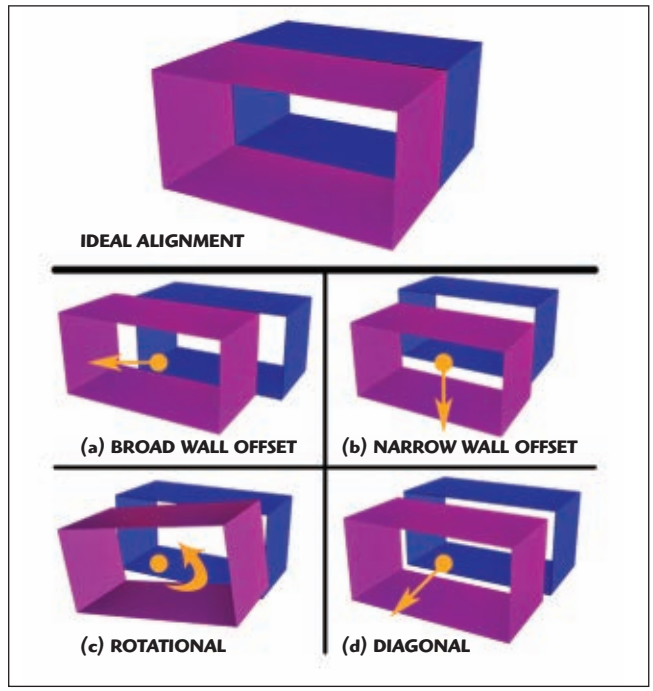


Fig. 4 Flange misalignment mechanisms.

TECHNOLOGY THAT IMPROVES FLANGE ALIGNMENT

At frequencies beyond 110 GHz, the coupling between waveguide flanges is a complex task requiring parallelism between front and rear faces along with dimensional precision in related machining activities. In practical terms, engineers need to avoid binding between pieces or worst-case, permanent damage. This binding scenario can happen when tolerances are too tight. Ideally, engineers want best electrical performance; therefore, avoidance of loose tolerances that adversely impacts alignment is a conflicting prerequisite. Finding a balance in terms of metrology, machining and manufacturing will ensure repeatable

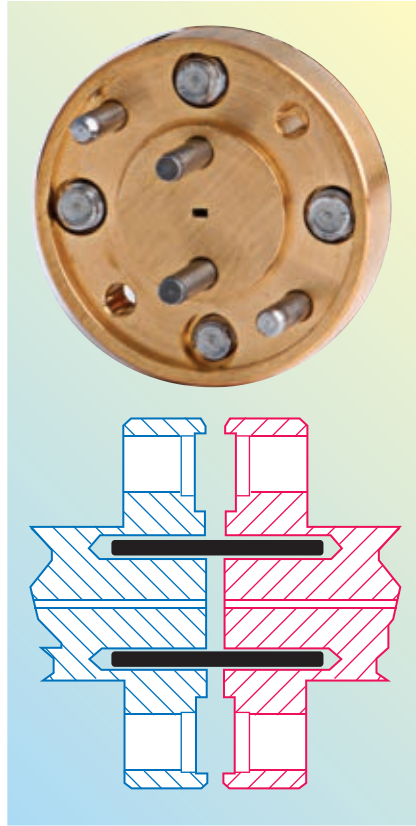


Fig. 5 WR-03 flange shows precision alignment pins and aperture alignment (side view).

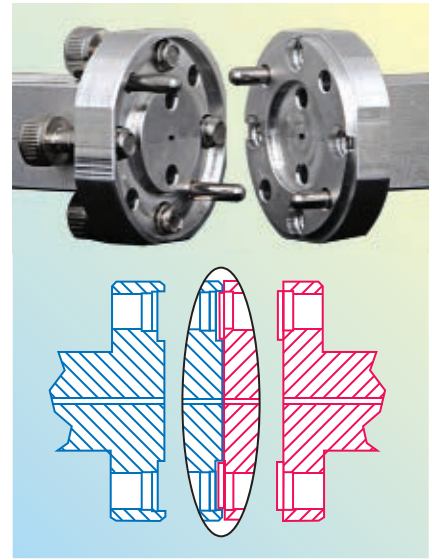


Fig. 6 WR-03 innovative boss and jack interface can improve aperture alignment when mating (side view).

and precise connections for applications beyond 110 GHz.

ANTI-COCKING

When initially coupling the two flanges together, the mating of the two faces is critical to avoid gaps. Cocking is the terminology given to the effect of the two mating surfaces not touching at all points. In the mating process, the captive waveguide screws are equally tightened, but uneven or over torque can cause cocking. To counteract uneven tightening, an outer ring is added to the flange as an anti-cocking feature to improve parallelism of the mating surfaces. This outer ring is visible in Figure 3. By adding a simple anti-cocking feature, superior flange-to-flange contact is possible, especially for alignment of the two flat faces in the uneven tightening scenario.

PRECISION ALIGNMENT PINS

With shorter wavelengths on the mm-wave frontier, misalignment becomes susceptible to the mechanical tolerances in manufacturing the flanges. For that reason, a modern improvement to the flange is, as shown in ***Figure 5***, the introduction of precision alignment dowel pins/holes both over and under the waveguide aperture. Compared to the conventional flange, the addition of dowel pins and precision holes improve upon the coarse tolerances from the outer permanent alignment pins/holes. Manufacturers typically promote this flange as a modified version of MIL-DTL-3922/67D to maintain backward compatibility with the original standard.

This remedy involves improving alignment with additional tighter

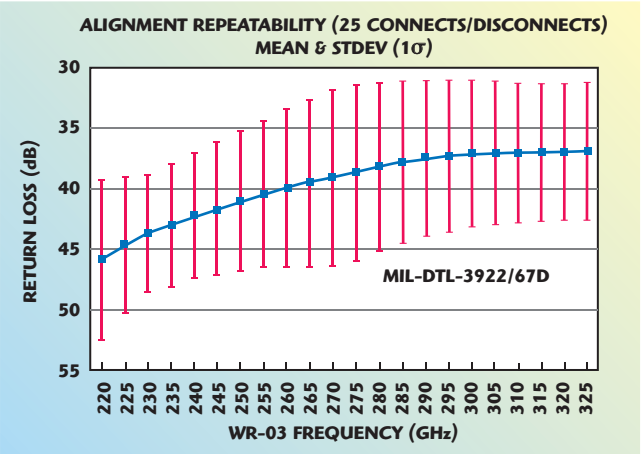


Fig. 7 Return loss comparison in WR-03 for three flange variants.

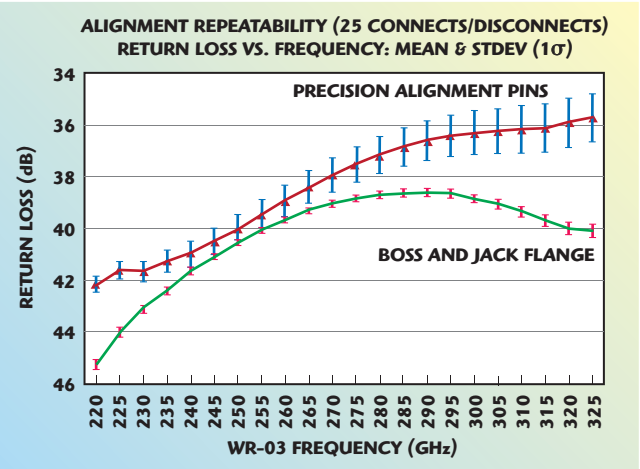


Fig. 8 Repeatability comparison in WR-03 for three flange variants.

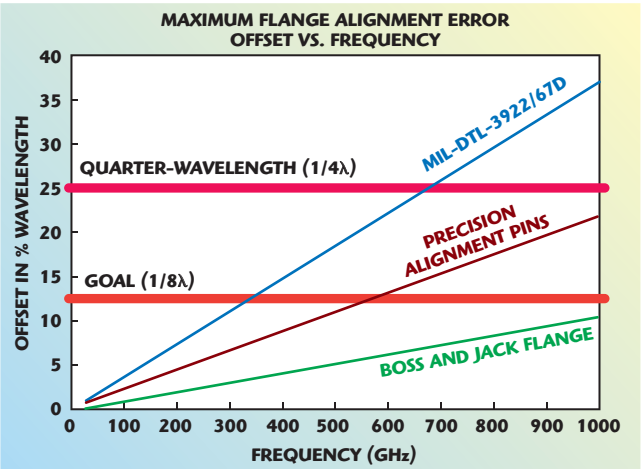


Fig. 9 Alignment comparison vs. mm-wave spectrum for three flange variants.

tolerance alignment pins/holes, but this approach fundamentally suffers from the build-up of three mechanical tolerances: waveguide interface #1, waveguide interface #2 and alignment dowel pins/holes (refer to Figure 5). The advantage of this approach is 100 percent compatibility with the existing MIL-DTL-3922/67D standard. The effort to standardize this flange variant involves finalizing precision alignment placement and tolerances.

BOSS AND JACK FLANGES

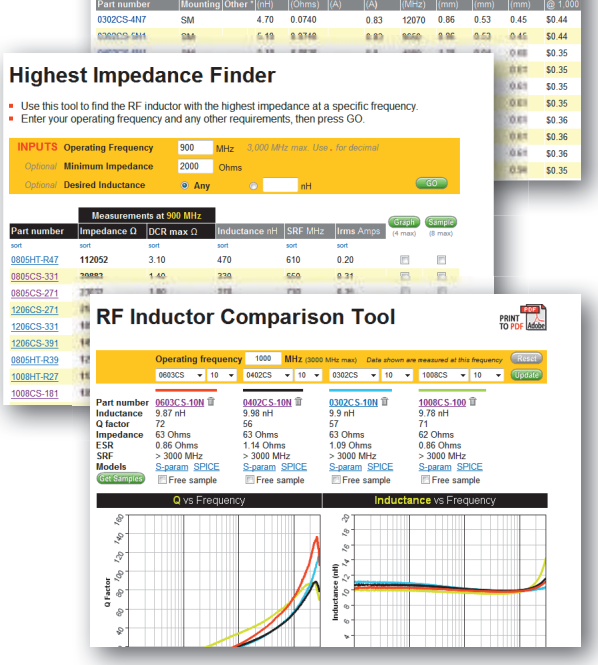
Other variants of flange interfaces are available, but generally speaking they fundamentally suffer from the build-up of three tolerances. One patented flange design from OML being considered overcomes this tolerance build-up limitation with an innovative interface.[7] In contrast to using precision alignment pins, this waveguide interface improves alignment by using a concentric mating mechanism consisting of a boss and jack interface (see ***Figure 6***). This design simplifies the tolerance build-up to just two interfaces by eliminating the need for alignment pins.

Using the boss and jack technology, the mating process simplifies to connecting one flange to the other using the permanent outer waveguide alignment pins/holes for coarse alignment and then the concentricity feature for final alignment. Precision pins are not necessary when using boss and jack as the alignment mechanism. Similar to other flange variants for calibration, tighten the flange screws with 15.5 in-oz of torque (± 1.5 in-oz) to complete the connection for signal propagation. For primarily compatibility purposes, precision pins are available in the boss and jack flange to support connecting to other flange variants. The outer waveguide pins control the rotational alignment, which is not a significant source of electrical degradation. The boss and jack technology is 100 percent compatible with the MIL-DTL-3922/67D standard.

FLANGE DESIGN COMPARISON

To evaluate the representative differences between the various mm-wave waveguide flanges, an experiment in WR-03 (220 to 325 GHz) was conducted on a single flange that incorporates the three main design elements: MIL-DTL-3922/67D, precision alignment pins and boss and jack variants.[8] In this experiment, a one-port short, offset-short, offset load (SS_oL_o) calibration is performed on each version using a mm-wave vector network analyzer system. To reveal the quality of the interface, return loss is measured using a gated time domain technique. In addition to precision, the evaluation of repeatability is possible by comparing results for 25 connect and disconnect sequences.

As a baseline in ***Figure 7***, the MIL-DTL-3922/67D flange exhibits poor return loss plus an undesirable inconsistency. In contrast, ***Figure 8*** shows the performance benefits of the alignment improvements from the other two flange variants. These results demonstrate that the precision alignment pins flange will improve on performance and repeatability; however, the boss and jack flange exhibits the best overall performance. In general, these results in the mm-wave bands are indicative of the improve-



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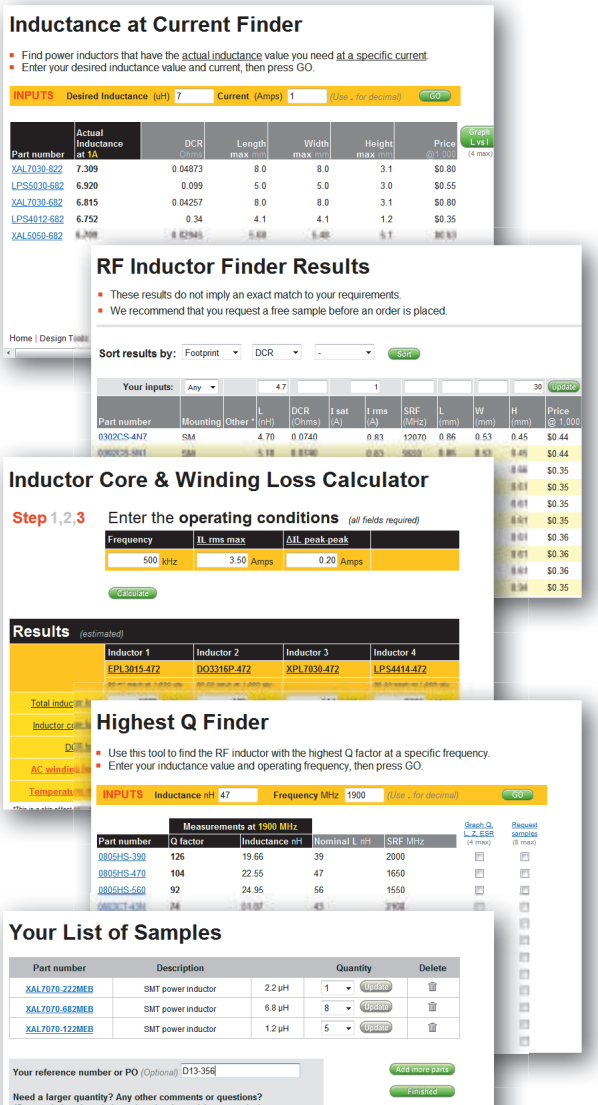

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ments that will soon become available from the standardization process.

In WR-03, the boss and jack flange demonstrates on average a 5 dB improvement in return loss characteristics due to the improved alignment. Using standard deviation as an indicator, the repeatability comparison shows an improvement of approximately 70 percent. The experiment using a single flange machined using ± 0.5 mil tolerances enables this comparison to extract a meaningful side-by-side comparison of the alignment benefits in WR-03. Scaling these flange design elements to lower frequencies with larger aperture dimensions will have proportionally lesser effects. Similarly, scaling these flange design elements to higher frequencies with smaller aperture dimensions will proportionally improve alignment performance. As this experiment demonstrates, the improvement in flange technology will create a solid foundation on which future measurements are more precise and repeatable.

WAVEGUIDE STANDARD ABOVE 110 GHz (IEEE P1785)

With all the mm-wave flange alignment improvements in circulation, the need for standardization is apparent. Above 110 GHz, there currently does not exist a standard for the interconnect interface. As previously described, the industry is working around this situation by maintaining backward compatibility with the existing 110 GHz standard (i.e., MIL-DTL-3922/67D) while adding additional alignment features to address precision and repeatability issues (e.g., alignment dowel pins). The industry goal of standardization, similar for coaxial measurements, is to build an ecosystem that encourages competition and produces correlation across many supplier configurations.

Beginning in 2008, the Microwave Theory and Techniques Society (MTT-S) of the IEEE has been defining a new rectangular waveguide interface standard in the P1785 Working Group.[9] This standard is organized into three main components. The first goal is to define the waveguide dimensions (by frequency band), including the transition to the metric system. The second goal, and perhaps most important task, is to complete a flange standard. The third goal is to define the framework for summarizing the performance and the expected uncertainty of the interfaces. These goals are similarly organized and intertwined with the existing MIL-DTL-3922/67D standard. This on-going standardization effort is currently celebrating its fifth anniversary since inception.

FLANGE STANDARD

The flange standard is one of the main focuses of the P1785 Working Group. In this labor-intensive process, industry experts evaluate compatibility criteria and the relationship between mechanical tolerances, alignment mechanisms and electrical performance. As previously noted, degradation typically becomes noticeable in WR-08 (90 to 140 GHz) and beyond; especially as multiple waveguide interfaces are often cascaded in the system signal path. As a practical consideration, the evaluation also requires an analysis of available machining technology and its fundamental dimensional limitations.

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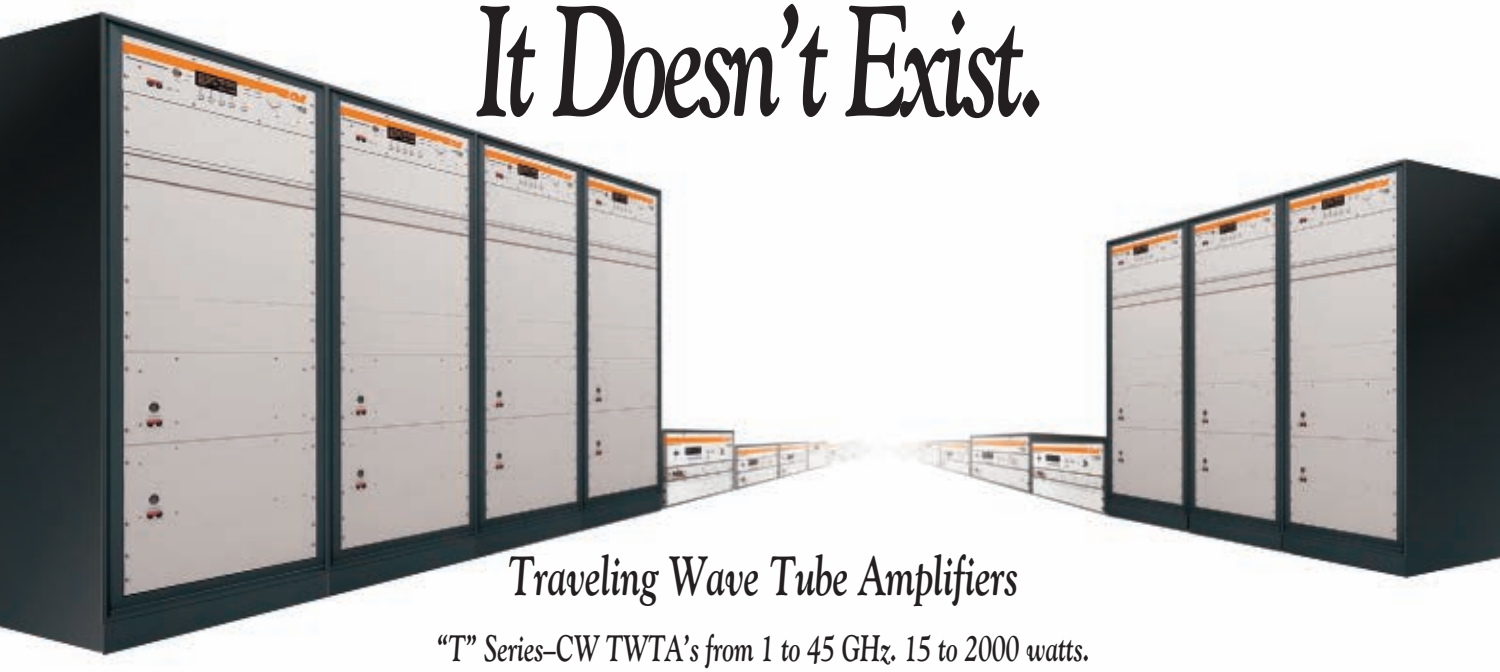

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SCALING TO MM-WAVE FREQUENCIES

More experimental results for the three flange variants are available for further analysis.[10] The P1785 Working Group is conducting additional experiments and extrapolating overall performance with respect to dimensional tolerances to consider how flanges will operate at even higher frequencies. As shown in ***Figure 9***, the three flange variants will predictably exhibit greater alignment errors as frequency increases.[11] This undesirable behavior is the primary motivation in defining the flange standard.

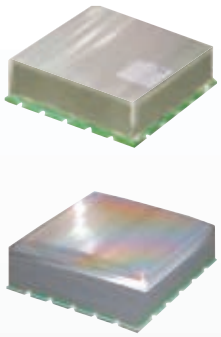
In the 325 to 500 GHz band, for example, the WR-02.2 (WM-570) waveguide has aperture dimensions of 22 × 11 mils (570 × 285 µm). On the vertical axis, the offset in percent-wavelength is plotted. For reference, quarter-wavelength (25 percent) is a natural limit to avoid due to the 180° phase shift (the impedance difference between short and open on the Smith Chart). Given this constraint, the practical goal is to limit alignment errors to below the eighth-wavelength threshold (12.5 percent). This goal implies that the MIL-DTL-3922/67D is not capable of repeatable and precise measurements beyond 325 GHz. In contrast, the boss and jack variant represents the flange with potential for the overall highest performance.

As the previous experimental results demonstrate, using a ±0.5 mil machine tolerance will produce measurable differences between the three flange variants. As another practical constraint, the current state-of-the-art machining capabilities are ±0.2 mil, which is also a flange standard consideration. For a 1 THz flange, the aperture dimensions are 10 × 5 mils so a ±0.5 mil machining tolerance converts into a 10 percent wavelength error for the boss and jack variant, which is perhaps an acceptable balance for convenience, performance and cost. Time will tell whether this practical approach becomes woven into the flange standard.

These examples illustrate the key takeaway that machining tolerances will determine overall electrical performance on the mm-wave frontier. The primary cause of degradation is due to narrow and broad wall offsets in the aperture alignment. The motivation to improve measurement precision and repeatability is fueling the efforts to release a standard as soon as possible to address this issue. To date, the boss and jack approach, with the least amount of tolerance build-up, has been shown to offer the best alignment performance in the flange interface. These superior alignment techniques and subsequent electrical performance will scale to other mm-wave and sub-mm-wave bands.

UPDATE ON STANDARDIZATION PROCESS

After five years of investment, the P1785 Working Group is on the verge of releasing standards. As an update, the frequency band and waveguide dimensions activity is nearly complete, including the conversion to the metric system. In addition, the protocols and criteria for evaluating flanges are nearing completion. This effort is particularly labor intensive with experts



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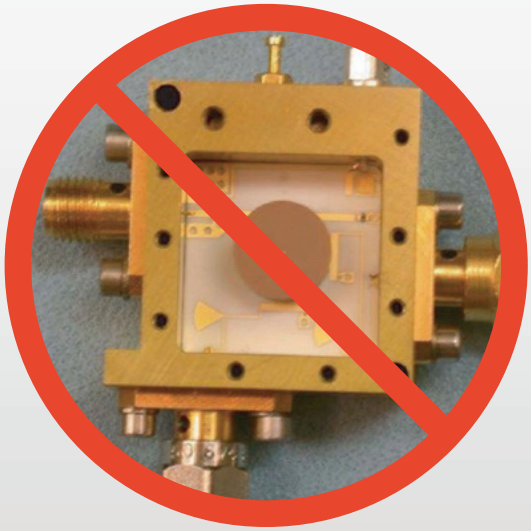

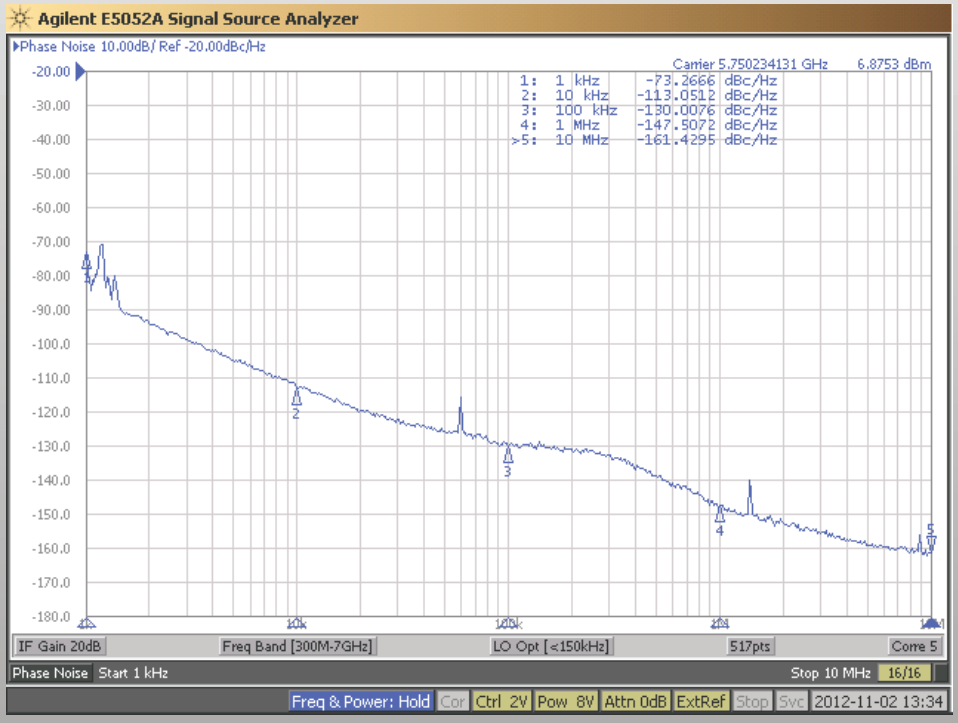

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evaluating compatibility, mechanical tolerance, electrical performance (both simulated and measured) and uncertainties. Lastly, the recommendations for summarizing the performance and expected uncertainties are also undergoing review. These three main activities are correlated so release depends on thorough analysis.

