

Vol. 55 • No. 12

December 2012

Microwave Journal



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to
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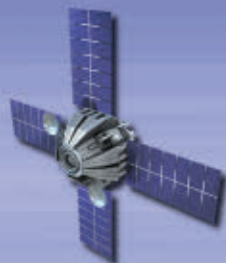
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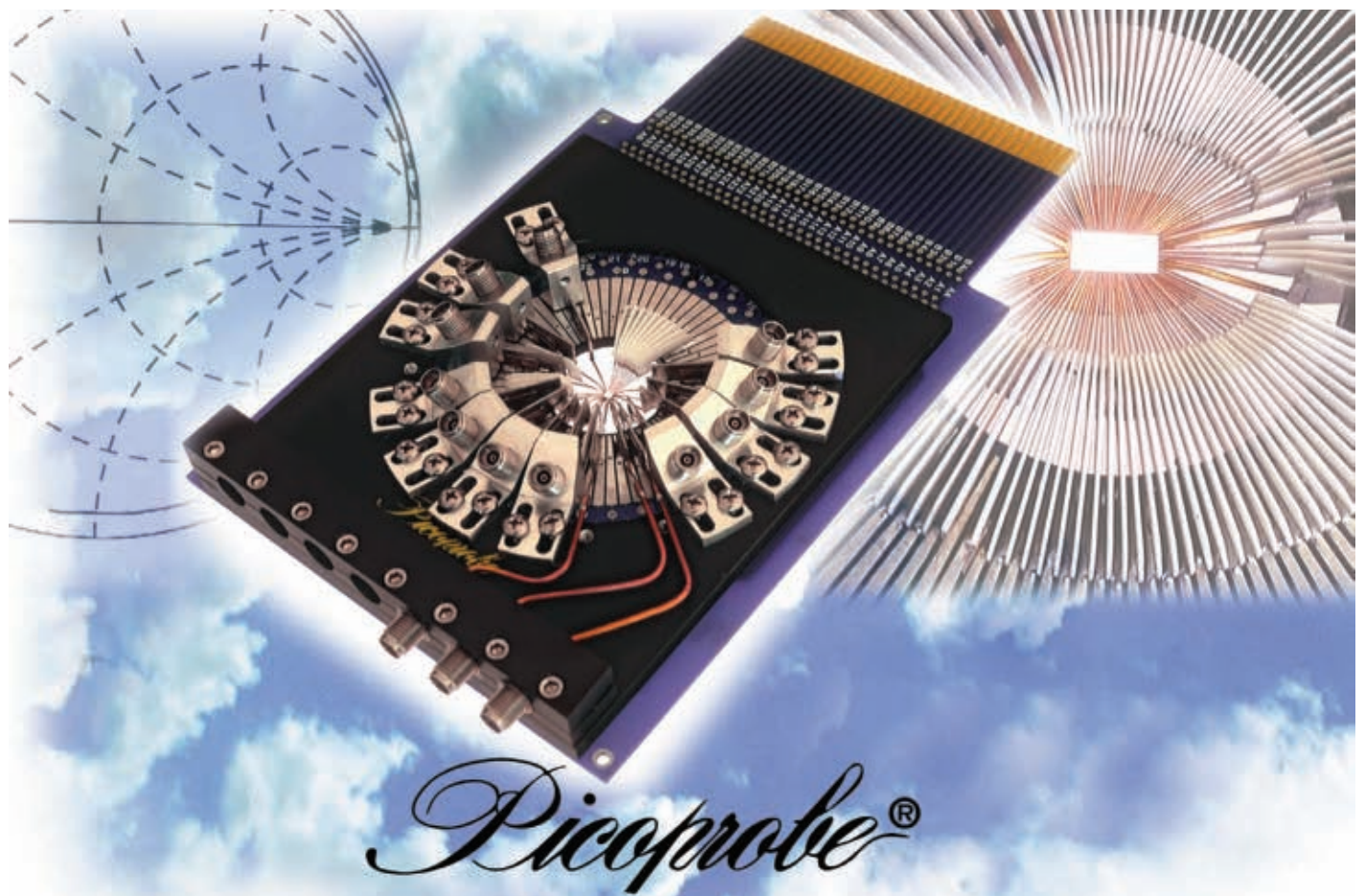
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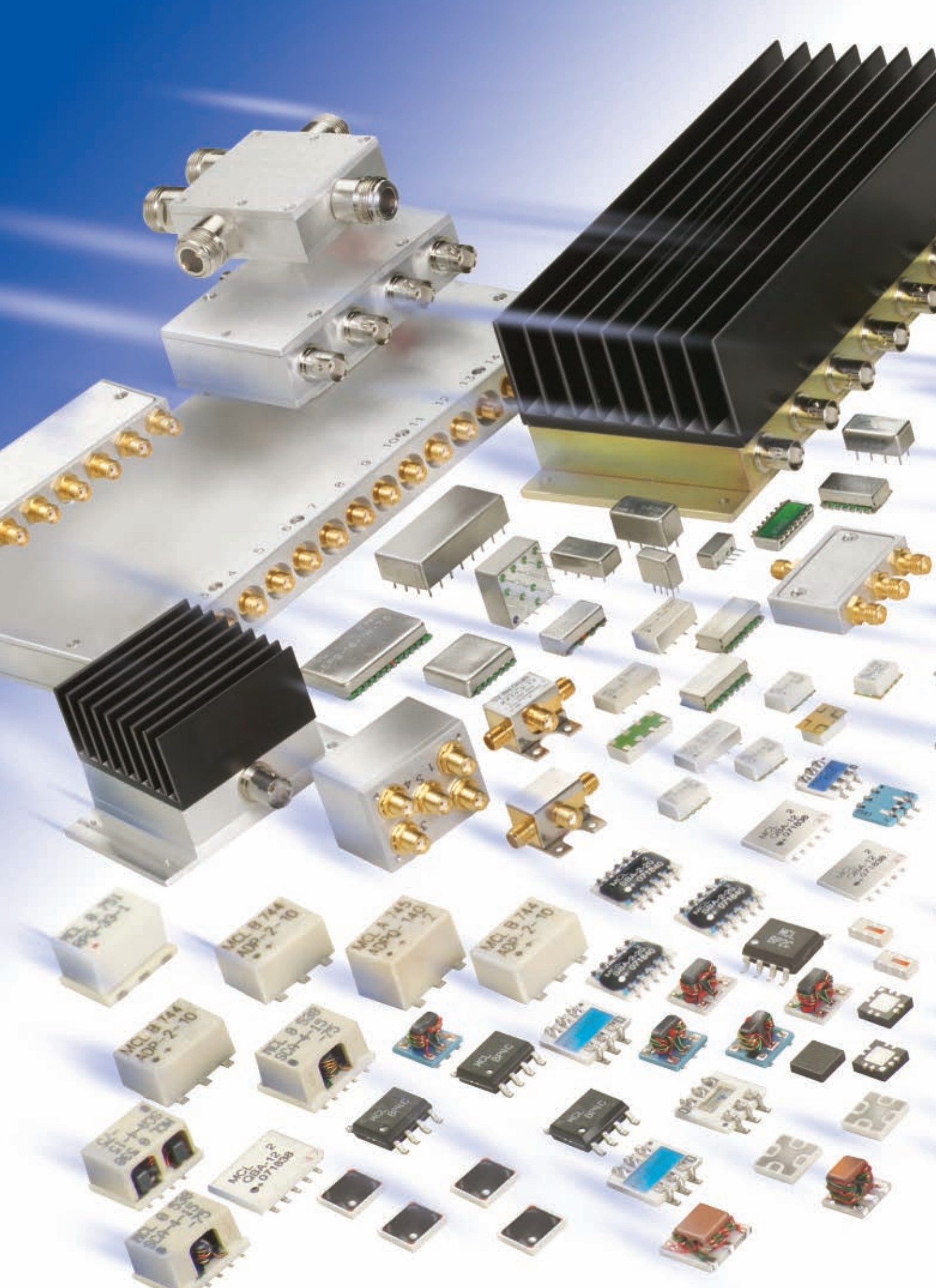
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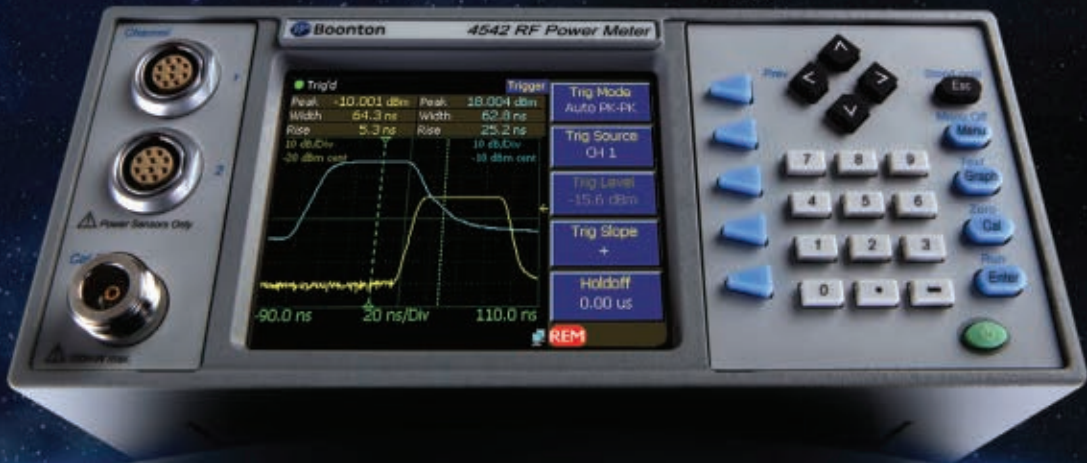
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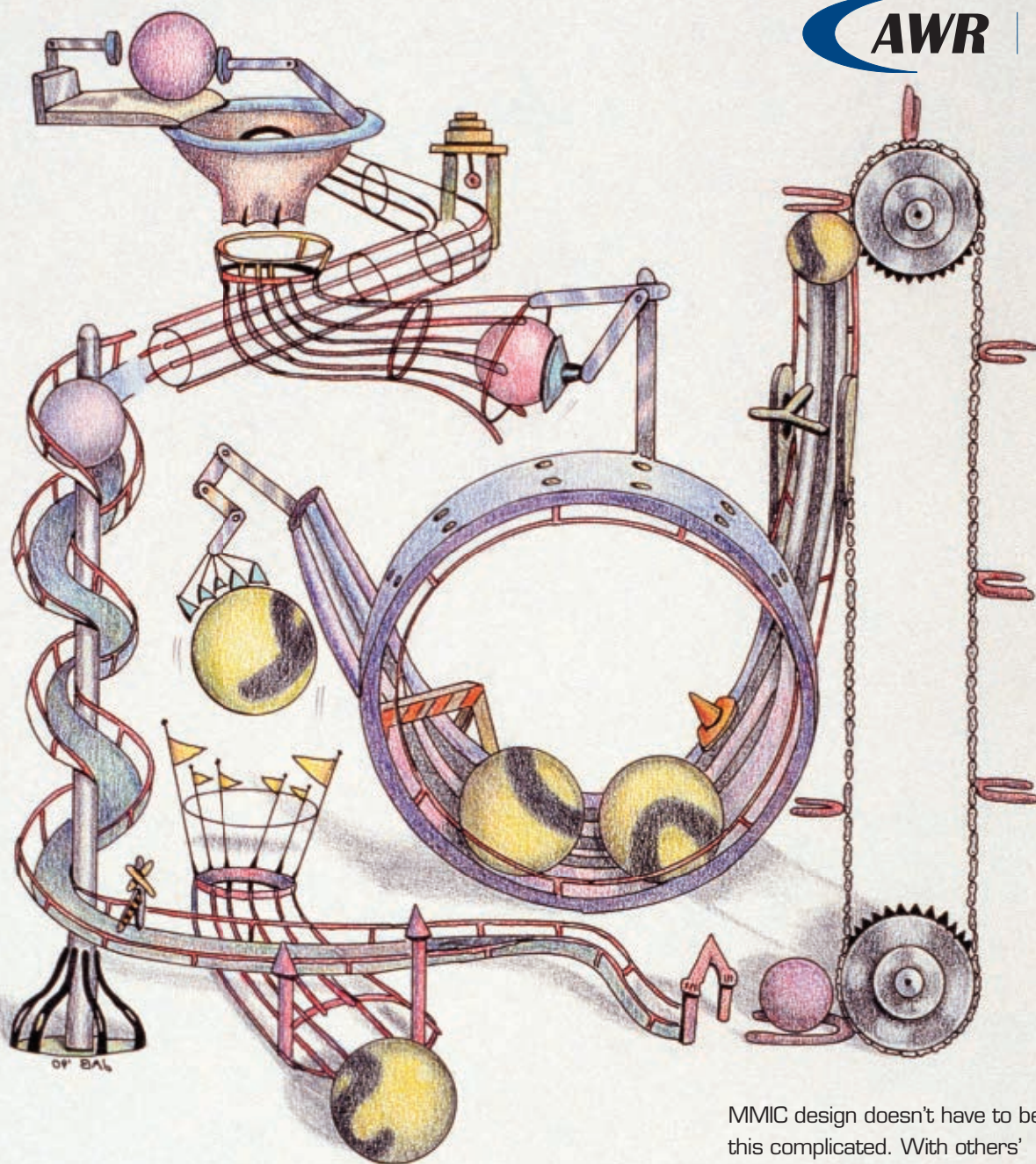
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Constraint Driven Co-Design

12/6, 11:00 AM ET

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Simulation of EMI in Hybrid Cabling for

Combining Power and Control Signaling

12/13, 11:00 AM ET

Innovations in EDA

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Envelope Tracking Simulation and Analysis

12/13, 1:00 PM ET



October Survey

"...Had the Biggest Impact on the Development of Microwave Technology"

MIT Rad Lab [49 votes] (33%)

DARPA's MIMIC Program [20 votes] (13%)

NASA's Space Program [20 votes] (13%)

The Cold War [41 votes] (27%)

The Smartphone [20 votes] (13%)



Executive Interview

Robert Stephens, President of Aeroflex / Weinschel, talks about the RF/microwave control components market, the evolution of the technology to support today's systems and test instrumentation and the company's 60 year milestone.

White Papers

Higher Data Rates Require New De-embedding Techniques

White Paper, Anritsu

Arbitrary Waveform (AWG)

White Paper, Agilent Technologies

Understanding and Correctly Predicting Critical Metrics for Wireless RF Links

Joel Kirschman, AWR Corp.

CVD Diamond High Power Resistors and Terminations

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