The industry goal of standardization will help build an ecosystem that encourages competition and produces correlation across many supplier configurations. At first glance, this progress may seem slow, but this proven IEEE methodology grants vital industry participation in the standardization process. Once completed, measurements will no longer depend on a sole supplier. Instead, a metrology standard for traceable measurements will encourage competition so mm-wave growth can accelerate. Indeed, the future of mm-wave innovation is about to become much brighter as we journey beyond the current frontier.

CONCLUSION

Pioneers have identified some key hurdles in exploring the mm-wave frontier. This article attempts to explore the answers to three important questions: why, what and how. As a first step, the commercialization process and ecosystem growth depends on the development and deployment of standards that ensure measurement precision and repeatability, irrespective of individual suppliers. At the physical layer, a solid foundation begins with the waveguide flange.

There are formidable engineering challenges to overcome, but the P1785 Working Group is close to releasing standards. Its effort will address measurement inconsistencies due to waveguide flange alignment, including machining tolerances and natural irregularities in the waveguide interface. With a physical layer standard for connection, engineers can focus on innovation and discoveries instead of the cause for inconsistency, incompatibility and inaccuracies in their measurement tasks. In this way, the mm-wave ecosystem can continue to evolve along with the deployment of exciting new mm-wave applications. ■

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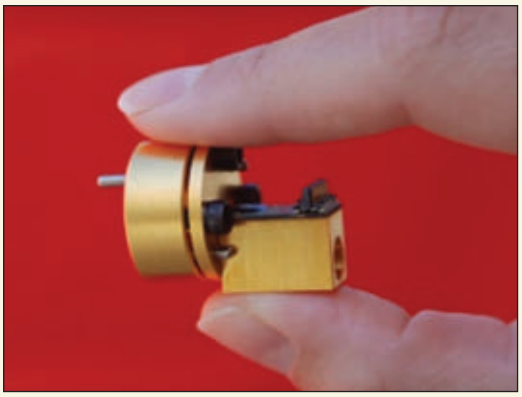

60 GHz Integrated Waveguide Transceivers

In most countries, the 60 GHz band is allocated for unlicensed use with up to 7 GHz of bandwidth (57 to 64 GHz in the U.S. and Korea, and 57 to 66 GHz in Japan and Europe, as examples). This is 7 to 9 GHz of spectrum for use in unlicensed applications. As a point of comparison, the 2.4 GHz unlicensed band in the U.S. is 83.5 MHz wide (on the order of 1 percent of the bandwidth available at 60 GHz). The applications that can be supported by such wide bandwidths are multi-gigabit communications for backhaul links, high definition uncompressed video transmission and high resolution radar systems, to name a few.

Integrated circuits (IC) are now available that can operate up through the 60 GHz millimeter-wave spectrum. Typical RF ICs that operate at the lower frequencies can be built into standard IC packaging such as SOIC, QFN and TSSOP. As the frequency of operation increases and into the realm of millimeter waves above 30 GHz, the problems of bond wire self and mutual inductance, parasitic capacitance and PCB trace parasitics start to dominate and limit performance. In order to provide useable components at millimeter waves, some vendors provide a built-in antenna, such as a patch antenna, that is directly connected with very short traces to the IC die pads in order to reduce the parasitic effects. In order to reduce the parasitic lead effects, flip-chip mounting technology is also used.

The problem of getting 60 GHz energy on and off the die is not trivial, and special consideration must be given to creating efficient designs that can facilitate easy development at the component level. Since the antennas that are typically used in fully packaged solutions are small and fairly low-gain with associated wide beam patterns, the resulting operating distance that can be achieved is quite short (on the order of 10 m or less). These compact, short range antennas work fine for applications such as indoor wireless links, small radar sensors or even as high-bandwidth versions of near-field communications. But many applications require longer range requiring highly directional, larger aperture antennas. High-gain antennas significantly increase operating range while reducing multipath and interference.

The most efficient method for interconnecting or coupling a variety of different millimeter-wave antennas is to use industry standard waveguide flange couplings. For the 60 GHz band, the EIA designated waveguide size is WR15 (which covers 50 to 75 GHz), and the standard flange is designated as the UG-385/U. 60 GHz research-

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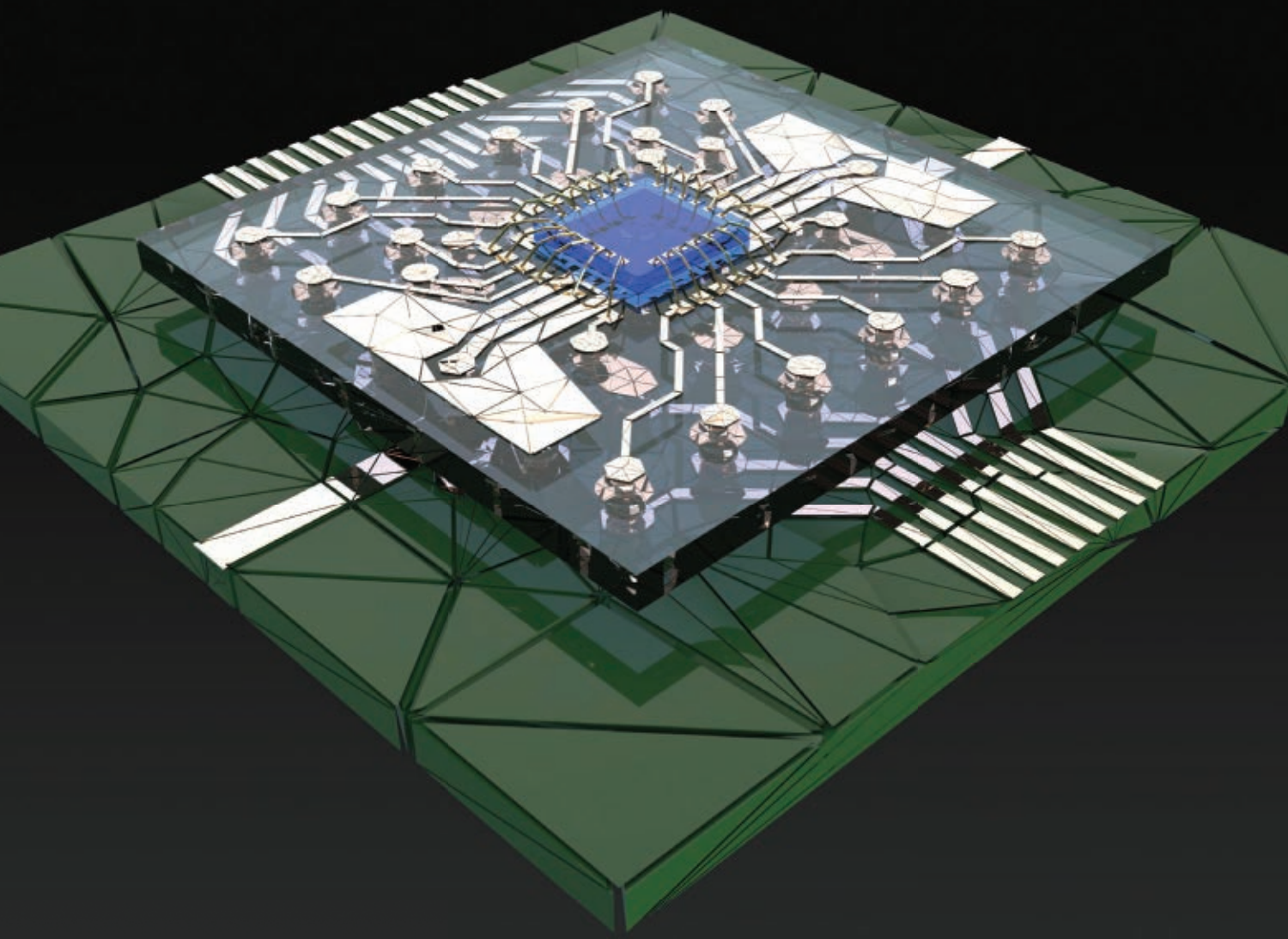

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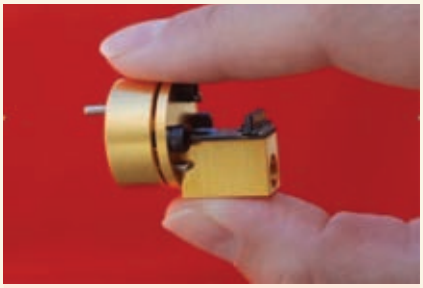
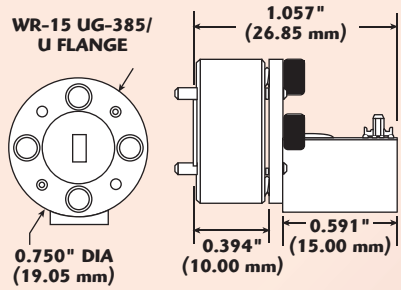
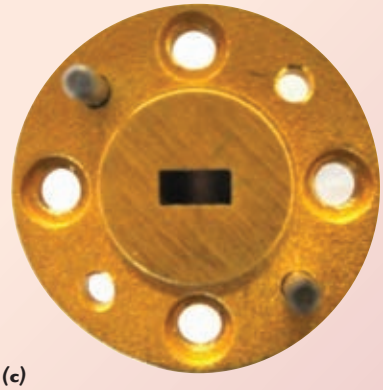


(a)



(b)



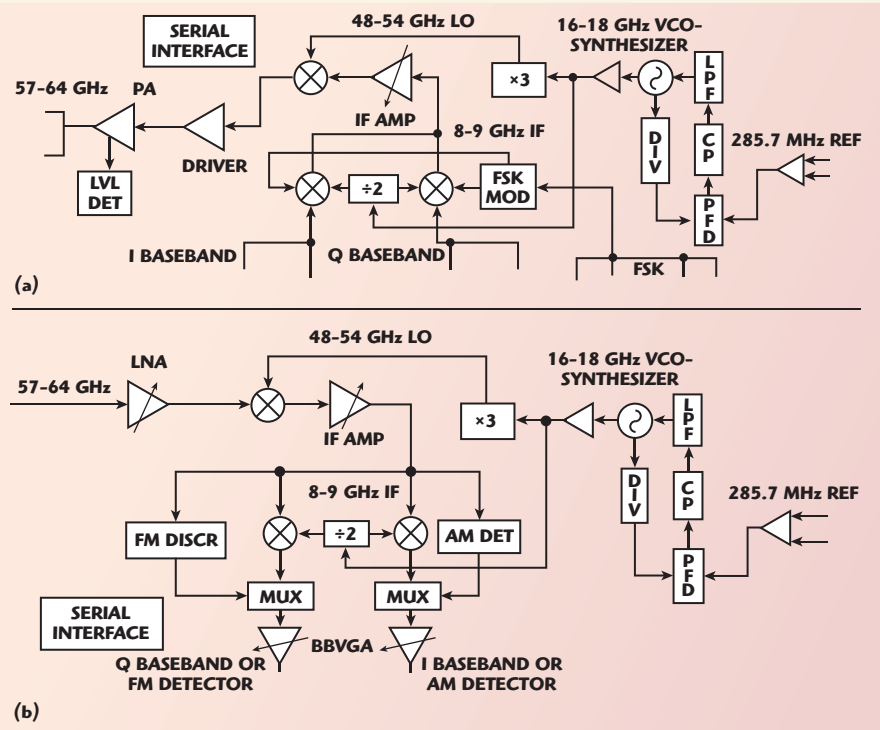
(c)

▲ *Fig. 1 Vubiq waveguide module (a), dimensions (b) and flange close up (c).*

ers and developers need to connect external antennas, of any arbitrary size and gain, to the RF front end of the system. Efficiently coupling the signals at these frequencies into and out of the waveguide port from an integrated circuit is a challenge. There are vendors that have successfully built MMIC type amplifiers, mixers and other separate millimeter-wave functions using ceramic substrates packaged in precision machined waveguide block type assemblies. These blocks are good for basic research in a laboratory environment, but not for an integrated and low-cost solution intended for commercial product development.

LOW COST WAVEGUIDE MODULE

To answer the need for easily attaching a variety of antennas to low cost integrated 60 GHz transmitters and receivers, Vubiq Inc. introduced its 60 GHz waveguide modules, the V60TXWG2 transmitter and V60RXWG2 receiver. ***Figure 1*** shows a photo and a dimensional drawing



▲ *Fig. 2 V60TXWG2 transmitter block diagram (a) and V60RXWG2 receiver block diagram (b).*

of the Vubiq waveguide module.

The waveguide module design incorporates a simple low frequency I/O connector (Samtec ST4) for interfacing the required voltages, reference clock and modulation signals (up to 2 GHz response). The modules incorporate SiGe BiCMOS radio chips with the ability to produce +12 dBm P1dB transmit output power, 6 dB receive noise figure and take up less than one cubic inch (<16 cm^3) of total volume. The on-chip synthesizer produces RF carrier frequencies from 56.5 GHz up through 64 GHz in 500 MHz channel step increments. The transmitter up-converts I and Q input signals in the form of analog baseband capable of up to 1.5 GHz modulation bandwidth. The receiver down-converts from 60 GHz to analog baseband I and Q signal outputs. In addition, the receiver incorporates selectable AM and FM detectors. See ***Figure 2*** for the transmitter and receiver IC block diagrams. The Vubiq waveguide module design exhibits very low loss and is a connectorized module with DC and modulation signals applied at the input signal connector, with modulated 60 GHz energy produced at the output waveguide flange.

Figure 3 shows the return loss and insertion loss modeled from the actual IC die output pads to the waveguide flange port. Less than 1 dB loss is incurred in the module across the band from 57 through 66 GHz. Careful design, modeling and design for manufacturing (DFM) were applied throughout the process of creating these modules. The result is a set of high performance 60 GHz transmitter and receiver modules that are designed for high-volume production.

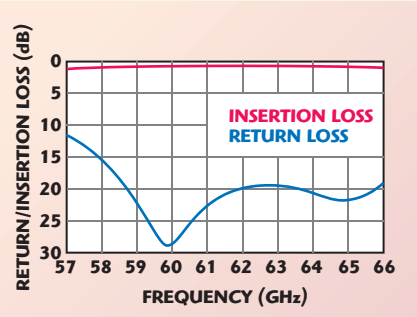


Fig. 3 Waveguide module insertion loss and return loss across the 60 GHz band.

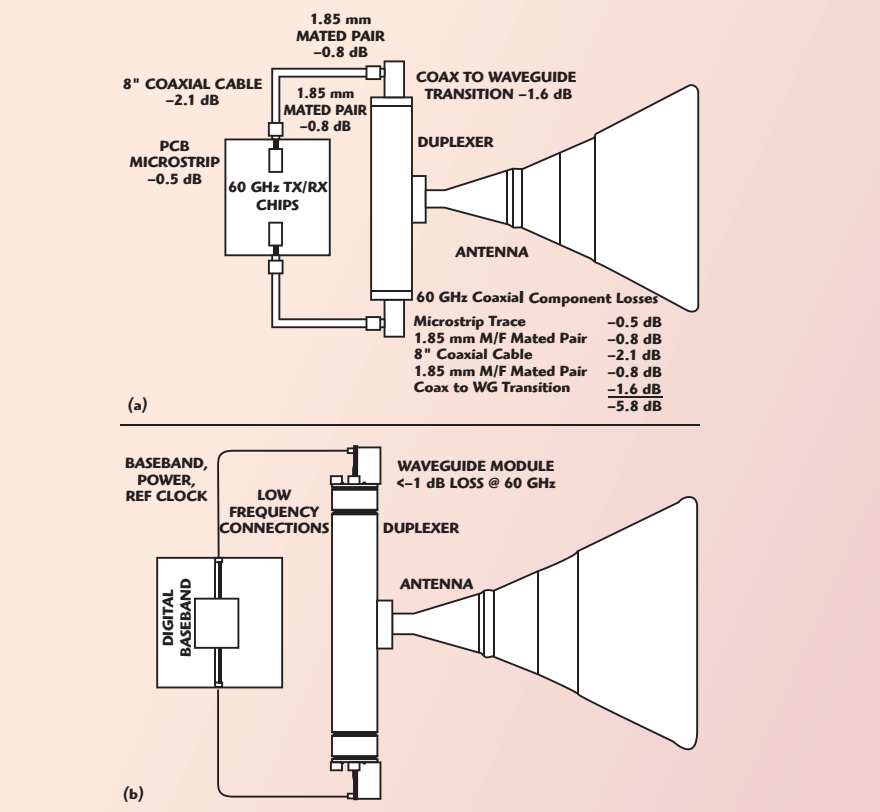


Fig. 4 Typical loss values of coaxial components (a) and waveguide module (b) in a 60 GHz backhaul link.

A COMPARISON: COAX VERSUS WAVEGUIDE AT 60 GHz

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signal-to-noise ratio in communications systems. At 60 GHz in particular, oxygen absorption adds specific attenuation at 15 dB/km (at sea level) to the traditional free space loss equation. For point-to-point links, every dB counts to work over the longer ranges required in applications such as high-bandwidth gigabit backhaul.

As a general comparison, coaxial connectors, transmission line and coax-to-waveguide transition components exhibit significant losses and are expensive. The types of coaxial connectors that are used up to 67 GHz are the 1.85 mm threaded "V" connector and the newer MMPX series, which is an unthreaded snap connector. A quick analysis shows that using a coaxial transmission line can add 5 to 6 dB of additional losses at each end of a link, totaling to more than 10 dB of additional link budget loss as compared with the waveguide approach. ***Figure 4a*** illustrates the loss build up for a coaxial component design of a full duplex link at 60 GHz for backhaul applications. The total additive losses for the link are in excess of 10 dB, which would be equivalent to losing half the range capability for a typical 300 meter link.

The Vubiq waveguide module brings the source of the 60 GHz energy directly to the waveguide aperture which translates to significantly reduced losses at the system level. ***Figure 4b*** shows how the interconnections between the digital baseband board and the millimeter-wave front-end waveguide module of a full duplex link terminal are limited to the lower frequency baseband signals, power and reference clock and

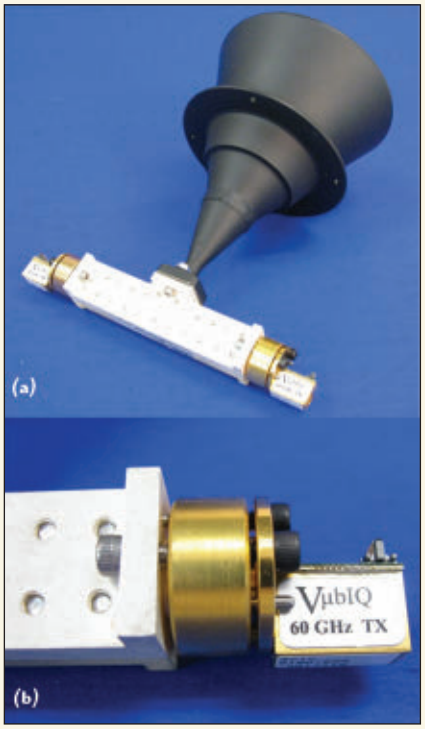
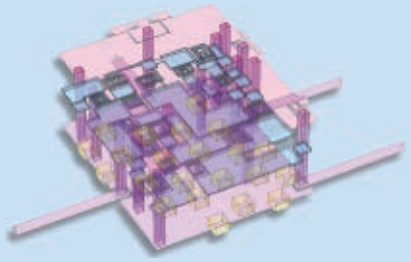
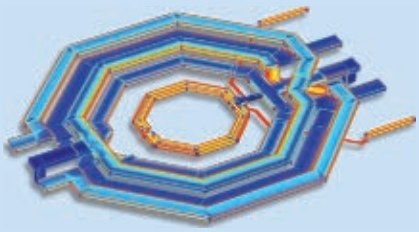
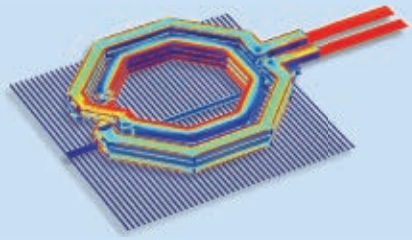


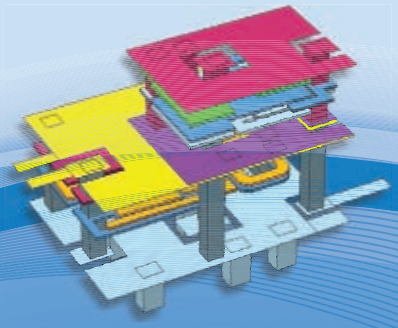
Fig. 5 Waveguide modules with duplexer/antenna (a) and close up of the TX module (b).

Fig. 6 V60WGD02 development system.









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do not include more complex RF interconnections. The loss incurred at 60 GHz in this approach is exactly the loss of the waveguide module which is less than 1 dB.

In ***Figure 5a***, a full duplex RF front end is shown with a waveguide transmitter module, waveguide receiver module, a wideband duplexer and a 35 dBi horn antenna. This arrangement is designed for use in a full duplex, gigabit Ethernet link with greater than a 500 meter range at 1.25 Gbps. ***Figure 5b*** shows a close up of the transmitter module interfaced to the WR15 flange of the duplexer.

DEVELOPMENT SYSTEM FOR QUICKLY GETTING ON THE AIR

The waveguide modules are controlled via a Serial Peripheral Interface (SPI) port. Users who want to have a fast, out-of-the-box experience for getting 60 GHz on the air in minutes can also obtain the Vubiq Development System (V60WGD02 – see ***Figure 6***) that provides a USB powered interface set of boards and a simple software control GUI that allows for easy setup in the lab.

The TX and RX boards in the development system provide power supply regulation, reference clock generation and a USB to SPI interface to the waveguide modules. Each board has MCX coaxial connectors for easy interfacing to analog baseband signals. Each board contains a low phase noise reference clock (285.7 MHz) but can also use an external reference source for phase locking the TX and RX together if desired.

The aperture produces a pattern equivalent to about a 7 dBi gain antenna, which is approximately a 70 degree wide beam pattern. Bench top testing of various modulation schemes and bit rates can be done in this manner with easy TX to RX alignment since the patterns are so wide. For longer range testing, a directional gain antenna significantly increases the gain. Directional adjustment is made at the tripod head for pointing.

The control GUI that comes with the system is a graphical, easy-to-use screen for completely setting up the transmitter and receiver functions. The GUI screen also provides monitoring of synthesizer lock, module and board temperatures, and power supply voltages.

The future of millimeter-wave technology is accelerating into the present by the introduction of highly integrated silicon that can operate into the spectrum above 30 GHz. With the standards bodies and regulatory agencies promoting the latest technologies for millimeter-wave operation, in particular the unprecedented global bandwidth available for unlicensed operation at 60 GHz, the future of broadband wireless networking is well in hand. High performance must be matched with low cost, practical components for the 60 GHz band – and Vubiq is playing a vital role in providing much needed components and engineering development systems.

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OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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AEHF Team Completes Major Integration Milestone Ahead of Schedule

The U.S. Air Force and Lockheed Martin have integrated the system module for the fourth Advanced Extremely High Frequency (AEHF) satellite six months ahead of schedule. The milestone marks the completion of the first major phase in the satellite's assembly. Integration and test are key indicators that Lockheed Martin and the Air Force are successfully streamlining processes to achieve affordability goals.

AEHF, the next generation of protected military satellite communications satellites, provides vastly improved global, survivable, highly secure, protected communications for strategic command and tactical warfighters operating on ground, sea and air platforms. The system also serves international partners including Canada, the Netherlands and the United Kingdom.

The AEHF-4 system module includes the satellite's payload structure module and electronic components that are critical to controlling its communications payload and ensuring the satellite's health and safety throughout its on orbit mission life. The AEHF payload provider, Northrop Grumman, will now integrate the satellite's advanced communications payload with its system module. The fully integrated system module will then be returned to Lockheed Martin's Sunnyvale, CA facility for final satellite integration and test.

"We look forward to integrating the advanced communications payload and ultimately delivering this satellite in support of strategic and tactical protected communications users worldwide," said Col. Rod Miller, the U.S. Air Force's AEHF program manager.

Lockheed Martin is currently under contract to deliver four AEHF satellites and the Mission Control Segment. The program has begun advanced procurement of long-lead components for the fifth and sixth AEHF satellites. AEHF-1 and AEHF-2 have both launched and are in orbit. Lockheed Martin has completed work on AEHF-3 and is now preparing the satellite for a September 2013 launch date.

Source: Lockheed Martin

Northrop Grumman Awarded U.S. Army Global Tactical Advanced Communications Systems

Northrop Grumman Corp. has been awarded the Global Tactical Advanced Communications Systems and Services contract from the U.S. Army Program Executive Office Command, Control and Communications-Tactical (PEO C3T). The award enables Northrop Grumman to compete for task orders under the five-year, multiple-award, indefinite delivery, indefinite quantity (ID/IQ) contract, which has a total value of $10 billion. Northrop Grumman is one of 20 companies that were selected for this contract.

Contractors on the program will bid on task orders to provide tactical command, control and communications (C3) systems hardware, software, engineering and logistics that support the networked battle command needs of the warfighter.

"Northrop Grumman has been supporting PEO C3T since the late 1980s and we are proud of our record as a reliable partner able to respond rapidly to customer requirements."

"Northrop Grumman has been supporting PEO C3T since the late 1980s and we are proud of our record as a reliable partner able to respond rapidly to customer requirements," said Kevin Sculley, vice president of integrated mission systems, Northrop Grumman Information Systems. "We have demonstrated our ability to manage large ID/IQ contracts and to provide innovative and affordable C3 solutions – qualities we will apply to this program."

Raytheon Awarded $254 M for Tomahawk Missile

The U.S. Navy awarded Raytheon Co. a $254.6 million contract to procure Tomahawk Block IV tactical cruise missiles for fiscal year 2013. The contract calls for Raytheon to build and deliver Tomahawk Block IV cruise missiles, conduct flight tests and provide life-cycle support. Production and delivery of the missiles are scheduled to begin in 2013.

"Tomahawk Block IV enables the warfighter to precisely engage heavily defended and high-value targets from extremely long distances, which is critical to maintaining national security," said Capt. Joe Mauser, U.S. Navy Tomahawk program manager. "With more than 2000 combat missions and 500 successful tests com-

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A major enhancement to the Tomahawk Block IV missile includes a two-way satellite data-link that enables a strike controller to redirect the missile…

pleted, Tomahawk has proven its outstanding reliability and effectiveness."

A major enhancement to the Tomahawk Block IV missile includes a two-way satellite data-link that enables a strike controller to redirect the missile in-flight to pre-programmed alternate targets or more critical targets.

"Tomahawk has an excellent record of reliability, effectiveness and accuracy. No other tactical cruise missile in the world can come close to matching it," said Harry Schulte, vice president of Air Warfare Systems for Raytheon Missile Systems. "This missile provides unparalleled capability and has greatly contributed to the security of our country and our allies."

Raytheon UK Wins First Contract for New Lightweight GPS Anti-Jam Capability

Raytheon UK has been awarded a significant contract by the UK Ministry of Defense for delivery of a new GPS Anti-Jam Antenna System. The contract is for an undisclosed number of advanced systems for deployment in operational theaters spanning multiple vehicle platforms. This urgent operational requirement (UOR) contract is the first award for Raytheon's GPS Anti-Jam (AJ) Land product family.

Bob Delorge, chief executive, Raytheon UK, commented, "Raytheon UK has a track record of on-time delivery for GPS AJ systems, having delivered over 7000 units for air and naval capabilities in the UK and U.S. Many of the military platforms used in operations are protected by the proven Raytheon GPS anti-jam technology and the first order for our Land GPS AJ product family marks a significant success."

The contract will see the deployment of the systems under a very short timescale, with final delivery of the capability expected to be completed six months from the contract award.

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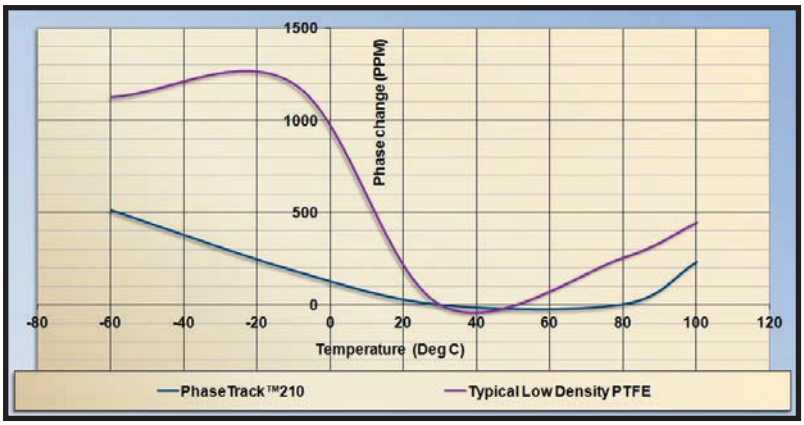

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GSA Confirms LTE is Mainstream

The Evolution to LTE Report (January 8, 2013) produced by the Global mobile Suppliers Association (GSA) confirms that 145 operators have launched commercial services in 66 countries. According to the report, 97 networks were commercially launched during 2012 and LTE-enabled mobile broadband services are available in 37 more countries than 12 months ago. One hundred and four new operators committed over the past year to investing in LTE network deployments, raising the total number of committed operators to 330 in 104 countries and the GSA forecasts that 234 LTE networks will be commercially launched in 83 countries by the end of 2013.

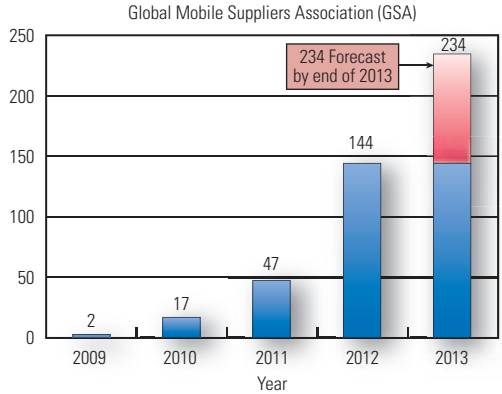
Alan Hadden, president of the GSA, said: "With 145 LTE networks commercially launched and over 560 user devices announced in the market supporting millions of customers worldwide, LTE technology is mainstream and firmly established as the fastest developing mobile system technology ever."

The majority of network deployments use the FDD mode of the LTE standard, operating in paired spectrum. 1800 MHz (3GPP band 3) has emerged as the dominant band for LTE network deployments in virtually all regions of the world. The report confirms that 58 operators, i.e., 40 percent of all commercial LTE operators, use 1800 MHz spectrum either as a single band system, or as part of a multi-band deployment, in 39 countries. At least another 22 LTE1800 network deployments are in progress in the Asia Pacific region, Europe, the Middle East, Africa and Latin America.

The second most popular band in which LTE systems are deployed is 2.6 GHz (band 7). The TDD mode of the LTE standard has also gained strong traction and interest across the world. A total of 13 operators have launched commercial services using LTE TDD, which is the optimal solution for use in unpaired spectrum. Six TDD systems are deployed in band 38 (2.6 GHz), five systems are in band 40 (2.3 GHz) and there is one deployment each in band 41 (2.5 GHz) and bands 42/43 (3.5 GHz).

Commercial LTE Network Launches Cumulative Totals

Global Mobile Suppliers Association (GSA)



Source of Data: GSA Evolution to LTE report – January 8, 2013 www.gsacom.com

New Partnership to Support UK Defence Industry

The Defence Growth Partnership (DGP) is a new partnership between industry and government. The UK government, working closely with industry, is determined to support the sector and already plays a leading role in promoting defence exports and encouraging defence SMEs. The DGP will continue this work but will also look at how links between civil and military technologies can be better exploited. In addition, it will look at the skills required for the sector and how there can be more flexibility in the workforce between the defence sector and advanced manufacturers.

The UK's defence industry is a significant contributor to the UK's economy, contributing more than £22 billion of annual revenues, of which £5.4 billion is from exports. It directly employs more than 107,000 people.

UK business minister Michael Fallon said, "The UK's defence sector is world class – employing the latest technology and advanced engineering to products relied upon by armed forces around the world. In doing so, it provides many thousands of highly skilled jobs in the UK and is an important part of the nation's industrial base. Along with other parts of the economy, the sector is facing tough times. This new partnership between government and industry will help address the barriers to growth for the sector."

"The MoD has active engagement with the defence industry which faces testing times as defence budgets come under pressure across the world."

UK minister for defence equipment, support and technology Philip Dunne commented, "The MoD has active engagement with the defence industry which faces testing times as defence budgets come under pressure across the world. It is important for government and business to understand each other and work together. The Defence Growth Partnership will help us to confront these challenges and build on existing relationships and industry successes to date – helping the UK defence industry maintain its position as the world's second largest exporter of new defence products and services."

Cisco and NXP Invest in Cohda Wireless to Enable the Connected Car

Cisco and NXP Semiconductors have each made an investment in Cohda Wireless to advance intelligent transportation systems (ITS) and car-to-X communications. The investment brings together the expertise of the three organizations to make the Internet of Everything

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a reality for the automotive industry, creating a safer and more enjoyable driving experience while improving the traffic flow.

Car-to-car (C2C) and car-to-infrastructure (C2I) communications enable active safety systems and C2I communication holds great potential for ITS management and reducing greenhouse gas emissions from vehicles. C2C and C2I communications require highly reliable and secure data exchange between fast moving vehicles and infrastructure in a range of conditions.

…make the Internet of Everything a reality for the automotive industry…

NXP and Cohda Wireless have built a market-ready, flexible wireless communication solution for onboard-units based on Cohda's existing advanced radio and NXP's market-proven software-defined radio technology. This makes it a key element to connect to Cisco's vision of a ubiquitous and highly-secure Internet of Everything. Onboard and road side units developed using technologies from the three companies have been tested to global standards in major field trials.

The three companies will apply their collective expertise and technologies to help automotive OEMs, suppliers, enterprises and consumers to connect vehicles with ITS infrastructure. This will be spearheaded by producing the first automotive-qualified IEEE 802.11p products for on-board and road side units that are ready for C2C and C2I deployments across the globe.

EURIPIDES Announces 2013 Spring Call

EURIPIDES, the EUREKA cluster for smart systems and electronic systems integrated in packaging, launched its 2013 Spring Call for project proposals. A first project outline is to be presented by February 26, 2013, while the deadline for the submission of full project proposals by potential participants is May 16, 2013.

Along with CATRENE, ITEA2 and Celtic+, EURIPIDES is one of the four EUREKA clusters in information and communication technologies (ICT). The markets that the Spring Call addresses include communication, automotive industry, aeronautics, secure societies, advanced manufacturing, health (medical) and green energy.

EURIPIDES launches two calls per year in order to facilitate the application process for potential partners in a project and grants access to public funding for successful applicants. All 40 EUREKA member countries and associated countries can financially support EURIPIDES projects. Partners are funded directly by their respective governments, according to national procedures.

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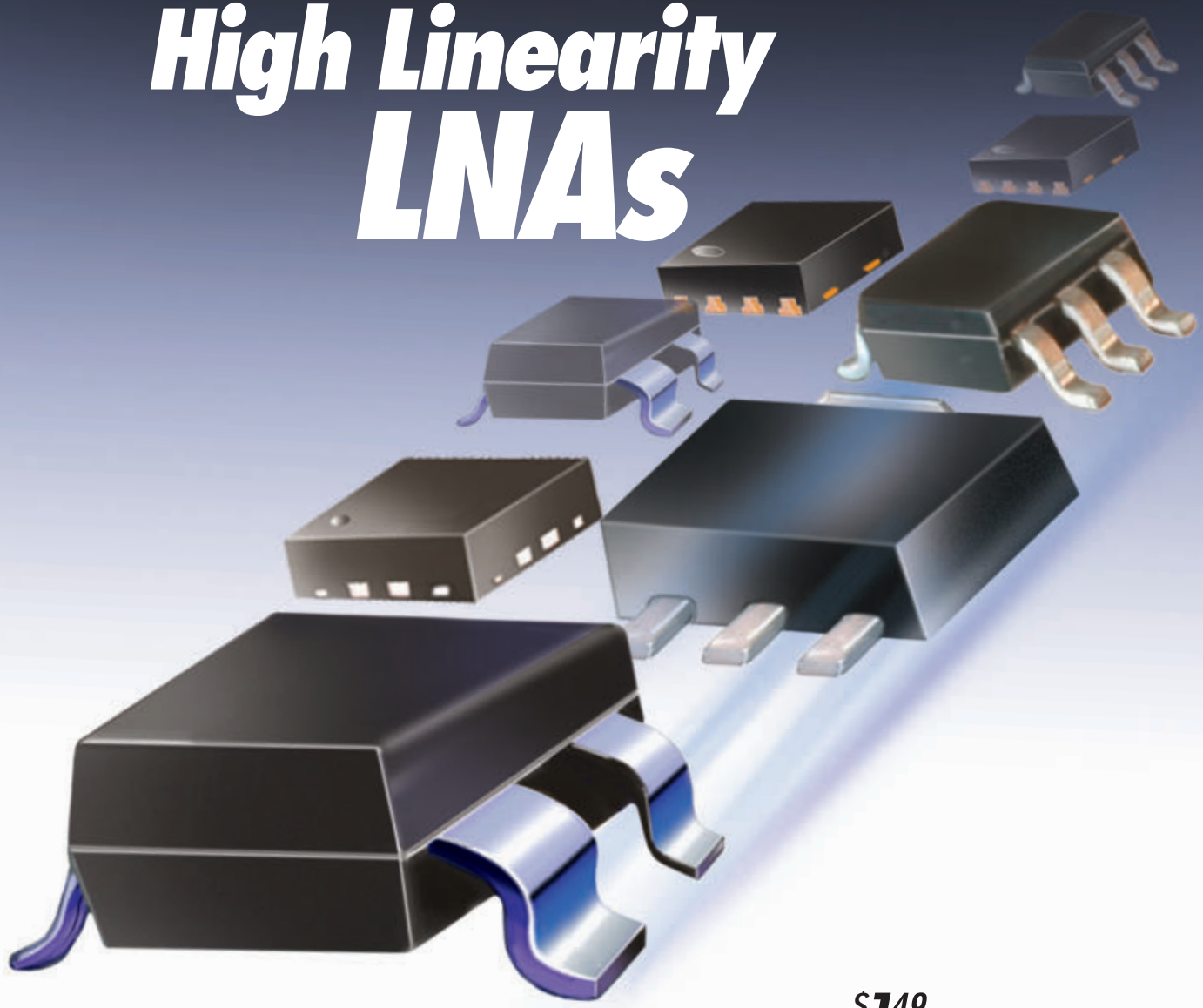

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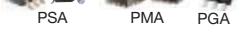
PMA2-162LN+	700-1600	22.7	**0.5**	**30**	20	55	2.87
PMA-5452+	50-6000	14.0	**0.7**	**34**	18	40	1.49
PSA4-5043+	50-4000	18.4	**0.75**	**34**	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	**0.8**	**33**	19	40	1.49
PMA-5451+	50-6000	13.7	**0.8**	**31**	17	30	1.49
PMA2-252LN+	1500-2500	15-19	**0.8**	**30**	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	**0.9**	**33**	22	158	4.95
PMA-5454+	50-6000	13.5	**0.9**	**28**	15	20	1.49

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
PGA-103+	50-4000	11.0	**0.9**	**43**	22	60 (3V) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	**0.7**	**37**	20	60	1.49
PSA-5453+	50-4000	14.7	**1.0**	**37**	19	60	1.49
PMA-5456+	50-6000	14.4	**0.8**	**36**	22	60	1.49
PMA-545+	50-6000	14.2	**0.8**	**36**	20	80	1.49
PSA-545+	50-4000	14.9	**1.0**	**36**	20	80	1.49
PMA-545G1+	400-2200	31.3	**1.0**	**34**	22	158	4.95
PMA-545G2+	1100-1600	30.4	**1.0**	**34**	22	158	4.95
PSA-5455+	50-4000	14.4	**1.0**	**32**	19	40	1.49



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Worldwide Pay-TV Subscriber to Reach 907 Million

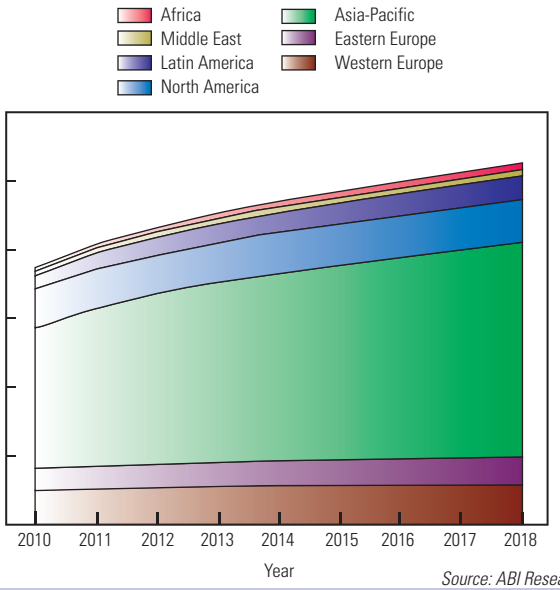
Global pay-TV market added nearly 47 million subscribers in 2012, reaching a total of 864 million subscribers. "The growth in satellite, cable and IPTV markets was strong, although digital terrestrial TV growth was flat in 2012. ABI Research expects that the pay-TV market will continue to grow in 2013 to reach 907 million subscribers," said Jake Saunders, VP and practice director of core forecasting.

Worldwide IPTV subscriber base has been increasing rapidly over the past few years. In 2013, the worldwide IPTV subscriber base is expected to add over 9 million subscribers to reach 79.3 million. More than half of the net addition will be from Asia-Pacific; China alone is expected to add more than 3 million subscribers.

The cable TV market will remain strong, especially due to the growth in Asian Pacific markets such as China and India. Cable TV will maintain the largest market share of the overall pay-TV market in 2013. However, rapidly growing IPTV will cause cable's market share to decline to 65.4 percent in 2013 from 66.2 percent in 2012.

At present, 33 percent of worldwide pay-TV subscribers are using High Definition (HD) TV services. HDTV penetration is the highest in North America followed by Western Europe; accounting for 84 percent and 76 percent of total pay-TV subscriptions respectively. As many of the countries in different regions are trying to switch over to digital transmission, the number of HD channels and packages offered by the operators increase. "Worldwide HD service adoption is expected to grow. ABI Research forecasts that 38 percent of global pay-TV subscribers will be subscribing to HDTV services in 2013," noted Khin Sandi Lynn, research analyst.

Pay-TV Subscribers by Geography
World Market, Forecast: 2010-2018



Source: ABI Research

An Estimated 103 Million 4G LTE Mobile Devices Shipped in 2012

Apple's iPhone 5 and Samsung's Galaxy smartphones have provided LTE-enabled handset shipments a substantial lift in 2012 – even if it has not necessarily assisted the 4G mobile operators with "each and every" LTE handset sold. When 3G handsets came into the market in 2003 and 2004, there was pretty much a 1:1 correlation between a 3G handset sold and a subscription upgraded from 2G to 3G. "That is not happening with every LTE handset sale," said Jake Saunders, VP of forecasting at ABI Research. "But carriers should not be panicking – it is seeding the market with 4G handsets. A number of purchasers are simply coveting their favorite 'brand' and/or carrying out a much needed update to one of their key fashion accessories."

All this purchasing momentum is expected to have boosted LTE-enabled handsets to 91 million units by YE-2012 and the balance coming from other mobile devices. Almost 95 percent of handsets shipped can be attributed to the North American and Asia-Pacific market. LTE USB dongles may have found their way under the Christmas tree for consumers and also put on IT Department Purchase Orders for businesses, but at 6 million units, it was overshadowed by LTE smartphone sales. Media tablet sales are proving robust. However ABI Research estimate only 3.35 million media tablets shipped with LTE since the majority of media tablet purchasers are proving price sensitive and happy to settle for Wi-Fi-only.

"New sign-ups and conversion of 3G subscribers with LTE-capable handsets should gather pace in 2013 and 2014. By 2017 we are anticipating 785 LTE million subscribers, up from 58 million at the end of 2012 – generating US$14 billion in annual service revenues," added Phil Solis, research director.

WiGig Alliance Endorses Publication of IEEE 802.11ad Standard

The Wireless Gigabit (WiGig) Alliance, which formally contributed to the IEEE 802.11ad standard process, has heralded its publication as a critical moment in bringing a global wireless ecosystem of interoperable, high performance devices that work together seamlessly.

"We congratulate IEEE and the WiGig member companies on the completion and publication of the 802.11ad standard and look forward to seeing its adoption across the industry," said Ali Sadri, president and chairman of the WiGig Alliance. "Our members have worked closely with IEEE on developing the standard. We are excited to say that the WiGig MAC/PHY specification is completely aligned with the published 802.11ad standard. Gaining approval from a global standardization body gives WiGig Alliance additional international

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recognition and moves us one step closer to widespread industry adoption."

WiGig is on track to become the most important next generation wireless networking technology. Speeds of up to 7 Gbps using the unlicensed 60 GHz frequency band, combined with advanced protocol adaption layers (PAL), will mean its applications go beyond that of a straight forward access technology. The same implementation of a WiGig Alliance PAL specification can operate on top of the published 802.11ad standard or the WiGig MAC/PHY specification.

Femtocell Bounce in 2H 2012 Suggests Market Could Be Turning a Corner

While the femtocell market struggled in the first half of 2012, the market has bounced back in the second half of the year. ABI Research's latest femtocell forecast update suggests that 2012 ended up with shipments reaching slightly above 2 million units. The shipments in the second half more than doubled from the first half, making up for some of the lost momentum.

The forecast covers the enterprise and consumer femtocells market, with enterprise femtocells making up one-third of the total shipments. On the other hand, revenues from enterprise femtocells made up to two-thirds of the total revenue for femtocell access points. Airvana, Alcatel-Lucent, and NEC/Ubiquisys remained the top vendors in terms of shipments, making up 78 percent of the total shipments in 2012.

"The appetite for femtocells continues to persist as suggested by this second half bounce, which can be attributed largely to inventory levels needing a refresh, but also due to renewals of contracts driven by newer versions of access points. This is also evident in the continued growth in contracts which have reached a total of 130 globally, as per our estimates," says Aditya Kaul, practice director, mobile networks.

Kaul adds, "The lack of operator willingness to use femtocells as a competitive network quality differentiator, rather than a defensive churn reduction tool, continues to plague the market. Nevertheless, it is encouraging to see demand back up, with new markets such as Latin America and Russia lighting up. Competitive factors in certain markets are causing domino effects with one operator leading and the others following. This is enough to keep the momentum going forward, with new business models, like femtocells as a service, adding to that momentum and bringing lower tier operators into the fold. Overall the market looks like it might be turning a corner."

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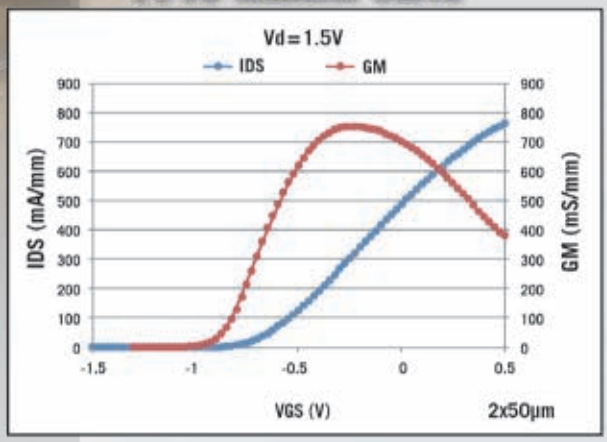
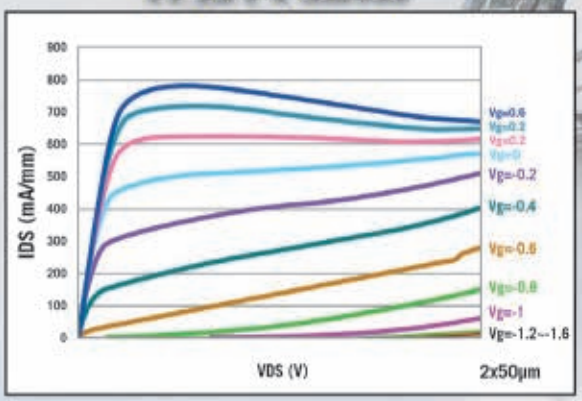


PP10 I-V Curves



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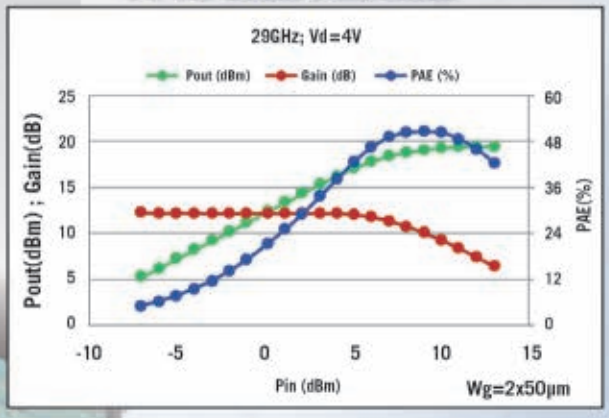

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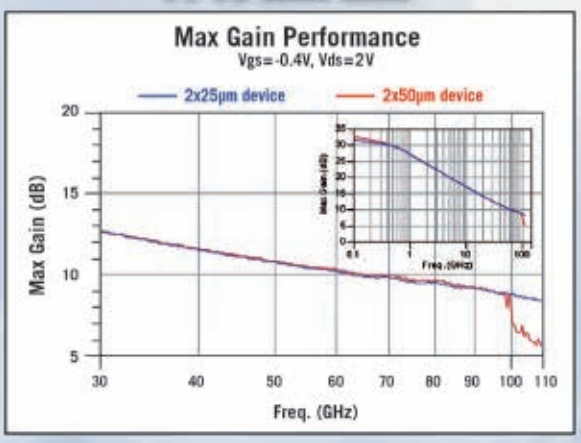

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Around the Circuit

Laura Glazer, Staff Editor

MERGERS & ACQUISITIONS

ITT Exelis has signed a definitive agreement to acquire **C4i Pty. Ltd.** (C4i) based in Melbourne, Australia, from the **Longreach Group Ltd.** for an enterprise value of approximately USD 16.8 million. Pending Longreach Group shareholder approval, the transaction is expected to close in the first quarter of 2013 subject to customary closing conditions and regulatory approvals. The acquisition is not material to Exelis 2012 results. C4i provides advanced communications software that is central to the needs of air traffic management systems and mobile communications solutions for commercial, homeland security and defense systems around the globe.

COLLABORATIONS

Cobham has been selected by **Inmarsat** as a "Launch Partner" to provide land-based satellite communication terminal antennas specifically designed to support the global service introduction of Inmarsat's Global Xpress® (GX) network. Cobham will ensure availability of its GX land terminals at service introduction of the new Ka-Band satellite network, which will be the first to provide global superfast broadband.

Ericsson has helped **MTN South Africa** launch a commercial LTE network which will be rolled out across the country. Along with its RBS 6000 family of base stations, the company is supplying the Evolved Packet Core, Home Subscriber Server (HSS) for user data management, Operating Support Systems (OSS), project management and services. This is the first commercial LTE network built by Ericsson in Africa and the launch comes after the pilot network has been running for more than a year.

NEW STARTS

Boeing has developed an advanced method to test wireless signals in airplane cabins, making it possible for passengers to enjoy more reliable connectivity when using networked personal electronic devices in the air. Boeing engineers created a new process for measuring radio signal quality using proprietary measurement technology and analysis tools. This enables engineers to more efficiently measure how strong a signal is and how far it spreads, ensuring safe yet powerful signal penetration throughout an airplane cabin. Once the new method was established, testing that previously took more than two weeks to conduct was reduced to 10 hours.

The **New America Foundation**'s Open Technology Institute (OTI) has completed the first phase of construction on a next generation wireless network located in the Cass Corridor section of Detroit, MI. OTI will use the Detroit network to test Commotion — a new, open-source wireless technology — ahead of its public release in early 2013. The Detroit Commotion testbed is supported by a grant from the John S. and James L. Knight Foundation, whose mission is to promote informed and engaged communities, and by the U.S. Department of State, which sees the potential of the technology in places like Egypt or Syria where dictators have cut off access to the Internet.

PCTEL Inc. announced that it is combining the Antenna Products Group and Connected Solutions into PCTEL Connected Solutions. The consolidation of the company's product and service groups into two businesses reflects the similarity in customers and focus between the scanning receiver business and network services and, similarly, the shared customers and product solutions between Connected Solutions (formerly Telworx) and the Antenna Products Group. The company anticipates that PCTEL Connected Solutions will contribute approximately 70 to 80 percent of the total revenue in 2013 with RF Solutions contributing the balance.

AWARDS

Rogers Corp. announced that it has received the 2012 Innovation Excellence Award from the Connecticut Technology Council (CTC). The annual award recognizes significant technology leadership and innovation by Connecticut-based technology companies. Rogers is the ninth company to receive the Innovation Excellence Award from CTC, Connecticut's industry association for the technology sector. Previous winners include ATMI Inc. of Danbury, Pitney Bowes of Stamford, FuelCell Energy of Danbury, Open Solutions Inc. of Glastonbury, Sonalysts Inc. of Waterford, United Technologies Corp. ESPN of Bristol, and Tangoe Inc. of Orange.

STMicroelectronics has been awarded the prestigious 2012 Corporate Award from the IEEE Standards Association (IEEE-SA) in recognition of its outstanding leadership and contributions to the development and advancement of standards in electrical and electronics engineering. In addition to making technical contributions, ST holds membership on the IEEE-SA Corporate Advisory Group, and has employees who hold individual memberships on the IEEE-SA Standards Board and the IEEE-SA Strategic Planning & Portfolio Management Committee.

CONTRACTS

Harris Corp. has been awarded an $85 million indefinite delivery, indefinite quantity (IDIQ) contract to provide the **U.S. Air Force** with Falcon multiband manpack tactical radios and accessories. In conjunction with the contract, Harris also received initial delivery orders of $33 million. The company has also received a $7 million order to deliver Falcon® tactical radios to a nation in Central Asia. The radios will provide interoperable communications to support the International Security Assistance Force in Afghanistan.

Raytheon BBN Technologies has been awarded $16 million under the Deep Exploration and Filter of Text

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HIGH POWER PRODUCTS

POWER DIVIDERS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.] ◦	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	5	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	5	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316

◊ In excess of theoretical split loss of 3.0 dB
◦ With matched operating conditions

HYBRIDS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
CSDK3100S	30 - 1000	0.8 / 1.2	0.05 / 0.2	0.2 / 3	25 / 18	1.15:1	50	378
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ◦	Package
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KFK-10-1200	10 - 1200	40 ±0.75	±1.0	0.4 / 0.5	22 / 15	150	376
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322

* Add suffix - LF to the part number for RoHS compliant version.
◦ With matched operating conditions

Unless noted, products are RoHS compliant.

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(DEFT) program, sponsored by the **Defense Advanced Research Projects Agency** (DARPA) and the **U.S. Air Force Research Laboratory**. Drawing on decades of experience in speech and language technologies, Raytheon BBN scientists will tackle two significant goals of the DEFT program: to develop new techniques to infer meaning, discover relationships, and detect anomalies in text; and to research and develop tools to integrate new, individual facts into existing large information stores.

XTAR LLC has gained significant contracts in the growing airborne intelligence, surveillance, and reconnaissance (AISR) market over the last 12 months. These contracts represent more than 100 MHz of bandwidth and are valued at more than $8 million. Under these various contracts, XTAR will provide high-powered X-Band capacity on its XTAR-LANT and XTAR-EUR payloads to support critical services on manned aircraft using advanced antennas designed specifically for airborne applications. This capacity will provide service over a coverage area extending from North and South America to Africa and the Middle East. Contract terms vary from six months to as long as 72 months.

API Technologies Corp. has received a $1 million order to provide electromagnetic integrated solutions (EIS) for a major military radio program. This order includes both filtered and unfiltered specialty connectors and will be used in multiple radio configurations for both U.S. and foreign military sales. No additional information is available due to the secure nature of this program.

NEC Corp. has signed a global framework contract with **Telenor**, Norway's leading fixed and mobile telecommunications operator, for the supply of its compact iPASOLINK microwave communications system, including the '5000ips' long-haul, large capacity microwave system and related services such as installation and commissioning. Additionally, NEC Corp. announced that **NEC Europe Ltd.**, a wholly owned subsidiary, has signed a multi-million, multi-year global framework contract giving **Tele2 Sverige AB** the possibility to expand and upgrade its mobile access network in 10 countries across Europe. Starting in Russia, NEC will provide its iPASOLINK series of microwave radio solutions, training and maintenance support services.

Ducommun Inc. announced that it has received a contract from **The Boeing Co.** to produce titanium detail components and subassemblies for the Boeing 787 Dreamliner. Under the terms of the contract, production on the titanium assemblies will continue at the Ducommun AeroStructures facility in Coxsackie, NY.

PEOPLE

H. Richard (Dick) Johnson, co-founder of **Watkins Johnson Co.**, died December 9th surrounded by his loving family. Johnson and Dean Watkins began the Watkins-Johnson Co. in 1957 with Watkins as president and Johnson as VP. In 1987, when Johnson stepped down after 10 years as president and CEO to vice chairman of the board, W-J had about 3100 employees and annual sales of $264 million. Johnson was an electri-

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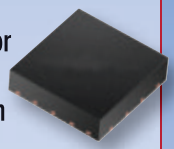
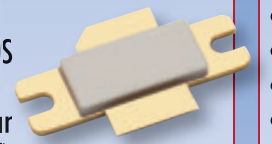
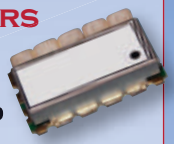


RF Amplifiers
- Gain Blocks
- Coaxial Module
- Low-Noise
- Linear Drivers
- High Power
- Variable Gain

RF Transistors
- GaN
- LDMOS
- GaAs
- Bipolar
- High Power
- High Frequency

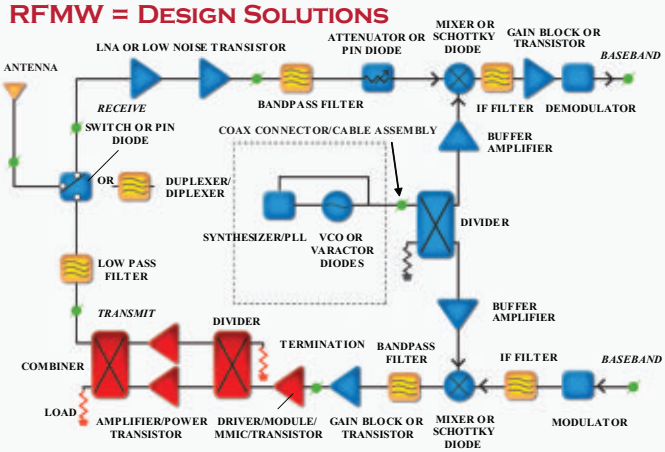


RF Filters
- Monoblock
- SAW / BAW
- HP / LP / BP
- Ceramic Resonator
- Duplexer / Diplexer
- Cavity

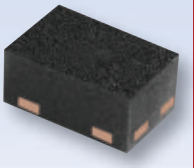


RF Oscillators
- OCXO
- VCXO
- TCXO
- PLL Synthesizers
- RF Generators

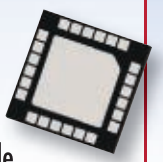
RFMW = Design Solutions



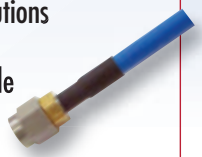
RF Diodes
- PIN
- Schottky
- Varactor
- Limiter
- Gunn



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

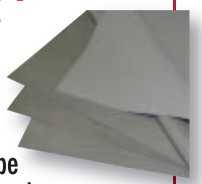


RF Cable Assemblies
- High-Performance Test
- In-Box Solutions
- Pigtails
- Conformable
- Flexible
- Semi-Rigid



Test & Measurement
- USB Controlled
- Signal Generators
- Power Meters
- Switches • Attenuators
- Vector Modulators
- Cable Assemblies
- Coax Components

EMI / RFI
- RF Absorber
- RF Gaskets
- Wire Mesh
- Fingerstock
- Shelding Tape
- Filtration Panels
- Shielded Windows



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cal engineering lecturer at UCLA and Stanford and served on panels of the National Security Agency Scientific Advisory Board. He was an IEEE fellow and a member of the National Academy of Engineering.

The board of directors of **Empower RF Systems** has approved the creation of a new role, executive chairman of the board, and the appointment of a new CEO. **Barry Phelps**, current CEO, will be transitioning to the role of executive chairman of the board, remaining active and involved with the company and leading the management/oversight of board responsibilities. Phelps joined the board of directors in 2007 and moved into a full time role as CEO in 2009. **Jon Jacocks** has been promoted to president and CEO of Empower RF Systems. Jacocks joined Empower in November 2007 as the company's first VP of sales and he has served in that capacity for the past five years. Related to this, **Rob Lauria**, Empower's vice president of business development, will expand his role and responsibilities to become vice president, business development and sales.


▲ *Todd Witchall*

Crane Aerospace & Electronics announced the appointment of **Todd Witchall** as vice president of finance and chief financial officer of the Electronics Group of Crane Aerospace & Electronics. In this role, Witchall will report directly to Bob Tavares, president of Crane Electronics Group. Witchall will be responsible for finance, accounting and information technology for all of the Electronics Groups locations including Beverly, MA, Chandler, AZ, Ft. Walton Beach, FL, Redmond, WA, West Caldwell, NJ, Kaohsiung, Taiwan and San Jose, Costa Rica. His primary location will be Redmond, WA.

LPKF Laser & Electronics has announced the appointment of a new COO, **Christian Bieniek**. As the fourth member of the LPKF Board of Managing Directors, Bieniek will oversee the operational performance of the company, including all management, control and organizational processes. A native of Lower Saxony, the German state that is home to LPKF worldwide headquarters, Bieniek looks forward to returning home and representing the ever-growing LPKF Group.

Coaxial Components Corp., also known as Coaxicom, announced the appointment of **Chris Feys** to the company's quality assurance team. As QA manager, Feys will have overarching responsibility for all cable and connector assembly as well as product manufacturing quality control. Feys will also play an instrumental role in administering the ISO 9001:2008 and the AS 9100C processes for the company.

EDI CON 2013 organizers have announced the selection of **Dr. Song Junde**, professor at the Beijing University of Posts and Telecommunications, as the honorary chair of the inaugural technical conference and trade exposition. Junde was chosen in recognition of his many contributions to advancing microwave technology and the

Around the Circuit

▲ *Song Junde*

communications industry in China. In his role as honorary chair, Junde will be consulting on the final details of the technical program and will be delivering the Welcoming Message at the keynote plenary session on March 12th.

▲ *Kevin W. Kobayashi*

RF Micro Devices Inc. announced that RFMD Fellow **Kevin W. Kobayashi** has been named a Fellow of the Institute of Electrical and Electronics Engineers (IEEE) by the IEEE board of directors. The IEEE grade of Fellow was conferred on Kobayashi in recognition for his extraordinary contributions to monolithic microwave integrated circuits (MMIC). Less than one-tenth of one percent of the total IEEE voting membership is recognized each year by the IEEE Board of Directors for elevation to IEEE Fellow.

REP APPOINTMENTS

Carlisle Interconnect Technologies announced two top tier connector distributors – **Richardson RFPD Inc.** and **RFMW Ltd.** – now have inventory and full design support capabilities for both the TMP® and WMP® Push-on Connector Series. Common configurations are in stock and available for immediate delivery.

CTS Electronic Components Inc., a global leader in ceramic, quartz and piezoelectric technologies, announced it has recently added **Carpatec Complete Component (CCC) Solutions** as the representative company for CTS Electronics Components in Sweden.

Delta Microwave, a supplier of amplifiers, filters, filter/amplifiers, multiplexers, and integrated microwave assemblies, announced the appointment of **Wavelength Sales** as the company's exclusive representative in upstate NY.

Global electronic components distributor **Digi-Key Corp.** announced an agreement to distribute **GeneSiC Semiconductor**'s industry-leading silicon-carbide technologies worldwide.

Eastern OptX has appointed two new sales representatives for Europe and Canada. Effective immediately, **AR Europe** will represent Eastern OptX in all areas of Europe except Germany and Italy. In Canada, Eastern OptX has appointed **Testforce** to represent Eastern OptX in all provinces.

NuWaves Engineering has added **MicroBee Systems** as its first domestic value-added reseller. MicroBee Systems will increase exposure of NuWaves' commercial-off-the-shelf (COTS) RF module-level products in the DoD test and training range market. NuWaves' products will be offered both independently and as part of higher-level integrated system solutions by MicroBee for flight test telemetry, vehicle tracking, and remote systems monitoring and control applications.

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Nurturing Design Innovation for China's Future

Guy Séné, President of Agilent Technologies' Electronic Measurement Group
Santa Clara, CA

China has undergone great change in the last decade and now stands as the world's second largest economy. Continuing this growth will require innovation in a broad range of markets. Design innovation, in particular, will be critical to China's ongoing industrial and economic development. Sometimes, however, innovation requires help. That's what the Electronic Design Innovation Conference (EDI CON) hopes to accomplish, when it debuts in March 2013 and it is what we at Agilent Technologies do on a daily basis – provide the solutions and technology necessary to nurture and encourage design innovation and development. It is this desire to inspire innovation, through its focus on applications, emerging technologies and practical engineering solutions, that makes Agilent proud and honored to serve as EDI CON's Platinum sponsor in its inaugural year.

The journey to realizing EDI CON began back in October of 2011, at the European Microwave Week in Manchester, England. It was there that talks began with Horizon House, an experienced and well-established event organizer, on the need for an event to provide design engineers and system integrators the latest information on RF, microwave and high-speed digital products and technologies. It was clear that Agilent should play a critical role in helping plan and participate in the event. As the world's largest test and measurement company, it is our job to help bring technology innovation to China so that digital, RF and microwave technologies can move forward.

Agilent has a long and well-established history in China, beginning when it was known as Hewlett-Packard (HP) and spanning almost 30 years. In 1981, David Packard visited China and came away with the foresight and wisdom to understand that China was an emerging market and a measurement company, like HP, could be a crucial player in its economic and societal development. That insight prompted the opening of HP's first office in Beijing in 1985. Today, Agilent has a significant presence in China, providing customers with sales, marketing and business support, as well as service. Agilent also has R&D and manufacturing organizations in Beijing, Shanghai and Chengdu. The company's largest software applications development organization is based in Beijing.

The partnership Agilent established with Horizon House to bring EDI CON to China is yet another way in which we will continue to play a role in China's ongoing development. This event will enable researchers, scientists and engineers in China to gain insight into challenges in digital, RF and microwave design. By bringing designers together with measurement scientists in a collaborative environment, EDI CON will be able to highlight and help foster emerging technologies and solutions for effectively addressing those challenges.

Now more than ever before, China needs an event like EDI CON. The technical problems facing today's wireless and digital product designers are getting more complex and difficult to solve. For example, in the wireless industry alone, design and test are complicated by increasing device complexity and functionality, higher data rates, rapid growth in software content, increased focus on network security and higher integration of components and modules. Wireless engineers must also now confront different measurement requirements for different technologies, multiple technologies converging in single devices and the constant evolution of existing technologies and emergence of new technologies.

The challenges are no less daunting for digital product designers. Here, technologies are continuing to transition from analog to digital and devices require more integration and functionality – at a lower cost. Devices also require higher speed and lower power, prompted by the growth of video and social media. Additionally, consolidation is underway in the digital arena as design shifts into Asia. Each of these trends drive new challenges that engineers must learn to address effectively if they are to succeed. Many of these trends are key topics on the agenda for EDI CON 2013, which will take place at the Beijing International Convention Center on March 12-14, 2013, in Beijing, China.

EDI CON promises to be an exciting and transformative event for China, one that we support on many different levels. Agilent is not only the event's Platinum sponsor, we also will have a booth on the show floor and be presenting a number of technical papers. Additionally, I am honored to be delivering the keynote address. We look forward to a great event and hope to see you all there. ■

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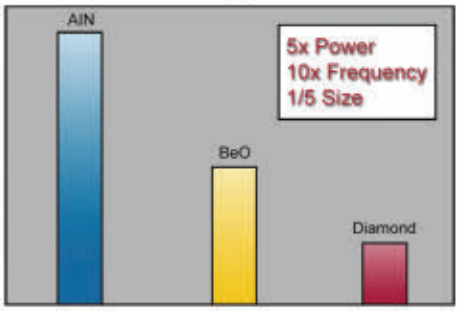
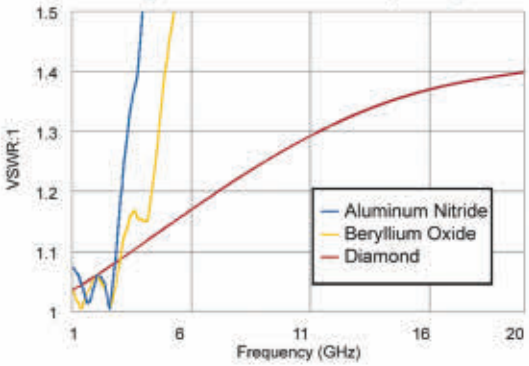


Common Substrate pF / Watt Comparison

Highest Power & Frequency



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- Point-to-Point Radio
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- High PAR Applications
- Wilkinson Dividers/Combiners
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EDI CON Program Preview

The Electronic Design Innovation Conference (EDI CON) to be held in Beijing, China next month will offer engineers and researchers practical training and insight into the state of technology driving RF, microwave and high-speed component design and system integration. The conference program will emphasize measurement, simulation and semiconductor technologies that support electronic component design for high-frequency systems from telecommunications to satellite navigation. EDI CON will serve the industry by providing access to the knowledge and expertise that engineers need to meet tomorrow's challenges.

The bulk of papers have been provided by companies at the forefront of our industry's technical innovations. As a result, the conference reflects global trends at the device and system levels. To understand technology trends in the context of market opportunities, the opening day will feature keynote presentations from multiple business and engineering perspectives.

KEYNOTE TALKS

- Honorary Chair, Dr. Song Junde, academic director at Beijing University of Posts and Telecommunications, will open the ceremonies with a talk on the "Present and Future of RF/Microwave and High-Speed Digital Devices and Systems," a look at the development and consumption of communication ICs in China and the systems driving this demand.
- Strategy Analytics' Beijing-based senior analyst Guang Yang will share insights on the mobile communications industry, discussing R&D efforts in China, standardization and strategic analysis for 3G/4G, spectrum, and emerging wireless technologies.
- Guy Séné, president of Electronic Measurement Group, Agilent Technologies, will discuss Agilent's long history (starting as Hewlett Packard) in China and the company's vision for the future in his talk, "Nurturing Design Innovation for China's Future," previewed in this month's special report.
- Bertram Arbesser-Rastburg, head of the Electromagnetics and Space Environment Division of the European Space Agency and last year's European Microwave Week chair, will provide a look at the aerospace industry and share global developments with our Chinese audience.
- The second plenary session will feature executives from China Mobile Research Institute, ZTE Microwave Products Group and Beijing's Radio Institute for Metrology and Measurements (BRIMM).
- Deng Jie (ZTE) will discuss the mobile backhaul microwave radio market and his company's R&D efforts in this area.
- Dr. Liu Guangyi, chief researcher with the country's largest mobile carrier, China Mobile, will offer an operator perspective on the system technologies being presented in the conference as well as China Mobile's future product roadmap and its current leadership in small cells where the Beijing team is working to accelerate the field trials of TD-LTE small cell systems across its network.
- Feng Keming, a director at BRIMM, will discuss his institute's research on ultrafast optoelectronic technology for terahertz metrology, advances in metrology standards and his department's development of highly precise microwave timing solutions for China's GNSS project.

TECHNICAL TRACKS

Peer-reviewed papers from industry experts offer insights on a range of topics related to wireless communications, high-speed computing and aerospace and defense systems. The design track explores the latest circuit and component design techniques and architectures with examples of key active and passive devices found in radio front-ends and transceivers for WiFi, small cell, 3G and LTE base-stations, backhaul networks, radars, etc. The measurements and modeling track looks at the tools and techniques used in support of virtual prototyping and design verification. The systems engineering track looks at various wireless systems and standards, receiver architectures, modulation techniques, etc., to provide broader overview of the networks driving component requirements and specifications. The commercial resources track provides a mix of vendor-based solutions and products for specific applications and engineering challenges.

David Vye
Microwave Journal *Editor*

Conference Program: **A Sneak Peek**

Design	Measurements & Modeling	Systems Engineering	Commercial Resources
Implementation of a Digitally-Controlled Oscillator for Jitter Cleanup *Yin-Chen Lu and R. Reist, SI Time*	Improvements in mm-wave Noise Figure Measurement Accuracy *Jon Martens, Anritsu*	Impact of Wideband I/Q Vector Impairments on 802.11ac *S. Dark and C. Behnke, National Instruments*	**Agilent Education Forum** RF Concepts for High Speed Digital Design *Kai Li, Agilent Technologies* Design of Equalization Circuit to Improve Performance at > 5 GHz Data Rates *Q. Lu, Agilent Technologies*
A Novel Ultra-Low Phase Noise Octave-Band Synthesizer Using X-Band Frequency Reference *Dr. Sergey Beltchicov, Elvira*	Noise Figure Measurement of Non-Frequency Converting and Frequency Converting Devices Using a VNA *S. Neidhardt and V. Herrmann, Rohde & Schwarz*	Queuing Behavior of an 802.11 Wireless Communication System *Yi Cai, National Instruments*	
Design of a Novel Multi-Slot Antenna *Milton Lien, AWR*	Modeling of GaN HEMT Devices *Y. Tajima, Auriga Microwave*	Welch Periodogram Detector for QPSK Based AWGN Baseband and Passband Cognitive Radio System *M.Tahir Mushtaq, Institute of Communication Networks and Satellite Communication (IKS)*	Diamond Rf™ Resistives: The Answer to High Power and Low Capacitance *EMC/Florida RF Labs*
Ten-Element 4G Antenna Array for Tablets *Corbet Rowell, ASTRI*	Practical Considerations for High-Power X-Parameter Measurements of a 130 W LDMOS Power Transistor *Di Liu, Agilent Technologies*	Spectrum Re-Use Through Real-Time Signal Processing *Trang D. Nguyen, National Instruments*	Impact of Conductor Roughness on Insertion Loss and Propagation Constant of High Speed Signals *A. Horn, Rogers Corp.*
Wide Dynamic Range Multi-Nested Envelope Tracking Power Amplifier for LTE Application *Z. Wang, Nokia Siemens Networks*	Simulating FPGA Power Integrity Using an S-Parameter Model *H. Fahmy, J. Carrel, R. Anderson and C. Warwick, Agilent; H. Fu and R. Mayder, Xilinx*	GNSS and Their Wide Range of Applications *R. El Assir, Rohde & Schwarz*	Dynamic Measurements in Radar and Electromagnetic Spectrum (EMS) Warfare *Walt Shulte, Agilent Technologies*
A High-Efficiency, Small-Size GaN Doherty Amplifier for LTE Micro-Cell and Active Antenna System Applications *P. Xia and M. Jankovic, TriQuint Semiconductor*	Methods of Improving Time/Frequency Domain Measurements Suited for 3D-EM Simulation *A. Neves, Wild River Technology LLC*	'Design to Test' Platform Solution for Direct-Sequence Spread Spectrum (DSSS) Communication System for LEO SATCOM *Jinbiao Xu, Lei Yue and Fan Wang, Agilent Technologies*	Signal Analysis Using a Mixed Domain Oscilloscope *Tektronix*
A 60 GHz Four Channel CMOS Receiver with 7 GHz Ultra-Wide Bandwidth for IEEE 802.15.3c Standard *Chunyuan Zhou, Lei Zhang, Hongrui Wang and He Qian, Tsinghua University*	3D EMC Simulation of Automotive Multimedia Systems *R. Kakerow, Continental Automotive GmbH*	Optimizing TD-LTE Performance from RF to Subscriber QoE *Simon Wang, Spirent*	Technological Advances of Gallium Nitride *Bruce Green, Freescale Semiconductor*
Simulation, Modeling and Design Enablement of Integrated Passive Devices in CMOS Technologies *Brian Chen, Agilent Technologies*	Time-Domain Based Measurements and the Related Speed Improvements for EMI Testing *Karl-Heinz Weidner, Rohde & Schwarz*	System-Level Design of an LTE TDD Tri-Band Receiver *S. Lafi, F. Ditore and R. Vandyke, Agilent Technologies*	Challenges in the Design and Selection of Power Broadband Amplifiers *Wolfram Titze, Rohde & Schwarz*
Device Characterization Methods for Advanced RF/Microwave Design *Nikhil Ayer, National Instruments; Chun-Hsien Lien, AWR*	Signal Lines to Power Plane Coupling Caused by Common Mode Current in High Speed SerDes Interconnect Design *L.K. Teoh and H.Y. Lee, eASIC; C.T. Chiang, K. Krohne and A. Ciccomancini Scogna, CST*	Digital Upconversion VS IQ Modulation Using a Wideband Arbitrary Waveform Generator *B. Hoehne, Agilent Technologies*	Error Analysis of Equivalent Source Reflection Measurements *C. Igor, VNIIFTRI; C. Vladislav, MIET; A. Pivak, Rohde & Schwarz*
High Efficiency Inverse Class-F Amplifier Design for Envelope Tracking Line-Up Driver *Zhancang Wang, Li Wang, Rui Ma and S. Lanfranco, Nokia Network Systems*	Electrical Validation Considerations for MIPI D-PHY and M-PHY Physical Layer Transmitter Specifications *M.J. Chong, Agilent Technologies*	Correlation Between RF Receiver Architecture and RF Measurement *N. Ayer, National Instruments*	Modeling Magnetron Sources with VSim *Chuandong Zhou, Tech-X*
PLL Frequency Synthesizers Based on the DDS in Feedback Loop *Andrew Polyakov, Peter Bobkovich and Andrey Kuzmenkov, Advantex*	Memory Polynomial Digital Pre-Distortion Measurement and Implementation *J. Xu, H. Wu and Z. Deng, Agilent Technologies*	Bluetooth-Based Room Localization Research Based on NB and SVM Approach *Pengming Wang and Qing Chen, East China Jiaotong University*	Cree GaN HEMT for Telecom *David Dai, Sanetronic*
A Fast-Switching, Low Noise Frequency Synthesizer Using a Frequency Offset Technique *Alexander Grechishkin, Nikolay Tikhomirov, Stanislav Romanov and Dmitry Rakhmanin*	Carrier Aggregation Performance Testing: Challenges and Opportunities *E. Ork, Azimuth*	Analysis of UHF RFID SD Tag Antennas *Abdul Karim, Technischi Universität Darmstadt (TUD)*	Linearizing GaN Microwave Power Amplifiers Using RF Pre-Distortion *Mendy Ouzillou, Scintera*
Wideband Branch Line Coupler with Sharp Skirt Selectivity Bandpass Filter Function *W.A. Arriola and I.S. Kim, Kyung Hee University*	Accurate Test of 28 Gb/s High-Speed Data Electrical Interface *H. Hu, Agilent Technologies*	Novel Architecture for 8×8 MIMO MMSE Detection with LabVIEW FPGA (LVFPGA) on Xilinx Virtex-5 Target *Y. Rao and I. Wong, National Instruments*	Accelerating USB 3.0 Protocol Development *D. Schoenecker, Agilent Technologies*
A Square-Law Microwave Transistor Detector with Extended Dynamic Range *Sergey Ivanov, A.P. Lavrov and Y. Matveev, St. Petersburg State Polytechnical University*	Comparison and Contrast of State-of-the-Art Time Domain Reflectometry Measurement Instruments *Takuya Hirato, Agilent Technologies*	Design and Implementation of FPGA-Based 4 GHz Bandwidth Digital IFM *Megha S. Badad, KS. Institute of Technology*	Discrete Active Devices: Recovery Time of Schottky-PIN Limiter *Chin Leong Lim, Avago Technologies*
New Design of a 5.8 GHz Microwave Rectifier Circuit *Chengyang Yu and Changjun Liu, Electronic Information Institute of Sichuan University*	Modeling of Antennas and Arrays Using Domain Decomposition Method *K. Zhao and N. Lambert, ANSYS*		RFID Product Lifecycle Testing Techniques *Zhang Zhihua, HWA-Tech*
	Equivalent Current Reconstruction Applications *F. Chauvet, SATIMO*		

Workshops: Wednesday, March 13, 2013

RF CMOS Foundry Workshop – Addressing RFIC Reliability
TowerJazz Semiconductor

Ultra CMOS Technology Enables Today's High-Performance RF and Microwave Designs
Jian Zhou, Peregrine Semiconductor

Doherty Power Amplifier Theory and Design for Cellular Infrastructure Applications
Damon Holmes, Freescale Semiconductor

Design Methodology for GaAs MMIC 1 W X-Band PA
Dr. John Dunn, AWR

Single Connection Amplifier Characterization
Fabricio Dourado, Rohde & Schwarz

Vector Signal Test and Measurement
Sponsored by National Instruments
Yanbo Zhao, VI Service Network

High-Speed Interconnects
Bob Buxton, Anritsu

Smart Portable Test Equipment for ATE Applications
Chi Man Shum, Mini-Circuits

Time Domain Modeling of Drude and Lorentz Dielectrics with VSim
Chuandong Zhou, Tech-X

Antenna Design and Platform Integration Workshop
Dr. Matt Commens, ANSYS

Integrated Antenna Design for a GSM Tracking Device
Dr. Klaus Kohne, CST

MIMO Beamforming in All Its Forms – Maximizing Efficiency in Limited Spectrum
Kang Chen, Spirent Communications

Agilent PA Workshop

A Doherty Power Amplifier with Envelope Tracking Design
Cheng-Cheng Xie, Agilent Technologies

GaN Panel

Sponsored by Richardson RFPD

GaN Based Power Transistors in the Cellular Infrastructure Market
Mario Bokatius, Freescale Semiconductor

Micro-Cell and Active Antenna System Applications
Peter Xia, TriQuint Semiconductor

GaN Power Transistors in COTS Plastic Packaging
Damian McCann, M/A-COM

A Robust 75 W, 48 V, 0.02 to 1 GHz Broadband GaN Amplifier
Xinjian Zhao, Nitronex

GaN Power Transistors for Avionics and Radar Market
Jerry W. Chang, Microsemi

as of 1/24/13

Workshops: Thursday, March 14, 2013

RF Signal Analysis Workshop
CETC 41

Understanding Cable Assembly Solutions for Specific Commercial and Military Applications
Wei Liu, MITRON

How to Get the Best Performance Out of Your Cable Assembly
Insulated Wire

TD-LTE and TD-LTE-Advanced Workshop
Qin Zhang, Agilent Technologies

MW and MM Solutions (VNA, SpA, SG, Frequency Converters)
Christoph Wagner, Rohde & Schwarz

Getting More Than 12 Bit of Resolution from a 12-bit Oscilloscope
Ai-Lee Kuan, Agilent Technologies

How to Use a VNA to Analyze High Speed Backplane and Cable
Shaohan Lian, Agilent Technologies

RFIC Advances in Simulation for Transceiver Design
Xg Wang and Nebabie Kebebew, Cadence

Wafer-Level S-Parameter Calibration: How to Choose the Optimal Strategy for Your Application
Andrej Rumiantsev, Cascade Microtech

How to Remove the Effect of Fixtures and Probes in High Speed Test
Yong Zhao, Agilent Technologies

Connectivity Workshop

Sponsored by Sanetronic

Applications of Fiber Optic Links in RF and Microwave Systems
Howard Hausman, MITEQ

EDA Design Flow

Industry Best Practices for a High-Speed Digital Design Workflow
Colin Warwick, Agilent Technologies

Fully Integrating 3D Electromagnetic (EM) Simulation into Circuit Simulation
Jiang Dunn, AWR

HFSS-Inside
Matt Commens, ANSYS

GaAs Foundry Workshop

HBT Technologies for Multi-Mode, Multi-Band Power Amplifier Application
WIN Semiconductors

W-Band Chips-Set for Microwave Imaging
OMMIC

Nonlinear Device/Load-Pull Workshop

Load-Pull System Common Test Problems and Solutions
J. Lei, Focus Microwaves

Passive, Active, Hybrid-Active, Mixed Signal Active, Harmonic, Pulsed, NVWA/ Time Domain Load-Pull and Modeling Techniques
Maury Microwave

RF Front End Workshop

Wideband Tx, Rx and PPD-Feedback RF Solution
Lei Xu and Trung Tran, Altera

RF Front-End Solutions for High-Speed Designs
Aiguo Leng, TI

AWR/National Instruments DPD PA Workshop

Optimizing the Design and Verification of 4G RF Power Amplifiers
Peter Xu, NI

Simulating an NXP Doherty Power Amplifier with Digital Pre-Distortion
John Dunn, AWR

MIMO OTA Workshop & Panel

Sponsored by Spirent Communications

MIMO-OTA Testing Methodologies: Reverb vs. Anechoic
Kang Chen, Spirent

MIMO OTA Measurement with Anechoic Chamber Method
Francois Chauvet

The Changing Face of Testing: Moving from Conducted to OTA
Panel Session with Experts from Spirent, Blue Test, ETS-Lindgren and IMS

802.11ac Design Considerations for Mobile Devices

The rapid growth of smart mobile devices is driving mobile data usage and Wi-Fi proliferation, creating an ever-increasing demand for faster wireless networks to support bandwidth-intensive applications, such as web browsing and video streaming. The new IEEE 802.11ac standard is designed to meet this demand, by providing major performance improvements over previous Wi-Fi generations, as shown in ***Table 1***, which shows theoretical maximum data rates.

Mobile devices supporting 802.11ac are already becoming available. IMS Research predicts rapid adoption of 802.11ac and expects that over 400 million devices supporting the new standard will be shipped in 2016. For mobile devices, 802.11ac provides significant performance improvements over its predecessor, 802.11n. Single-antenna devices, such as smartphones, can achieve three times the data-transmission rate, compared with 802.11n, by using the wider 80 MHz channels with an advanced modulation (MCS 9), defined in 802.11ac. The additional performance means that 802.11ac will allow new types of WLAN usages as well as accelerating existing applications.

These new usages include simultaneous streaming of HD video to multiple clients throughout the home and instantaneous data sync and backup. 802.11ac achieves its performance improvements primarily by extending WLAN concepts initially introduced in previous 802.11 generations, such as 802.11n. In addition, 802.11ac uses the 5 GHz band, which is less crowded than the 2.4 GHz band used by most previous WLAN generations. This facilitates higher WLAN throughput with less interference. The biggest factors contributing to 802.11ac performance advantages are:

Wider Channels

802.11ac introduces mandatory 80 MHz and optional 160 MHz channel bandwidths in the 5 GHz band, in addition to the 20 MHz and 40 MHz channels specified in 802.11n.

Increased Modulation Complexity

With 802.11ac, the maximum modulation complexity increases from 64 QAM to 256 QAM, with a 5/6 coding rate. This change alone provides a 33 percent boost in the data rate, compared with 802.11n. To take advantage of this benefit over existing Wi-Fi networks, some equipment makers are expected to provide support for 256 QAM 802.11ac modulation over the 2.4 GHz band, as well as the 5 GHz band.

Expanded Support for MIMO and Beamforming

The number of simultaneous multiple-input multiple-output (MIMO) spatial streams increases from 4 × 4 to 8 × 8, allowing for a total maximum aggregate WLAN throughput of 6.93 Gbps. The 802.11ac standard also

Eid Alsabbagh, Haoyang Yu and Kevin Gallagher
TriQuint Semiconductor, Hillsboro, OR

TABLE I
THE EVOLUTION OF THE 802.11 STANDARDS

Protocol	Year Introduced	Maximum Data Transfer Speed	Frequency	Highest Order Modulation	Channel Bandwidth	Antenna Configurations
802.11a	1999	54 Mbps	5 GHz	64 QAM	20 MHz	1×1 SISO
802.11b	1999	11 Mbps	2.4 GHz	11 CCK	20 MHz	1×1 SISO
802.11g	2003	54 Mbps	2.4 GHz	64 QAM	20 MHz	1×1 SISO
802.11n	2009	65 to 600 Mbps	2.4 or 5 GHz	64 QAM	20 and 40 MHz	Up to 4×4 MIMO
802.11ac	2012	78 Mbps to 3.2 Gbps	5 GHz	256 QAM	20, 40, 80 and 160 MHz	Up to 8×8 MIMO; MU-MIMO

adds support for multi-user MIMO, allowing more efficient allocation of network capacity among multiple devices: each antenna of a multi-antenna device, such as a wireless router, can simultaneously communicate with a different single-antenna device such as a smartphone. 802.11ac supports standardized beamforming, which takes advantage of multiple antennas to increase signal strength and signal transmission range between communicating devices.

DESIGN CHALLENGES

While the new standard delivers significant performance improvements, it also creates a variety of new challenges for designers of mobile devices. These challenges make achieving the desired performance more difficult than ever. Key issues include:

- Maximizing linearity and achieving low dynamic Error Vector Magnitude (EVM)
- Generating high power output while minimizing power consumption
- Coexisting with cellular communications in the 2.4 GHz band

Each of these challenges is explained in more detail.

Linearity and Dynamic EVM

The increase in modulation complexity to 256 QAM contributes significantly to the increased performance of 802.11ac. With 256 QAM, the data rate is achieved by representing eight coded bits per Orthogonal Frequency Division Multiplexing (OFDM) symbol, compared with six bits with 64 QAM (the maximum supported by 802.11n). However, this higher-order modulation also creates significant design challenges.

As the data rate increases, signal quality becomes even more important. To successfully receive an 802.11ac 256 QAM signal, a receiver will require a significantly less distorted signal than with 802.11n 64 QAM. To deliver this signal, the power amplifier (PA) of the transmitting device will need to provide greater linearity.

This linearity requirement is reflected by a more stringent EVM specification. EVM is an important figure of merit used to measure the linearity of a transmitted OFDM signal. EVM is the magnitude of the difference between the measured vector and the ideal (reference) vector. In 802.11n, the maximum allowed system EVM for a transmitting device is –28 dB (4 percent), when using the highest allowed modulation (64 QAM) and a 5/6 coding rate. With the higher-order 256 QAM modulation supported by 802.11ac and a modulation bandwidth of 160 MHz, the maximum system EVM required is further tightened to –32 dB or 2.5 percent.

To meet this requirement, careful system budgeting is needed for each of the principal components of the device, such as the transceiver and the front-end module. The transceiver must provide sufficient linear drive for the front-end module; any shortcoming will need to be compensated by a higher gain from the PA. At the same time, the transceiver is expected to deliver a low EVM residual floor that is several dB below the overall system EVM requirement. Based on these assumptions, the PA is expected to achieve less than 2.5 percent EVM at the rated power.

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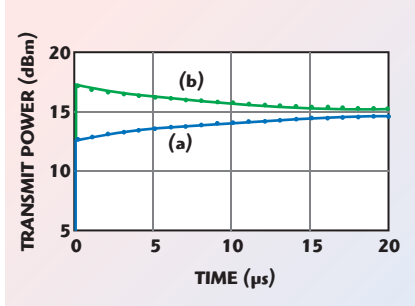
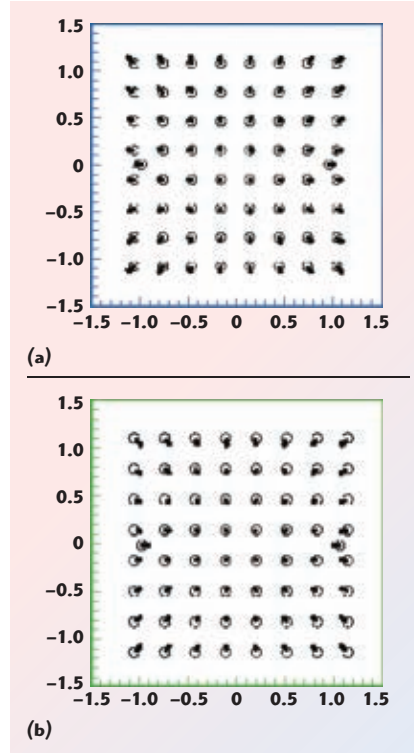


▲ *Fig. 1 Slow turn-on (a) and overshoot (b) transient response of the transmit power.*

When assessing PA linearity, it is essential to measure EVM in a way that is representative of actual use. Wi-Fi is a Time Division Duplexing (TDD) system, in which the PA continuously pulses on and off during use; it pulses on each time the device transmits data, then pulses off to save power. It is therefore important to measure EVM in this pulsed condition (dynamic EVM) rather than when the PA is always on (static EVM). In an ideal case, dynamic EVM should be the same as static EVM. But in reality, dynamic EVM is usually worse than static EVM due to the PA's transient response.

802.11ac defines a very strict transient response requirement. At the start of each packet, the transmitting device sends an OFDM training sequence used to calibrate the phase, amplitude and timing of the signal. The sequence consists of 10 short symbols and two long symbols. The short symbols include an automatic gain control (AGC) symbol used by the receiver to set its AGC amplifier so that it applies the correct gain to the received signal. The receiving device then assumes that the transmit power level remains constant until the end of the packet. The total transmission time for the training sequence is approximately 20 µs.

If the PA of the transmitting device exhibits slow power turn-on or power overshoot during this critical period, the constellation after OFDM demodulation will expand or shrink respectively, resulting in poor dynamic EVM. ***Figure 1*** illustrates the transient PA transmit power responses, resulting from slow turn-on and power overshoot respectively; ***Figure 2*** shows the constellations that result from these transient responses. Theoretically, if all points were centered perfectly within the circles, EVM would be 0 percent. These figures are



▲ *Fig. 2 64 QAM constellation after OFDM demodulation (a) slow turn-on results, (b) overshoot results.*

based on lab test results with 64 QAM; the problem is even more pronounced when using 256 QAM.

Because of this effect, a PA used in an 802.11ac device must exhibit an extremely stable transient power response, in order to minimize dynamic EVM. By designing for stable response, very low dynamic EVM has been achieved in PAs and front-end modules. For example, the TriQuint TriConnect™ WLAN/Bluetooth front-end module achieves 2.2 percent EVM at 18 dBm with 802.11ac 256 QAM (MCS 9, 40 MHz channel bandwidth).

As WLAN performance requirements will inevitably continue to increase in the future, more sophisticated techniques will be required to further improve signal range and quality. An example of such a technique is digital pre-distortion, in which the transceiver chipset uses feedback from the PA to adjust the signal so that the system EVM is minimized. FEMs will need to include the capabilities necessary to provide this feedback.

Generating High Power Output While Minimizing Current Consumption

Designers of mobile devices must balance a range of conflicting re-

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quirements to optimize WLAN performance, while managing power consumption. The challenge with 802.11ac is to achieve a design that successfully meets requirements for very low EVM, along with high transmit power output, while minimizing current consumption to lengthen battery life.

The challenges are accentuated as mobile devices become more complex and need to support a wider range of cellular and WLAN standards. Greater levels of integration are needed to make the best use of limited space, simplify design and enable faster development of next-generation wireless products. An example is how TriQuint's integrated single-band WLAN modules can replace as many as four discrete components. This highly integrated Wi-Fi front-end module, shown in ***Figure 3***, combines the discrete components required for WLAN transmit and receive chains into a single compact module. It houses a PA and a low noise amplifier (LNA) with a switched bypass mode, RF detector (V_{det}) and switch.

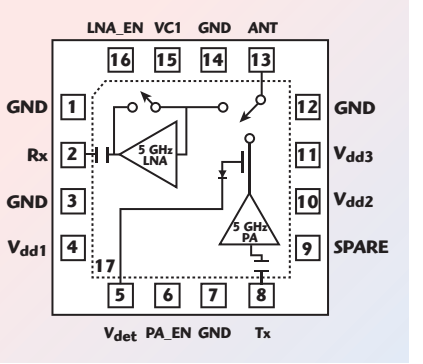
In these highly complex, integrated mobile devices, the WLAN signal must share the RF chain with crowded cellular bands. This in turn increases the need for filters and switches, resulting in greater signal losses in the transmission path of the PA. The resulting reduction in the signal-to-noise ratio makes it more difficult to achieve the required EVM. To compensate for these losses, the power output may be increased. However, as the PA approaches the power saturation level, linearity degrades. The relationship between power output and linearity typically resembles a "hockey-stick" curve; once a specific power level is exceeded, the EVM increases exponentially. The PA must therefore operate at a sufficiently backed-off power level to maintain the very low EVM required for complex 802.11ac modulation schemes.

The challenge for FEMs and PAs is to meet the EVM requirement, while producing adequate power output and minimizing current consumption. Focusing solely on WLAN performance, at the expense of power management, may compromise battery life. Conversely, focusing solely on power management may reduce WLAN performance. The tradeoff between performance and power consumption varies depending on the application; for mobile applications, the preferred tradeoff between current consumption and transmit power has been in the range of 16 to 20 dBm.

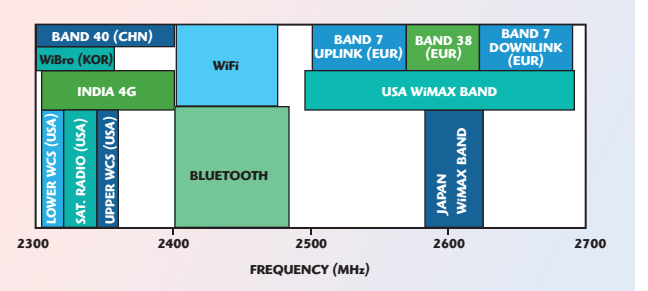
The selection of the manufacturing process technology is critical to meeting the needs of different applications. Many technologies are available for WLAN PA designs. GaAs design technologies have been developed to offer faster data-exchange rates, extended battery life and better amplification. For PAs, InGaP/GaAs HBT offers the greatest power handling capability and ruggedness, while GaAs PHEMT allows a high level of integration with switches and LNAs.

Coexistence with 2.4 GHz Cellular Networks

Though 802.11ac operates in the 5 GHz band, mobile devices will typically provide dual-band 5/2.4 GHz WLAN capability, for compatibility with existing Wi-Fi networks based on earlier standards such as 802.11n and 802.11g. To increase data rates over existing 2.4 GHz networks, some device



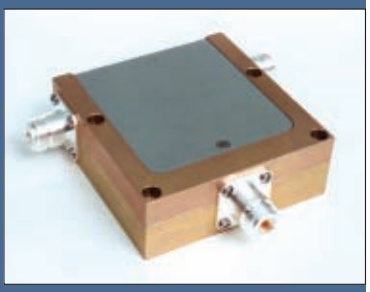
▲ *Fig. 3 Highly integrated Wi-Fi front-end module.*



▲ *Fig. 4 Scarce spectrum is leading governments worldwide to refarm existing spectrum and squeeze new wireless bands.*

HIGH POWER

100 MHz to 20 GHz



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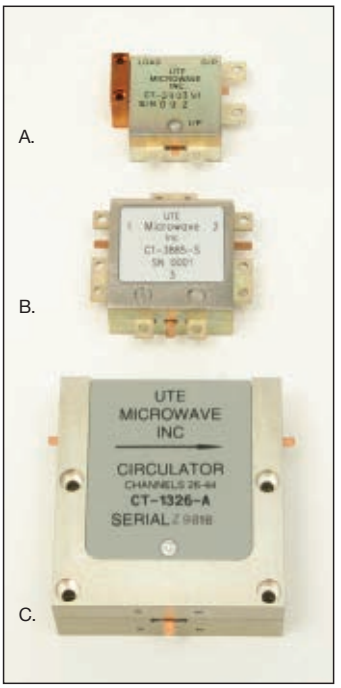

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manufacturers are expected to implement 256 QAM modulation – a key element of the 802.11ac standard – over 2.4 GHz WLAN channels. This will significantly increase 2.4 GHz WLAN performance, compared with the less-complex modulation schemes previously available with the earlier Wi-Fi standards, though the data rates will not match those available in the 5 GHz band due to other constraints of the 2.4 GHz band, such as narrower channels.

While dual-band operation offers obvious advantages, it also introduces coexistence challenges. Operating in the 2.4 GHz band increases the potential for interference with cellular communications – notably LTE networks – that utilize closely adjacent frequency bands, as shown in ***Figure 4***. Potential interference issues are multiplying quickly.

Designers, therefore, must address the potential for transmitted WLAN signals to desensitize LTE reception on the device and for LTE signals to interfere with WLAN communications. The challenges will increase as mobile devices grow in complexity; many next-generation smartphones will support up to 14 radio frequency bands.

Solving this coexistence challenge requires RF filters that are capable of rejecting closely adjacent frequencies. At the same time, the filters must minimize insertion loss in the WLAN transmission pathway, to help maintain the high signal-to-noise ratio and correspondingly low EVM required for 256 QAM modulation. Bulk Acoustic Wave (BAW) filters are particularly effective at meeting these requirements, offering significant advantages over the Surface Acoustic Wave (SAW) and ceramic filters, traditionally used for cellular applications. In the GHz range, BAWs can achieve quality factors (Q-values) that are superior to other traditional acoustic technologies. As a result of the high Q-values, the filter skirts will be very steep, while insertion losses remain low, even at the edges of the passband. While the performance of conventional SAW filters degrades at higher frequencies and reaches its practical limits at 2.5 GHz, BAW filters can address frequencies up to 6 GHz. BAW devices also have significantly less temperature dependency and much greater electrostatic discharge (ESD) robustness.

CONCLUSION

Double-digit growth is forecasted for devices enabled with 802.11ac, with annual shipments estimated to exceed 400 million by 2016. The 802.11ac standard provides substantial performance improvements over its predecessor, 802.11n. But achieving this performance will be more challenging than ever. Key design concerns include achieving low dynamic EVM, generating high power output while minimizing current consumption and coexisting with LTE cellular communications in the 2.4 GHz band. The good news is that highly integrated 802.11ac front-end modules and BAW filters are becoming available to help solve these challenges. ■

RF Characteristics of Coplanar Waveguide Fabricated on Flexible PES

A coplanar waveguide was fabricated on a polyether sulfone (PES) substrate for application to a flexible Radio Frequency Integrated Circuit (RFIC), and its RF characteristics were thoroughly investigated. According to the measured results, the coplanar waveguide on PES showed a very low loss, compared with a conventional silicon substrate. It showed an insertion loss lower than 0.6 dB/mm and an attenuation constant α lower than 0.065 Np/mm up to 50 GHz. The Q-factor of a coplanar waveguide on PES was 40.3 at a resonance frequency of 46.7 GHz. It showed a wavelength of 3.9 to 6.2 mm from 30 to 50 GHz, and an effective dielectric constant ε_{eff} of 2.35 to 2.9 from 10 to 50 GHz. The coplanar waveguide on PES showed a very weak frequency dispersion characteristic compared with silicon substrate. This work is the first known report of the investigation of RF signal transmission characteristics on PES substrate.

Flexible electronics have drawn significant attention, owing to their variety of applications such as flexible displays, smart tags and wearable products.[1-3] Especially for the development of a transparent flexible display for a mobile communication function, RF devices should be integrated into a transparent flexible substrate. Recently, polyether sulfone (PES) has drawn attention for application to transparent flexible display, due to its good heat-resisting property, high transparency and good flexibility.[4-7] The glass transition temperature (T_g) of PES is 230°C and it shows stable electrical and mechanical properties at high temperature, which enables the fabrication of electron devices at a relatively high temperature.[4-7] Because of a heat-resisting property, the electrical and mechanical properties of the PES do not change at even 300°C. Therefore, unlike other flexible substrates such as polycarbonate (PC) and polyethylene terephthalate (PET), the soldering and bonding processes for the electron devices on PES can be easily performed, which facilitates the packaging process of electronic devices. In addition, a very thin PES substrate, with a thickness less than 100 µm, can be used to fabricate electronic devices due to

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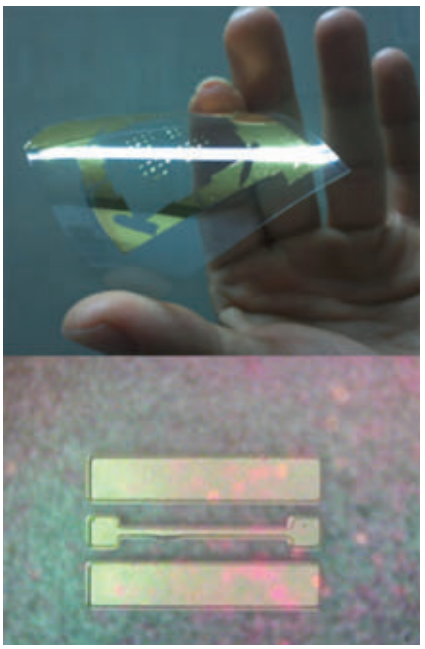
its tenacity, which is very effective for the miniaturization of RF components. Furthermore, the PES shows a contraction ratio less than 0.2 percent, even if it is exposed to a high temperature environment for a long time, which enables precise processes, such as a microelectromechanical system (MEMS) process. Besides the mentioned properties, the PES shows good water resistance.

For these reasons, PES is suitable for applications such as a transparent flexible display for mobile communications. Several groups have employed a PES substrate to evaluate the electrical properties of oxide films.[8] For applications to mobile communication flexible displays, RF passive components as well as active devices could be integrated onto PES substrates. For integration of RF passive components on a PES substrate, the RF signal transmission characteristic on a PES substrate should be thoroughly investigated. To date, no known studies of the RF characteristics of PES substrates has been performed. In this work, a coplanar waveguide was fabricated on PES substrate and its RF signal transmission characteristics were thoroughly investigated.

LOSS CHARACTERISTICS OF A COPLANAR WAVEGUIDE FABRICATED ON PES

Figure 1 shows a photograph of the coplanar waveguide fabricated on PES. Pt/Au was deposited on a PES substrate 200 µm thick, and the thickness of the Au/Ti was 2 µm. The line width W is 20 µm, and the distance between line and ground plane is 80 µm. ***Figure 2*** shows the measured insertion loss per 1 mm and the attenuation constant α of the coplanar waveguide on PES. The insertion loss was measured with a 50 Ω impedance system and was normalized to the characteristic impedance of the coplanar waveguide. For comparison, data for the same size coplanar waveguide on silicon substrate is also plotted, because silicon substrate is the most popular semiconducting substrate for RFIC applications. As shown, the coplanar waveguide on PES shows very low loss, compared to the silicon substrate. It shows an insertion loss lower than 0.6 dB/mm, and an attenuation constant α lower than 0.065 Np/mm up to 50 GHz. The low loss of the coplanar waveguide on PES originates from its excellent electrical insulat-



▲ *Fig. 1 Photograph of a coplanar waveguide fabricated on PES.*

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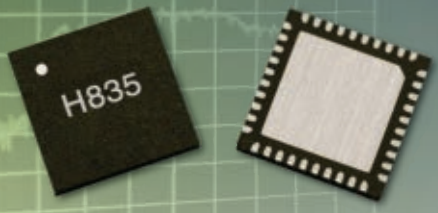

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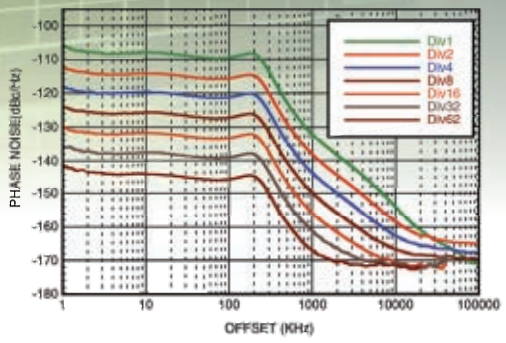
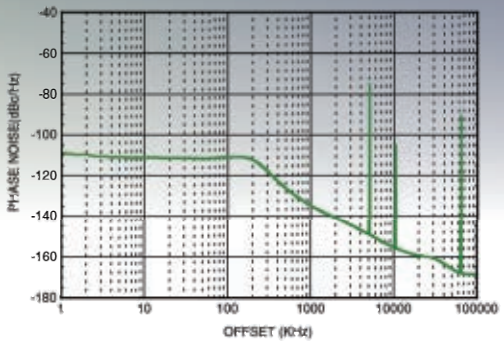


Fractional Spurious Performance at 2646.96 MHz, with Exact Frequency Mode ON or OFF



	Part Number	Frequency (MHz)	Function	Closed Loop SSB Phase Noise @ 10 kHz Offset	Open Loop VCO Phase Noise @ 1 MHz Offset	Pout (dBm)	RMS Jitter Fractional Mode (fs)	Integrated PN Fractional Mode (deg rms)
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	HMC830LP6GE	25 - 3000	Wideband PLL+VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	6	159	0.114 @ 2 GHz
	HMC832LP6GE	25 - 3000	Wideband RF VCO (+3.3V)	-114 dBc/Hz @ 2 GHz	-139 dBc/Hz @ 2 GHz	7	159	0.114 @ 2 GHz
	HMC833LP6GE	25 - 6000	Wideband PLL+VCO	-114 dBc/Hz @ 2 GHz	-141 dBc/Hz @ 2 GHz	-4	159	0.11 @ 2 GHz
	HMC834LP6GE	45 - 1050 1400 - 2100 2800 - 4200 Fo 5600 - 8400	Wideband PLL+VCO	-108 dBc/Hz @ 4 GHz	-134 dBc/Hz @ 4 GHz	5 2 2 -10	159	0.23 @ 4 GHz
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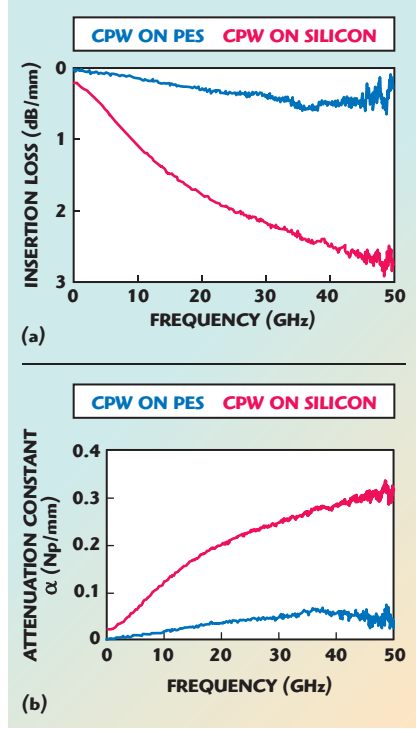
ing properties. In the case of coplanar waveguide on silicon substrate, there is a current flowing from the line to the ground plane, through the silicon substrate, due to the relatively high conductivity of silicon substrate, which causes a relatively high loss of electromagnetic energy.[9] In the case of coplanar waveguide on PES, there is no current flowing from line to ground plane through the PES substrate, due to its excellent electrical insulating characteristic.

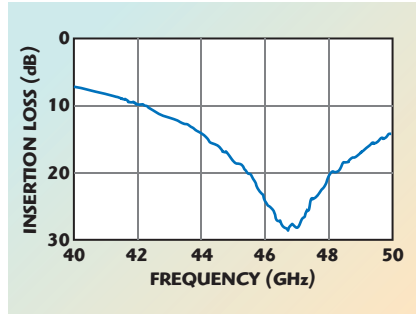
The quality (Q) factor of the coplanar waveguide on PES was also investigated. There are several methods to calculate the Q-factor.[10] Here, the transmission line Q-factor was derived from a resonator using a quarter wavelength long line at the resonance frequency f_0. The Q-factor was extracted by the ratio of –3 dB bandwidth to f_0, in other words, $Q = f_0/\Delta f_{3dB}$. ***Figure 3*** shows the insertion loss S_{21} of a quarter wavelength coplanar waveguide fabricated on PES. The Q-factor was 40.3 at a resonance frequency of 46.7 GHz. ***Table 1*** shows the Q-factors of transmission lines on PES and silicon substrate. As shown in this table, the transmission line on PES shows a Q-factor much higher than silicon substrate. The results indicate that the RF passive components on PES substrate can be used in applications at millimeter wave as well as microwave, due to its very low loss.

BASIC RF CHARACTERISTICS OF COPLANAR WAVEGUIDE FABRICATED ON PES

Figure 4 shows the wavelength of the coplanar waveguide on PES to be 3.9 to 6.2 mm from 30 to 50 GHz. In a highly integrated RF circuit, bulky passive components as well as transis-



▲ *Fig. 2 Loss characteristics of coplanar waveguide on PES and silicon substrates.*



▲ *Fig. 3 Measured insertion loss of a quarter wavelength coplanar waveguide fabricated on PES.*

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tors could be integrated onto the PES substrate. One of the largest RF components is a branch-line coupler, which is usually fabricated on PCB, not on semiconducting substrate due to its large size. To evaluate the integration capacity of RF passive components on PES substrates, the size of branch-line couplers consisting of λ/8 transmission lines[12] was calculated from the wavelength and is listed in ***Table 2***. As shown, the size of branch-line couplers is much less than 1 mm^2 over a frequency range of 30 to 50 GHz, which indicates that bulky passive components can be integrated onto a PES substrate with a small chip size in the millimeter wave frequency range.

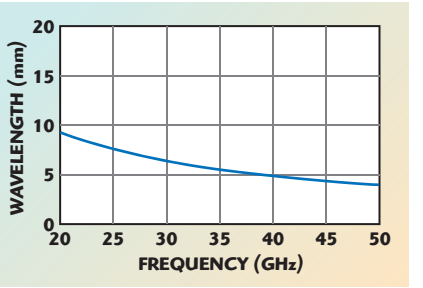
Figure 5 shows the characteristic impedance Z_0 of coplanar waveguides on PES as a function of line width. A characteristic impedance Z_0 of 50 to 160 Ω is obtained for a line width range of 10 to 110 µm. From this result, it can be seen that coplanar waveguides of various characteristic impedances can be realized on a PES substrate by only changing the line width W. They can be used for matching between RF components of various impedances.

Figure 6 shows the propagation constant β of the coplanar waveguide on PES. The coplanar waveguide on PES shows a β of 0.35 to 1.61

TABLE I

Q FACTOR OF A 20 µm WIDE LINE ON PES AND SILICON SUBSTRATES

Item	Q Factor	Frequency (GHz)	Type	Method
PES	40.3	46.7	Coplanar Waveguide	$f_0/\Delta f_{-3dB}$
Silicon[9]	6.3	40	Microstrip Line	$f_0/\Delta f_{-3dB}$
Silicon[11]	13	47	Microstrip Line	ωL/R
Silicon[11]	23	47	Coplanar Waveguide	ωL/R

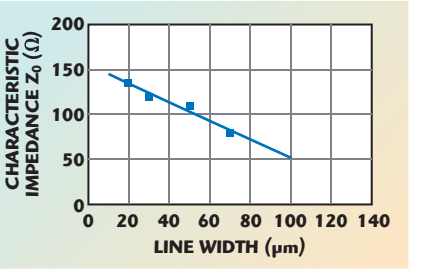


▲ *Fig. 4 Measured wavelength of a coplanar waveguide on PES.*

TABLE II

SIZE OF BRANCH-LINE COUPLERS CONSISTING OF λ/8 TRANSMISSION LINES ON PES

Frequency (GHz)	Size of Branch-line Couplers (mm^2)
30	0.619
40	0.36
50	0.239



▲ *Fig. 5 Measured characteristic impedance of coplanar waveguides on PES.*

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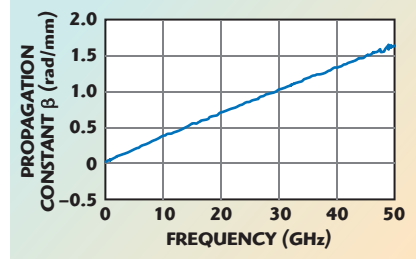
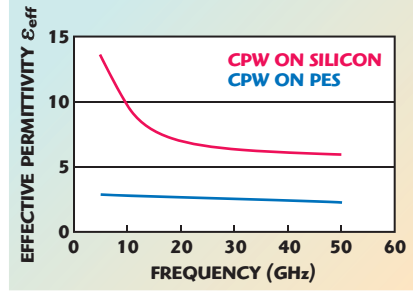
rad/mm from 10 to 50 GHz. ***Figure 7*** shows the high frequency effective permittivity ε_{eff} of the coplanar waveguide on PES. For a comparison, the ε_{eff} of the coplanar waveguide on silicon substrate is also plotted. As shown, the ε_{eff} of the coplanar waveguide on PES is lower than that of the silicon substrate. The coplanar waveguide on PES shows an ε_{eff} of 2.35 to 2.9 from 10 to 50 GHz, while the coplanar waveguide on silicon substrate shows an ε_{eff} of 5.9 to 13.6 from 10 to 50 GHz. Due to the lower ε_{eff}, the physical length of coplanar waveguide on PES is longer than on a silicon substrate for the same electrical length. ***Table 3*** shows the length of a $\lambda/8$ coplanar waveguide on PES and silicon substrate. The coplanar waveguide on a silicon substrate shows strong frequency dispersion characteristics. This tendency originates from the existence of various propagation modes on the oxide/silicon substrate. The skin-effect and slow-wave mode of propagation exists, in addition to the quasi-transverse electromagnetic (quasi-TEM) mode on oxide/silicon substrates, which causes a large change of ε_{eff} between 1 and 20 GHz.[9] On the other hand, the coplanar waveguide on PES shows a very weak frequency dispersion characteristic, compared to a silicon substrate, because the quasi-TEM mode propagates dominantly on the metal/high-insulating substrate structure.[13] The above results indicate that the coplanar waveguide on PES is suitable for broadband applications, due to its very weak frequency dispersion characteristic.



▲ *Fig. 6 Measured propagation constant β of the coplanar waveguide on PES.*



▲ *Fig. 7 Effective permittivity ε_{eff} of the coplanar waveguide on PES and silicon substrates.*

CONCLUSION

In this work, a coplanar waveguide was fabricated on a PES substrate and its RF characteristics were thoroughly investigated for the first time. The coplanar waveguide on PES showed a very low loss compared with a conventional silicon substrate. It showed an insertion loss lower than 0.6 dB/mm and an attenuation constant α lower than 0.065 Np/mm up to 50 GHz. The transmission line Q-factor was derived from a resonant tank built using a one-quarter wavelength long line at the resonance frequency f_0. According to a measured result, it was found that the Q-factor of a coplanar waveguide on PES was 40.3 at a resonance frequency of 46.7 GHz. The coplanar waveguide on PES showed a wavelength of 3.9 to 6.2 mm from 30 to 50 GHz, which means that bulky passive RF components can be integrated onto a PES sub-

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strate with a small area in the high frequency range. The sizes of conventional branch-line couplers consisting of λ/8 transmission lines on PES are smaller than 0.619 mm² from 30 to 50 GHz. Compared with a silicon substrate, the coplanar waveguide on PES showed lower ε_{eff}. The coplanar waveguide on PES shows an ε_{eff} of 2.35 to 2.9 from 10 to 50 GHz, which caused a physical length of transmission line longer than for a silicon substrate. The coplanar waveguide on PES showed a very weak frequency dispersion characteristic compared with a silicon substrate, which means that the coplanar waveguide on PES is suitable for broadband applications. The results indicate that the PES is a promising candidate for application to flexible RFIC at high frequencies. This work is the first known report of an investigation of RF signal transmission characteristics on a PES substrate. ■

TABLE III

LENGTHS OF λ/8 COPLANAR WAVEGUIDES ON PES AND SILICON SUBSTRATES

Frequency (GHz)	PES (mm)	Silicon (mm)
30	0.78	0.5
40	0.6	0.38
50	0.48	0.31

ACKNOWLEDGMENT

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Screen Printed RFID-Enabled Temperature Sensor Fabricated on Flexible Substrates

RFID tags are often used in supply chain management and storage of a wide range of goods. In many cases, it is necessary to control environmental conditions because many products are sensitive to low or elevated temperature. Currently, this is carried out mostly with the use of indicators or expensive and complicated sensors. The latter contains electronic components, which make them inflexible. Indicators exhibit durability to bending but cannot be read wirelessly. As a result, they have to be placed outside a package and can be destroyed. A screen printed RFID-enabled temperature sensor, both flexible and wirelessly read, was developed and tested. It was fabricated with silver paste on a foil or paper. This sensor works in the UHF frequency range and provides a maximum read distance of 80 cm. Its properties were investigated with regard to the materials used, as well as environment and storage temperature.

Radio Frequency Identification (RFID) is one of the most popular automatic identification systems. It is often used in supply chain management and logistics.[1,2] Many types of goods, such as dairy products or medicines, are susceptible to the influence of elevated temperature. Therefore, it is required to control their transportation or storage conditions. Otherwise, it can lead to their deterioration or even loss.

Nowadays, the temperature in a product environment is measured by various techniques. Semi-passive RFID systems are one of them. Their main component is a temperature logger, which records the temperature level and sends it to a reader. However, this device contains a battery that limits its lifetime and makes its unit cost higher, compared to RFID tags manufactured with printing techniques, such as inkjet,[3,4] screen printing[5,6] or photogravure.[7]

The temperature is also controlled with indicators, which have a much lower unit cost than loggers. Their color changes when the temperature increases.[8] Their main disadvantage is the optical method to identify their state. It is inconvenient and makes the temperature control efficiency lower.

Currently, more and more studies are focused on RFID-enabled sensors, consisting of an antenna, a chip and an active element. These devices can be read wirelessly, so it is possible to place them inside a package to avoid their damage. Yao et al.[9] described a low power temperature sensor with excellent power supply variation rejection ability for RFID tags. Other investigations were performed by Shenghua et al.[10] and by Zhang et al.[11] A temperature sen-

Kamil Janeczek, Małgorzata Jakubowska, Grażyna Kozioł and Wojciech Stęplewski
Tele & Radio Research Institute, Warsaw, Poland

sor integrated with a low power RFID tag chip was manufactured with 0.18 µm standard CMOS technology.

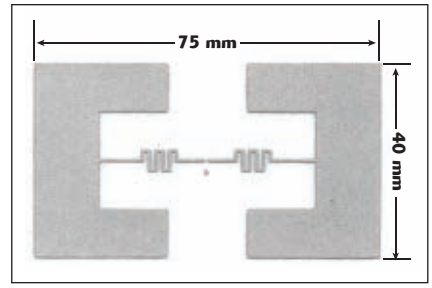
Other studies were presented by Guerin et al.[12] and by Yang et al.[13] A platinum-deposited based wireless temperature sensor was described by Guerin et al. based on a resistance change with temperature variations, which was combined with the frequency of a backscattering modulated signal. Yang et al. fabricated a wireless sensor transmitter, produced by an inkjet printing technique. It was a register, fitted with a temperature sensor and other electronic components, like quartz oscillator or battery. Thus, it was not flexible.

In this article, an RFID-enabled temperature sensor, manufactured on flexible substrates with screen printing techniques, is described. A UHF antenna was designed with the FEKO Suite and screen printed with a silver paste. A chip was assembled with a conductive adhesive and encapsulated with a fast flow underfill to increase its mechanical durability. An active element was printed with three types of silver pastes. The properties of the prepared temperature sensors were examined by reaction time measurements, depending on a substrate material and testing temperature level. In addition, their lifetime and read distance were estimated.

EXPERIMENTAL

The UHF antenna, shown in ***Figure 1*** and used in the RFID-enabled sensor, was designed with the simulation software FEKO Suite. Its return loss was taken into consideration. In the simulation, it was assumed that the antenna was made from silver on a foil (dielectric permittivity of 2.9, dissipation factor of 0.005 and thickness of 125 µm).

Then the simulated antenna was manufactured using a screen printing technique with a polyester mesh screen 68T. A polyethylene naphthalate (PEN) foil (Teonex Q51, from DuPont Teijin Films) and a photo paper (Everyday 180 g/m^2, from Emtec) were used as substrate materials. The EL/Ag paste used for the antenna printing contained 70 percent weight silver flakes dispersed in a conductive polymer PEDOT:PSS in the form of an EL-P3040 paste (Agfa Gavaert). After the screen printing process, the antennas were cured at 120°C for 15 minutes.



▲ *Fig. 1 UHF antenna designed in this study.*

In the next step, an RFID chip in an SOT-323 package (Alien Technology) was attached to the antenna using a conductive adhesive Ecolit 3654 (Panacol), which was cured at 120°C for 10 minutes Then these components were encapsulated with a fast flow underfill e1216 (Emerson & Cuming) and cured at 130°C for 10 minutes. Their shear force before and after encapsulation was measured with a Force Testing System Mecmesin i-1.

Finally, an active element of the RFID-enabled sensor was printed with the EL/Ag paste, a commercial silver paste PF-050 (OEM Electronics) and an SF paste. The last one consisted of 66 percent weight of silver flakes dispersed in a poly(methyl methacrylate)-poly(butyl methacrylate) (PMMA-PBMA) dissolved in butyl carbitol acetate with a concentration of 10 percent weight. After the printing process, all the pastes were cured at 120°C for 15 minutes.

The reaction time and long term stability of the active element of the fabricated RFID-enabled sensor were measured. The first parameter was defined as the time period to decrease the resistance of an active element below 100 Ω. It was estimated by continuous resistance measurements, during exposure to elevated temperatures (80° to 140°C). The stability of the active element resistance was evaluated by its measurements after storage in ambient conditions and in a refrigerator (-4°C) or in a freezer (-12°C). The read distance of an elaborated sensor was measured using an RFID reader tt8300 t+t netcom.

SENSOR CONCEPTION

The sensor was constructed, based on the idea that under elevated temperature, its resistance will change rap-

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idly. The resistance decrease is permanent so it was not possible to increase it again. An electrical schematic of the designed sensor is shown in ***Figure 2***.

The power wave reflection coefficient S_{11} can be expressed by the following equation:[15]

$$S_{11} = \frac{Z_{ant} - Z^*_{obc}}{Z_{ant} + Z_{obc}} \quad (1)$$

where Z_{obc} is the load impedance.

The antenna impedance Z_{ant} is equal to:

$$Z_{ant} = R_a + jX_a \quad (2)$$

where

$$R_a = R_{rad} + R_{str} \quad (3)$$

$$X_a = X_L + X_C \quad (4)$$

R_{rad} is the radiation resistance, R_{str} is the antenna loss resistance and X_L and X_C are the inductive and capacitive reactances of the antenna.

In the designed temperature sensor, a change in the antenna resistance R_a took place:

$$R'_a = R_{rad} + R_{str} + R_s \quad (5)$$

Along with an increase in the resistance R_S, the antenna loss resistance (R_{str} + R_s) increased. It resulted in a decrease of the power of the backscattering signal received by an RFID reader. When R_S decreases rapidly, most of the signal transmitted to a reader was interpreted as an exposure of a sensor to elevated temperature.

The schematic diagram of a fabricated RFID-enabled temperature sensor is shown in ***Figure 3***. The main part of the sensor is an active element, a layer of silver paste placed in a gap in an antenna circuit (see ***Figure 4***). The two layers (PEN foil and an adhesive tape) on the top of the sensor were used to protect the active element against external conditions, such as humidity or dust. They also prevent against rapid evaporation of the solvent contained in the silver paste.

RESULTS AND DISCUSSION

Antenna Simulation

The UHF antenna was simulated by the FEKO Suite software in the frequency range of 0.5 to 1.5 GHz (see ***Figure 5***). Its return loss was taken into consideration. The basic resonant frequency of the designed antenna was 876 MHz for the load impedance of Z = (32 - j228) Ω. The bandwidth of the antenna was greater than 200 MHz, which fully covers the UHF frequency band 860 to 960 MHz.

Chip Assembly

The mechanical durability of the assembled RFID chips was tested by shear force measurements. For all non-encapsulated chips, regardless of the substrate used (foil or paper),

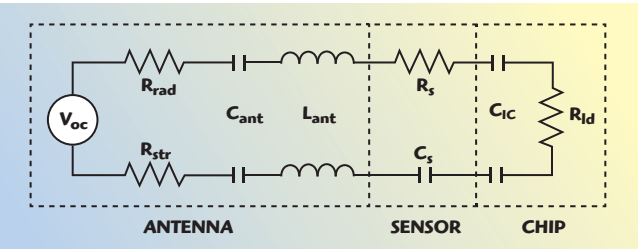


Fig. 2 Schematic of the temperature sensor.

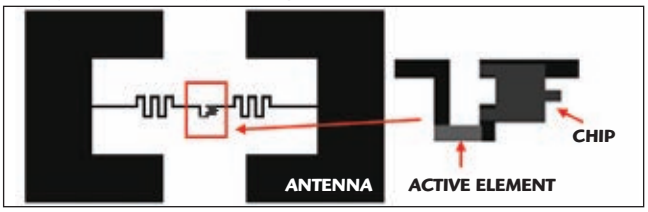


Fig. 3 Schematic diagram of the RFID-enabled temperature sensor.

Fig. 4 Cross-section of the sensor.

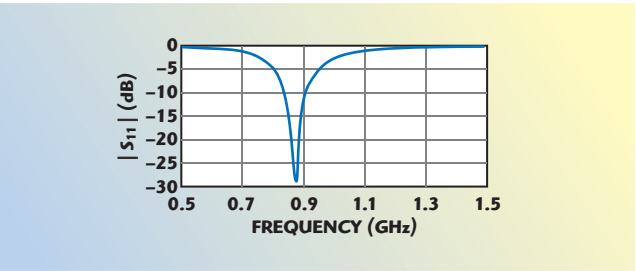
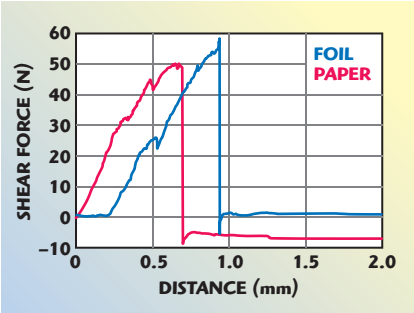
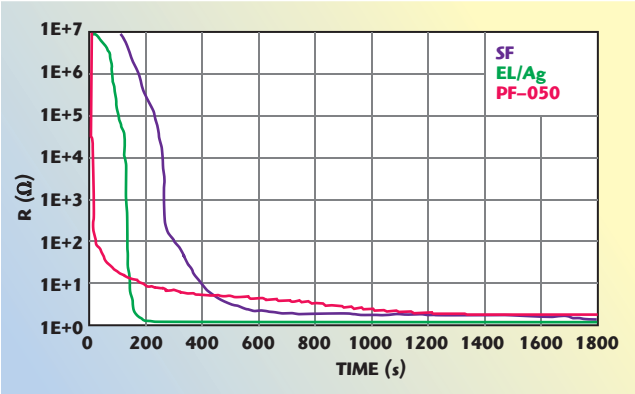


Fig. 5 Simulated S_{11} vs. frequency for the load impedance Z = (32 - j228) Ω.



▲ *Fig. 6 Shear force of the encapsulated chips assembled on foil and paper.*



▲ *Fig. 7 Resistance of an active layer depending on exposure time to 120°C.*

the measured shear force was below 1 N. Its value was insufficient for practical applications and therefore the chips were encapsulated. It resulted in an increase of shear force up to 50 ± 7 N for the chips assembled on paper and up to 58 ± 11 N for the chip mounted on foil (see ***Figure 6***).

The higher value of the shear force for encapsulated chips resulted from an increase of the bonding force between them and the substrate, resulting from a larger bonding surface. A type of substrate seemed to have an impact on a mechanical durability of the assembled chips. The surface of the polymer coated paper cracked during the shear test and this could contribute to a lower value of shear force in comparison to foil.

TABLE I

REACTION TIME OF A PF-050 SENSOR VERSUS TESTING TEMPERATURE

Temperature (°C)	*Reaction Time (s)*
80	1198 ± 48
100	187 ± 22
120	30 ± 10
140	10 ± 3

Sensor Properties

A basic parameter, describing properties of the investigated sensor, was the reaction time. As mentioned in the experimental section, the reaction time was defined as a period in which the resistance of an active element decreased below 100 Ω. It was evaluated for the temperature of 80°, 100°, 120° and 140°C. Under the influence of a temperature increase, a paste started to polymerize as a result of a solvent evaporation. Thus, the resistance of an active layer decreased rapidly (see ***Figure 7***).

The measured reaction time for active layers printed with the pastes: PF-050, EL/Ag and SF was equal to 30 ± 10 s, 135 ± 5 s, 315 ± 15 s, respectively. Its value depended strongly on the type of paste used, particularly on the solvent type. In the material (EL/Ag), a commercial paste (EL-P3040) was utilized as a polymer carrier. According to the manufacturer recommendation,[14] its curing conditions should be 120°C for only 3 minutes. In the case of the paste (SF) the curing temperature of the printed layer was also 120°C, but the time was 15 minutes. The five times longer curing time could cause the solvent to evaporate from this material much slower and in consequence, the SF sensor exhibited longer reaction time.

The reaction time depended also on the testing temperature (see ***Table 1***). At higher temperatures, polymerization occurred faster because of faster solvent evaporation. This resulted in shorter reaction time. Based on the achieved results, a model describing the reaction time against temperature is proposed. It can be expressed as:

$$t = (2.6 \times 10^{19})T^{-8.584} \qquad (6)$$

where t is the reaction time and T is the temperature.

In the case of a sensor printed on paper, it was not possible to evaluate

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TABLE II

AVERAGE LIFETIME OF SENSORS PRINTED ON FOIL FOR DIFFERENT TESTED PASTES

Storage Temperature (°C)	Lifetime (h)/Type of Paste		
	L-121	PF-050	EL/Ag
21	1146 ± 522	96 ± 48	820 ± 164
4	3540 ± 674	720 ± 232	4332 ± 704
-12	4836 ± 583	3564 ± 314	6254 ± 856

its properties. Solvents were absorbed by the substrate immediately after the printing process and, in consequence, the resistance of the active element decreased rapidly.

The second estimated parameter of sensors was their lifetime. It was evaluated depending on the storage temperature. The results shown in ***Table 2*** show that the lifetime, defined as a period in which the resistance of an active layer decreased below 100 Ω, increased when samples were stored in a colder environment. This was a result of a slower solvent evaporation.

The last tested parameter, which characterized the developed sensor, was the read distance. Its maximum value was 80 cm, placing the sensor inside a package for practical applications.

CONCLUSION

In this article, the measurement results of reaction time and lifetime for a screen printed RFID-enabled sensor fabricated on flexible substrates are presented. It is stated that the measured reaction time depended on the type of paste used and testing temperature. Its value was from 10 to 1198 s, when the testing temperature increased from 80° to 140°C. At 120°C, the reaction time was equal to 30 ± 10 s, 135 ± 5 s, 315 ± 15 s for the pastes PF-050, EL/Ag and SF. The maximum read distance of the developed sensor was 80 cm. The sensor was functional for at least for 3564 h (more than 148 days), which made them applicable in practical applications. ■

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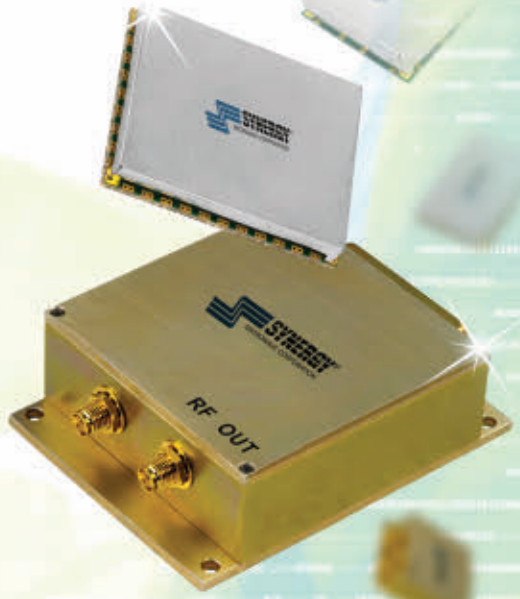

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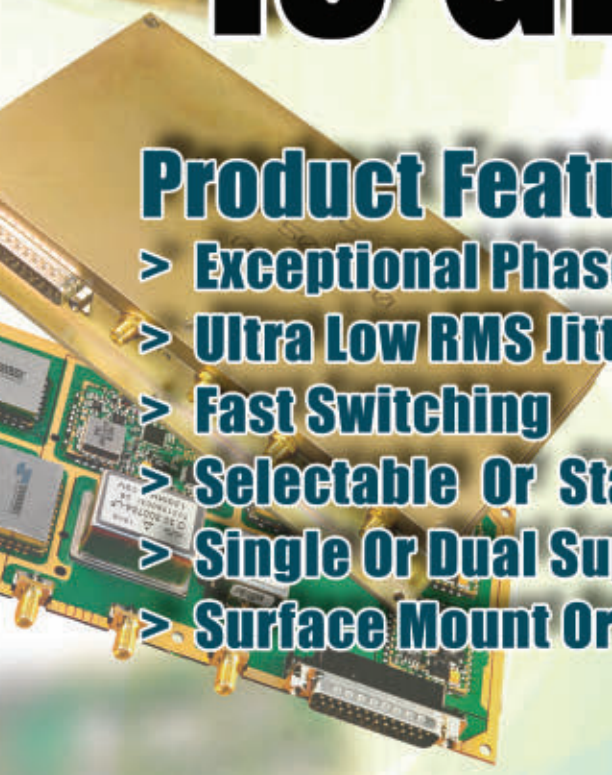

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Analog Devices' driver amplifiers incorporate a dynamically adjustable biasing circuit that allows for the customization of OIP3 and P1dB performance from 3.3 to 5 V, without the need for an external bias resistor. This feature gives the designer the ability to tailor driver amplifier performance to the specific needs of the design. The adjustable bias also allows for the drivers to be dynamically biased in order to conserve power consumption when the full performance of the driver amplifier is not required, such as when a system is in standby mode. This scalability reduces the need to

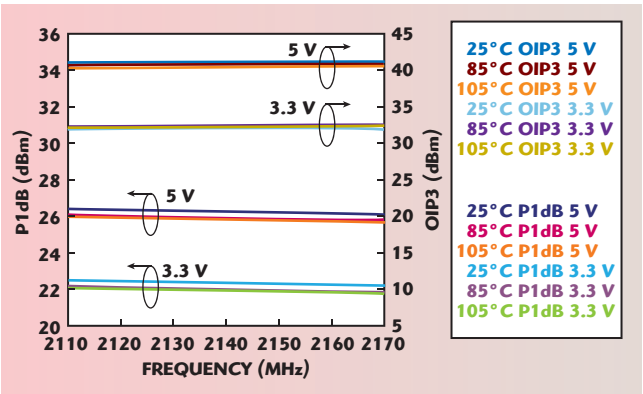

Fig. 1 ADL5320 OIP3 and P1dB performance vs. voltage bias.

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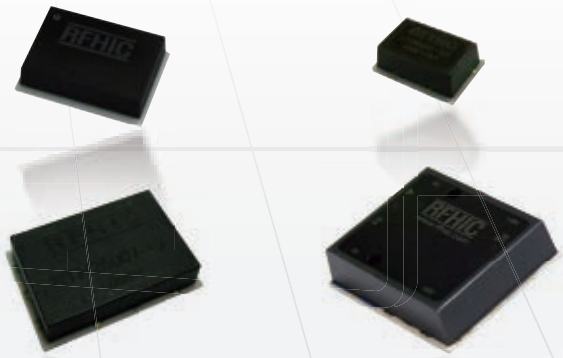

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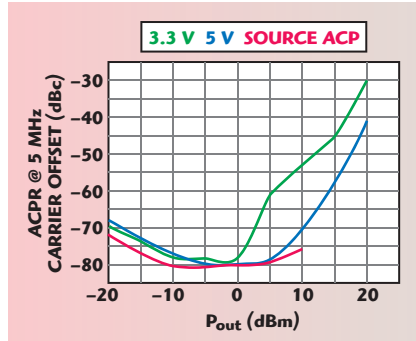
The ADL5320 GaAs HBT ¼ W driver amplifier operates from 700 to 2700 MHz, and consumes a low 5 V current of 104 mA. When operated at 5 V, the ADL5320 delivers a high level of performance at 880 MHz with an OIP3 of 45 dBm, a P1dB of 25.4 dBm, a gain of 16.9 dB and a low noise figure of 4.1 dB. When the bias voltage is reduced to 3.3 V, the driver only consumes 44 mA and delivers an OIP3 of 34 dBm, a P1dB of 21.5 dBm (see ***Figure 1***), a gain of 15.6 dB, and a lower noise figure of 3.2 dB at 880 MHz. The driver amplifier can also be biased anywhere from 3.3 up to 5 V to meet system needs that are in between the performance stated at 3.3 or 5 V. This feature creates the opportunity for dynamic biasing of the driver amplifier where a variable supply is used to allow for full 5 V biasing under large signal conditions, and then reduced supply voltage when signal levels are smaller and lower power consumption is desirable. The driver can deliver 16 dBm of output power at 2140 MHz, while achieving an ACPR of –55 dBc at 5 V. If the bias is reduced to 3.3 V the –55 dBc ACPR output power only minimally reduces to 9 dBm (see ***Figure 2***).

The ADL5321 GaAs HBT ¼ W driver amplifier operates from 2300 to 4000 MHz and consumes a low 5 V current of 90 mA. When operated at 5 V, the ADL5321 delivers a high level of performance at 2600 MHz with an OIP3 of 41 dBm a P1dB of 25.7 dBm, a gain of 14 dB, and a low noise figure of 4 dB. When the bias voltage is reduced to 3.3 V, the driver only consumes 37 mA and delivers an OIP3 of 31 dBm, a P1dB of 22 dBm, a gain of 12.6 dB and a lower noise figure of 3.5 dB at 2600 MHz. The driver amplifier can also be biased anywhere from 3.3 up to 5 V with its dynamically adjustable bias.



▲ *Fig. 2 ADL5320 ACPR performance vs. voltage bias.*

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EuRAD 2013
The 10th European Radar Conference
Co-sponsored by: AESS, APS

43rd European Microwave Conference 2013
The 43rd European Microwave Conference
Co-sponsored by: APS

EuMIC 2013
The 8th European Microwave Integrated Circuits Conference
Co-sponsored by: Electron Devices Society, GAAS

The ADL5324 GaAs HBT ½ W driver amplifier consumes a low 5 V current of 133 mA and also delivers very high performance at 2140 MHz with an OIP3 of 43.1 dBm, a P1dB of 29.1 dBm, a gain of 14.6 dB and a low noise figure of 3.8 dB. When the bias voltage is reduced to 3.3 V, the driver only consumes 62 mA and delivers an OIP3 of 34.4 dBm, a P1dB of 25.3 dBm, a gain of 13.6 dB and a lower noise figure of 3.2 dB at 2140 MHz. The driver amplifier can also be biased anywhere from 3.3 up to 5 V with its dynamically adjustable bias. The driver can deliver greater than 17 dBm of output power at 2140 MHz, while achieving an ACPR of –55 dBc at 5 V. If the bias is reduced to 3.3 V, the –55 dBc ACPR output power only minimally reduces to 15 dBm.

The three drivers further simplify RF design by eliminating the need for complicated external tuning. The drivers only use 50 Ω lines at the input and output of the amplifier, and also do not require an external bias resistor. The drivers only need one shunt capacitor at its input and one shunt capacitor at its output for frequency tuning. The usual AC coupling capacitors and DC bias choke inductor are also required, along with the standard bypass capacitance on the DC bias trace.

The driver amplifiers were also designed and packaged to simplify thermal considerations. The drivers have very low current consumption at either 3.3 or 5 V, which reduces the amount of heat that is created. The standard SOT-89 package also has a large backside ground paddle that allows for an efficient thermal transfer path from the amplifier. The datasheets show the recommended circuit board land pattern with added thermal transfer vias to further improve thermal transfer characteristics. This allows the driver to be kept within safe operating temperatures without the need for forced air cooling, and the driver is fully specified over the widest operating temperature range of –40° to +105°C. The drivers are also rated to a minimum HBM ESD rating of ±2 kV (Class 2), which makes it equally robust in high volume manufacturing environments.

Another way Analog Devices helps improve RF design is with the amount of information provided in the company's datasheets. Data provided, such as critical parameter variation versus temperature, from –40° to +105°C, voltage supply, from 3.3 to 5 V, and operating frequency, from 400 to 4000 MHz, reduces the amount of qualification time a designer needs to spend. That reduction in qualification time can significantly improve a projects' time-to-market. The comprehensive datasheet also allows the designer to accurately determine the least amount of power consumption achievable to meet the performance goals for his or her given application.

Analog Devices improves RF design in multiple ways: through innovative circuit design, simplified tuning requirements, and detailed datasheet information. These attributes allow RF designers to go to market quickly with solutions that meet their needs for smaller, lower power consuming systems.

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

Highly Integrated 60 GHz Radio Transceiver Chipset

The demand for high capacity data continues to grow at accelerating rates fueled by high data rate consumer applications, feature rich smartphones, video applications and the overall growth and use of the Internet. The 7 GHz of unlicensed spectrum available from 57 to 64 GHz offers wide bandwidth along with signal propagation properties that are ideal for short range multi-Gbps data communications. However, providing a complete radio at millimeter-wave frequencies can be a significant challenge requiring advanced materials and sophisticated design techniques.

Hittite has addressed many of the challenges by offering a highly integrated 60 GHz radio transceiver chipset, the HMC6000 and HMC6001, along with QFN packaged versions complete with integrated antennas, the HMC6000LP711E and HMC6001LP711E. The HMC6000 and HMC6001 contain everything required to convert between 60 GHz and analog IQ baseband with no external components beyond a lower frequency crystal oscillator reference. The HMC6000LP711E and HMC6001LP711E integrate these chips with a 7.5 dBi gain antenna in a low cost 7 × 11 mm plastic QFN package to provide a complete air-interface solution. The HMC6000LP711E and HMC6001LP711E support RF bandwidths up to 1.8 GHz, and feature a transmit EIRP up to 23.5 dBm and receiver noise figure of less than 7 dB.

Now Hittite is offering an evaluation kit, the EKIT01-HMC6450, for these antenna-in-package (AiP) components. The EKIT01-HMC6450 AiP transceiver evaluation kit, with two pairs of HMC6000LP711E and HMC6001LP711E AiP solutions, comes with software to control all of the functionality of the chips through an easy-to-use graphical user interface. This interface has both high level commands such as channel selection, gain and attenuation settings and filter control, as well as access to read and write from every low level register within the chips. The kit contains all of the supporting power supplies, reference clock and USB interface along with phase matched MCX to SMA connectors for the baseband differential interfaces to a customer's modem solution or test equipment. With the kit, a user can quickly set up a millimeter-wave link of up to 5 m at 60 GHz with universal analog I and Q interfaces for the rapid development of multi-Gbps data solutions.

VENDORVIEW

Hittite Microwave, Chelmsford, MA, sales@hittite.com, www.hittite.com.

Tech Brief

Planar K-Band Receiver

One of Spacek Labs' receivers in its line of planar components and systems, Model P1R-29B3-2208Y, combines exceptional functionality with compact size. This system is a rugged, high performance, full K-Band (18 to 26.5 GHz) planar receiver. Each receiver operates over an LO band of 28 to 31 GHz. If a lower frequency LO band is desired, the unit can be equipped with an integrated LO frequency doubler for a 14 to 15.5 GHz LO band. The internal modular design of the housing allows any unit to be retrofitted with different options with a minimum of effort and cost. This allows systems to be customized for any given application. The housing is designed to reduce EMI/RFI.

With K-Band communication and radar systems requiring increasingly better performance, this receiver can deliver. With a low noise figure of 3.5 dB, high conversion gain, and a flat response of 3 dB, this will make your systems performance exceed expectations. To achieve full K-Band operation, a wide IF bandwidth of 1 to 13 GHz, with filtering, is used. The unit can operate using a wide range of LO drive levels. Options exist for LO drive levels from as low as 0 dBm to as high as +16 dBm.

This planar receiver has a large set of options to meet a wide variety of specifications. With Spacek's in-house design and manufacturing capabilities, the units can be modified to meet any of your design requirements.

Spacek Labs Inc.,
Santa Barbara, CA
(805) 564-4404,
www.spaceklabs.com.

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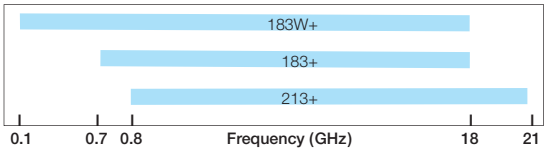
NEW ZVA-183WX+	0.1-18	28±3	27	35	4.0	1345.00
ZVA-183X+	0.7-18	26±1	24	33	3.0	845.00
ZVA-213X+	0.8-21	25±2	24	33	3.0	945.00

* Heat sink must be provided to limit base plate temperature.To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance



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IF/RF MICROWAVE COMPONENTS

440 rev M

Wideband Frequency Mixer

Mini-Circuits has released a new wideband mixer, ZX05-24MH+, operating from 7.5 to 20 GHz with an LO power of +13 dBm. The ZX05-24MH+ has low conversion loss of 7 dB typical (at 30 MHz IF), IP3 of 16 dBm, high LO-RF isolation of 30 dB typical, LO-IF isolation of 15 dB typical and wide IF bandwidth from DC to 7.5 GHz. It has a rugged construction, small size and can be utilized as an up and downconverter. It is housed in a small coaxial package (0.74" × 0.90" × 0.54") with SMA connectors and is RoHS compliant.

Maximum ratings include an operating temperature of –40° to 85°C, storage temperature of –55° to 100°C and RF power of 50 mW. The ZX05-24MH+ is well suited for applications such as fixed satellite, mobile and radio location.

Mini-Circuits offers a broad range of catalog mixers up to 20 GHz including state-of-the-art high dynamic range FET based designs with IIP3 up to +37 dBm and broadband surface-mount designs covering 5 to 20 GHz. LO levels span 0 to +27 dBm and include both single function mixers and an integrated mixer such as image rejection and integrated LO and IF amplifiers.

VENDORVIEW

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

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– Edwin Rorie, Telecommunications Specialist, Defense Information Systems Agency

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– Bill Flynn, Director, Navy Programs, AMERICOM Government Services

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– Jeffrey Carl, Sr. Offer Manager, AT&T

"It was the largest I've attended to date, with more exhibits and more of the latest technology on display."

– Kalu Kalu Oji, Chief Engineer (ICT), Ministry of Foreign Affairs

"Opportunity to meet in a very short time with customers and vendors otherwise scattered around the globe."

– Marshall Bloom, R CBPO, Homeland Security

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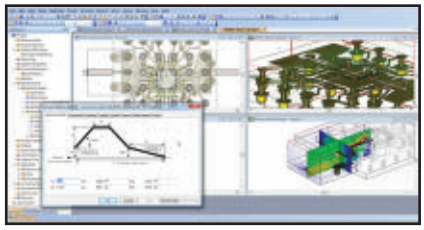
Software and Mobile Apps

Design Environment Update

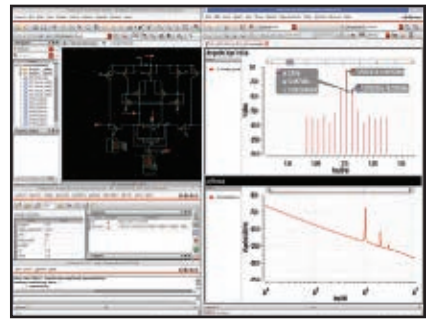
VENDORVIEW



AWR, the innovation leader in high-frequency EDA software, has announced AWR Design Environment™ V10.04, its first new software release in 2013. This update includes new features and enhancements to Microwave Office®/Analog Office® high-frequency circuit design software, Visual System Simulator™ (VSS) system design software, AXIEM® 3D planar electromagnetic (EM) software and Analyst™ 3D finite element method (FEM) EM software. AWR's software product portfolio is designed to streamline circuit and system design for maximum productivity and product performance.

AWR Corp.
www.awrcorp.com

Simulation Solution

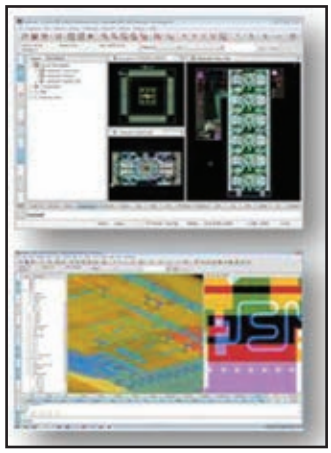


Cadence announced the next major release of Spectre® RF, a production proven, accurate and high performance simulation solution for a broad set of applications. It provides a platform for exhaustive simulation with its unique and comprehensive analyses and support for industry standard models, integrated in the Virtuoso Analog Design Environment. The latest release, MMSIM 12.1, features new user interface enhancements, support for new passive components, improved scalable multi-core performance and improved support for S-parameter simulation.

Cadence Design Systems Inc.
www.cadence.com

Design Automation Software

VENDORVIEW



Intercept Technology released version 7 of its Pantheon PCB Layout software, which includes embedded design flows for RF and hybrid design. The new award winning Pantheon version includes a completely redesigned user interface with significant performance and productivity increases across the entire design team user flow. New features include icons and toolbars designed to maximize project window space, windows that can be undocked and placed outside the application window, a Project Explorer for faster location and selection of components and nets, and a quick search toolbar.

Intercept Technology
www.intercept.com

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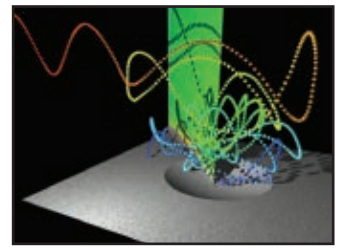
Updated Model Library

Modelithics announces the release of Modelithics® COMPLETE Library version 9.6 for Agilent's Genesys RF simulation software. It contains the complete updated and enlarged collection of passive and active component model libraries offered by Modelithics for Genesys to date. This new simulation model library release introduces over 30 new scalable Global Models for popular surface mount RLC component families from vendors such as Kemet, AVX, Coilcraft, Murata, Temex and Taiyo-Yuden. Version 9.6 of the COMPLETE library also offers 30 additional nonlinear models for diodes and transistors, including a new substrate-scalable SRD model.

Modelithics Inc.
www.modelithics.com

Particle-in-Cell Simulation Tool



Tech-X Corp. announced the release of Vorpal 6.0. New in the release is the customization of Vorpal for targeted industries. With the VSimEM package for electrostatic and electromagnetic problems, VSimMD for the microwave device optimization, VSimPA for plasma acceleration simulations, VSimPD for plasma discharge simulations, VSimBase for the educational market and VSimPro, which provides the full features of Vorpal, the pricing and use of Vorpal is more flexible and more focused on meeting the needs of customers.

Tech-X Corp.
www.txcorp.com

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- RF PCB Design
- Introduction to Antenna Simulation with COMSOL Multiphysics
- Radar Fundamentals II - Pulse Doppler Radar

CST Webinar Series
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- Chip/Package/Board: Constraint Driven Co-Design
- Simulation of Wearable Antennas for Body Centric Wireless Communication

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Presented by: Agilent EEsof EDA/Agilent Technologies
- Freescale's Power Amplifier Design Methodology Innovations
- Envelope Tracking Simulation and Analysis
- RF Module Design Using Amalfi CMOS PA
- Integrated Electro-Thermal Solution Delivers Thermally Aware Circuit Simulation

Agilent in Aerospace/Defense Series
- RF/uW Measurement Uncertainty: Calculate, Characterize, Minimize
- Using RF Recording Techniques to Resolve Interference Problems
- Essentials of OFDM and MIMO

Agilent in LTE/Wireless Communications Series
- Moving Forward to LTE-Advanced with Heterogeneous Networks
- 3GPP LTE Standards Update: Release 11, 12 and Beyond
- 10-Steps to Determine 3G/4G IP Data Throughput

RF and Microwave Education Series
Presented by: Agilent Technologies
- Signal Generator Fundamentals and New Applications

Optimize Wireless Device Battery Run-Time Series
Presented by: Agilent Technologies
- Impact of the Battery, Its Management, and Its Use
- Innovative Measurements for Greater Insights

FieldFox Handheld Analyzers Series
Presented by: Agilent Technologies
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Termination

Aeroflex/Inmet's improved 50 W terminations are rugged 50 Ω coaxial terminations that offer low VSWR characteristics (1.35:1 at 12.4 GHz). Inmet's TN180-50W series offers DC to 18 GHz broadband performance ideally suited for lab environments and high power combiner systems. The housing is anodized aluminum with fins for natural convection. A stainless steel type N male or female connector is standard. Other connector types and power levels are available.

Aeroflex/Inmet, www.aeroflex.com.

Surface Acoustic Wave Filter

API Technologies Corp. announced a new transverse coupled resonator filter (TCRF). This new surface acoustic wave (SAW) filter is designed for narrowband intermediate frequency filtering such as in satellite transponders, directional finders and anti-jam modems. It is capable of fractional bandwidths of 0.04 to 0.1 percent and is currently available from 80 to 1600 MHz. This TCRF is available in ceramic leadless chip carrier packaging. Other packaging styles are available for more rugged environments and applications.

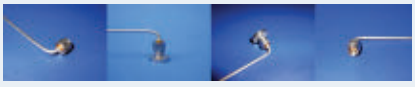
API Technologies Corp., www.apitech.com.

Demonstration Board

CML Microcircuits released a small demonstration platform for a complete software defined radio (SDR) for wireless data applications. The DE9941 is a credit card-sized demonstration board for a complete linear modulation-based SDR for wireless data. It is designed to be small and low cost with minimal components/values. The small form factor is made possible by the high integration of key functions provided by CML's market-leading devices.

CML Microcircuits, www.cmlmicro.com.

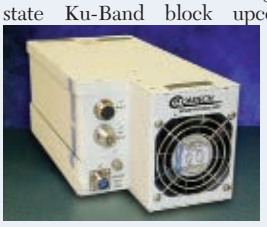
Right Angle Bend Assembly



Coaxicom's RAB assembly provides an alternative to the standard right angle SMA coaxial connector with a low-profile device, delivering increased electrical performance at higher frequencies. The 3221-1-L series of pre-bent right angle assemblies use the center conductor of 0.141" semi-rigid cable as the contact. "L" represents the overall length of the RAB. This fact, combined with Coaxicom's ultra-short SMA male, provides the same or a smaller profile than a right-angle connector, but without the performance penalty. Typical VSWR of these assemblies is 1.10 to 18 GHz.

Coaxial Components Corp., www.coaxicom.com.

Ku-Band BUC



Comtech Xicom Technology's new solid-state Ku-Band block upconverter, model XTS-40KHE-B1, was designed for transportable satellite communications uplinks, offers 40 W of P1 output power and provides 20 W of linear power. Breakthroughs in efficiency enable the self-cooled, feed-mountable amplifier to consume only 210 W when operated at linear power. Its features include temperature compensation, gain control, harmonic filtering, receive-band filtering and an output isolator. It comes in a compact outdoor unit (11.2" × 4.4" × 5.4") weighing less than 10 pounds.

Comtech Xicom Technology, www.xicomtech.com.

Low Loss Cable Assemblies

EAM's low loss cable assemblies provide the highest level of electrical performance for applications requiring extremely low attenuation over a broad frequency range. By combining silver-plated copper center conductor, expanded PTFE tape dielectric, aluminum polyester or polymide tape, silver-plated copper outer braid and FEP jacket, these low loss cable assemblies achieve outstanding electrical characteristics to 18 GHz (as low as .22 dB/ft.). Available in custom lengths with outer cable diameters of 0.195" and 0.335", these cables feature custom connectors with rugged stainless-steel solder-clamp construction.

Electronic Assembly Manufacturing Inc., www.eamcableassemblies.com.

Power Samplers

VENDORVIEW

RFMW announces sales and technical support for Florida RF Labs' SXU series of RF power samplers. These wideband samplers offer a cost-effective solution by eliminating the need for a termination commonly used with directional couplers, saving both PC board space and part count. Operating up to 4 GHz, power can be sampled 10, 20 or 30 dB down from the main line. Power handling is up to 50 W CW. Applications include power monitoring for antenna feeds and PAs, switch networks and test instrumentation.

Florida RF Labs, distributed by RFMW Ltd., www.emc-rflabs.com.

Fractional-N PLL

VENDORVIEW

Hittite has developed the HMC832LP6GE, a 3.3 V wideband fractional-N PLL with integrated VCO that generates continuous fractional frequencies between 25 MHz and 3 GHz. The HMC832LP6GE offers low power consumption of 560 mW while featuring industry leading phase noise and spurious performance. It also includes innovative programmable performance technology that allows designers to further reduce current consumption if demands on the noise floor can be relaxed. It features industry leading phase noise (-110 dBc/Hz at 3 GHz) and spurious performance across all frequencies.

Hittite Microwave Corp., www.hittite.com.

Double Balanced Mixer

The new M1-0012 combines the DC IF capability common to other existing double balanced M1 mixers with an extremely broad < 10 MHz to 12 GHz RF/LO band to make a unique mixer. In addition to the broad frequency range, the M1-0012 offers excellent isolations across the band. It is available in a connectorized, microstrip carrier, and both leaded and RoHS compliant surface mount packages. It features IF DC to 2 GHz, 7.5 dB typical conversion loss and ultra-broadband RF, LO and IF.

Marki Microwave Inc., www.markimicrowave.com.

High Pass Filter

VENDORVIEW

Mini-Circuits' new high pass filter, the HFCN-103+, is an LTCC-based 7 section design that extends the upper frequency cutoff range of the existing HFCN series to 10 GHz. Systems that previously relied on large distributed filter elements to support these lower frequencies can save space and system complexity by integrating the HFCN-103+ into new designs. These filters are offered in an EIA 1206 package size and have a typical stop band rejection of 30 dB.

Mini-Circuits, www.minicircuits.com.

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For rugged, reliable, and repeatable attenuation when accuracy is key, our customers have come to rely on Mini-Circuits Fixed Precision Attenuators, rated at 2W or 5W for DC-18 GHz signals. And now we've gone even further, with a new series of **2 W models up to 26 GHz,** and a new series of **20 W models from DC-18 GHz!** They feature stainless steel construction, precision attenuation from 1 to 50 dB, and SMA or N-type connectors for 50 Ω systems.

Inherent accuracy, and finely-graded attenuation levels, make our "BW" family invaluable on the bench or in the field. They're a ready solution for extending the range of test instrumentation or meeting circuit- and system-level requirements, such as better matching for high-VSWR components, reducing power to maximize sensitive applications, or protecting valuable circuitry. Just go to minicircuits.com—they're on the shelf and ready to ship today, at the low prices you've come to expect!

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IF/RF MICROWAVE COMPONENTS

331 rev S

New Waves

Fiber Optic Transmitter

VENDORVIEW

MITEQ introduced a new high reliability fiber optic transmitter with an operating bandwidth to 6 GHz. Transmitter model HRT-50K6G-28-20-M14 has a noise figure of 12 dB and is available in three different optical wavelengths (1550, 1490, 1310 nm). The operating temperature range is -40° to +85°C. With MITEQ's line of fiber optic receivers, it now is possible to have a complete fiber optic link that is sealed from the environment and has a spurious free dynamic range of 103 dB/Hz.
MITEQ Inc.,
www.miteq.com.

Power Divider

VENDORVIEW

Narda Microwave-East introduced model 2372A-2, a high-power, two-way power divider that operates from 500 MHz to 2.5 GHz, handles up to 250 W CW input power (2 kW peak power) and is well suited for both commercial and military applications. It has insertion loss of less than 0.6 dB, amplitude balance of ±0.25 dB or less, phase balance of ±5 deg., isolation of at least 13 dB from 500 to 700 MHz, 18 dB from 700 MHz to 2.5 GHz and VSWR of less than 1.5:1.
Narda Microwave-East,
www.nardamicrowave.com/east.

Bandpass Filter

VENDORVIEW

NIC introduced a wideband LC bandpass filter centered at 3600 MHz with an operating BW of 133 percent. This filter is capable of passing signals between L- and C-Bands offering low insertion loss, while rejecting any signals in the UHF and X-Bands. Custom designs and different package configurations are available upon request.
Networks International Corp.,
www.nickc.com.

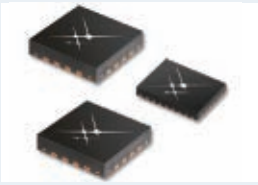
Drop-In Circulator

VENDORVIEW

Renaissance's new broadband circulator is ideal for transmitter protection application. Operating over 962 to 1213 MHz, this device can withstand 2000 W peak and 20 W average power levels. It is designed to sustain temperatures from -55° to +120°C while the loss is maintained below 0.5 dB.
Renaissance Electronics/HXI,
www.rec-usa.com.

SPDT Switches

VENDORVIEW



Skyworks unveiled three high power SPDT switches for multiple applications. The SKY12207-478LF (0.9 to 4 GHz; 50 W), SKY12208-306LF (0.02 to 2.7 GHz; 50 W) and SKY12210-478LF (0.9 to 4 GHz; 100 W) deliver transmit/receive and fail-safe switching functionality for TD-SCDMA and TD-LTE base stations, as well as land mobile radios and military communication systems. These PIN diode switches handle continuous wave RF input power and provide very low insertion loss in the antenna-to-Rx mode, minimizing the effect on receiver noise figure.
Skyworks Inc.,
www.skyworksinc.com.

New Products

Amplifiers

Solid State Amplifiers

VENDORVIEW

Models 15S1G6 and 50S1G6 are single band 15 and 50 W amplifiers that cover the 1 to 6 GHz frequency band. This type of amplifier is not unusual, but they all require dual bands (two separate amplifiers) to provide high output power and good gain flatness to provide one with a useable instrument. That is, until AR RF/Microwave Instrumentation created the single band Models 15S1G6 & 50S1G6. They provide linear output power with excellent gain flatness.
AR RF/Microwave Instrumentation, www.arworld.us.

Drivers

Intended for commercial C-Band radar applications including weather radars, the PNs IGN5259M10 and IGN5259M15 and MPAG5259M25 operate over the instantaneous bandwidth covering 5.2 to 5.9 GHz. Under 300 µs pulse width and 10 percent duty cycle pulsing conditions the IGN5259M10 typically supplies a minimum of 10 W of peak output power while the IGN5259M15 typically supplies a minimum of 15 W of output power. The MPAG5259M25 is a 50 Ω matched device that produces more than 25 W of output power.
Integra Technologies Inc., www.integratech.com.

Power Transistor

VENDORVIEW

The T1G6003028-FS is constructed with TriQuint's 0.25 µm process, which features advanced field plate techniques to optimize power and efficiency at high drain bias operating conditions. It is ideally suited for military and commercial radar, professional and military radio communications, test instrumentation, wideband or narrowband amplifiers and jammer applications. Key features include DC to 6 GHz frequency, output power (P3dB) of 30 W at 6 GHz, linear gain of > 14 dB at 6 GHz, operating voltage of 28 V, and low thermal resistance package.

TriQuint Semiconductor Inc., distributed by Richardson RFPD Inc., www.triquint.com.

MMIC Amplifier

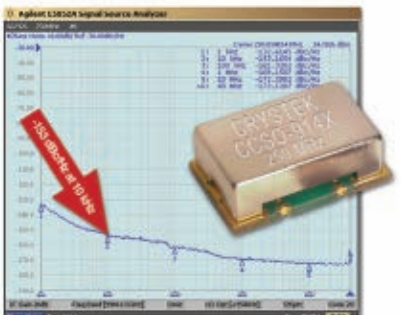
VENDORVIEW

RFMD's RFCA1008 is a high performance InGaP HBT MMIC amplifier designed with the InGaP process technology for excellent reliability. The heterojunction increases breakdown voltage and minimizes leakage current between junctions. A Darlington configuration is utilized for broadband performance. The RFCA1008 contains two amplifiers for use in wideband push-pull CATV amplifiers requiring excellent second order performance; the second and third order nonlinearities are greatly improved in the push-pull configuration.

RF Micro Devices, www.rfmd.com.

Sources

Clock Oscillator



Crystek Crystals announces the release of a 250 to 1090 MHz surface acoustic wave (SAW)

New Products

clock oscillator (in single frequency band), the CCSO-914X. Crystek designed the module using proprietary circuitry and SAW resonator technology to provide ultra-low jitter/phase noise performance with true SineWave output. The resulting oscillator (250 MHz variant) features -153 dBc/Hz phase noise at 10 KHz offset and a noise floor of -173 dBc/Hz. The CCSO-914X-250.000 has been verified with Analog Devices' AD9467 – a 16-bit, monolithic, IF sampling analog-to-digital converter (ADC).
Crystek Corp.,
www.crystek.com.

Hi-Rel Frequency Synthesizer

The THOR-14000-XA frequency synthesizer is designed to operate from 13.6 to 14 GHz in 1 MHz steps and features switching of ≤ 400 µSec band-edge to band-edge, and ≤ 300 µSec channel to channel. Locked to an external 10 MHz reference, the device exhibits low phase noise (<-86 dBc/Hz at 10 KHz) and low current draw (+5 V DC at 335 mA). THOR units are capable of maintaining excellent performance over vibration, shock and temperature featuring a rugged, module-mount package (2.50" × 1.1" × 0.4").
EM Research,
www.emresearch.com.

Voltage Controlled Oscillator

Z-Communications announced RoHS compliant VCO model V846ME24-LF in the S-Band. It operates at 3100 to 3500 MHz with a tuning voltage range of 1 to 12 V DC and provides better than 1.1:1 tuning linearity. This high performance VCO features a spectrally clean signal of -114 dBc/Hz at 100 kHz offset and a typical tuning sensitivity of 62 MHz/V. It is designed to deliver 3 dBm of output power into a 50 Ω load while operating off a 5 V DC supply and drawing typically 22 mA of current.
Z-Communications Inc.,
www.zcomm.com.

Test Equipment

Delay Lines

Eastern OptX announced two new delay lines for radar testing. They feature ultra-wide bandwidth, low loss, high isolation and high dynamic range. The E-501 fixed delay line is an economical, high-performance turnkey product for radar testing as well as WiMAX, wireless communications and altimeter applications. The E-3001 variable delay line is a high performance, turnkey product for the radar test industry. It has multiple delay cells with front panel or computer control with up to eight switchable delays.
Eastern OptX,
www.eastern-optx.com.

Test System

The 50BA-002-95 SMA consists of two solid-state programmable attenuators in a mini-benchtop enclosure. The programmable attenuators can be set from 0 to 95 dB in 1 dB steps. The unit is controlled remotely via Ethernet or RS-232. In order to make this test system plug-and-play, JFW provides a GUI test program that allows easy remote control of the 50BA-002-95 SMA. In addition to the basic remote commands, the test program has additional functionality that allows for handover testing and signal fading for wireless devices and handsets.
JFW Industries Inc.,
www.jfwindustries.com.

MICRO-ADS

Handbook of RF, Microwave and Millimeter-Wave Components

Leonid A. Belov, Sergey M. Smolskiy and Victor N. Kochemasov

This book offers a detailed treatment of the operations principles, key parameters and specific characteristics of active and passive RF, microwave and millimeter-wave components. It covers both linear and nonlinear components that are used in a wide range of application areas, from communications and information sciences, to avionics, space and military engineering.

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Star Trek Trivia

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1. **What year did the original Star Trek series air?**
   _ _ _ _

2. **What does the "T" in James T. Kirk stand for?**
   _ _ _ _ _ _ _ _

3. **What planet is Spock from?**
   _ _ _ _ _ _

4. **What was the name of the Enterprise's captain in the original TV pilot?**
   _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

5. **What is the verbal cue Captain Kirk uses to get transported back to the Enterprise?**
   _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

6. **Prior to commanding the Enterprise-D, Picard was captain of what starship for 22 years?**
   _ _ _ _ _ _ _ _ _ _ _ _ _ _

7. **Scotty was first introduced in which Star Trek story?**
   _

8. **What is the name of the traditional Vulcan weapon that Spock and Kirk used to fight each other?**
   _ _ _ _ _

9. **What was Dr. Leonard McCoy's nickname?**
   _ _ _ _ _

10. **What type of material is used to power the warp drive on the Enterprise?**
    _

11. **What is the non-lethal setting on the phaser weapon used in the original Star Trek?**
    _ _ _ _

12. **Live long and** _ _ _ _ _ _ _

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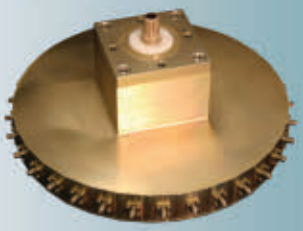

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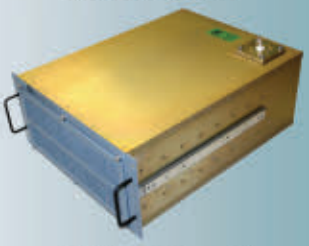

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D6857	32-Way Combiner / Divider	1,200-1,400	4,000	0.5	1.35:1
D8969	2-Way Combiner / Divider	1.5-30	12,500	0.2	1.25:1
D8182	5-Way Combiner / Divider	1,175-1,375	1,500	0.4	1.35:1
D8421	8-Way Combiner / Divider	1.5-30	12,000	0.3	1.30:1

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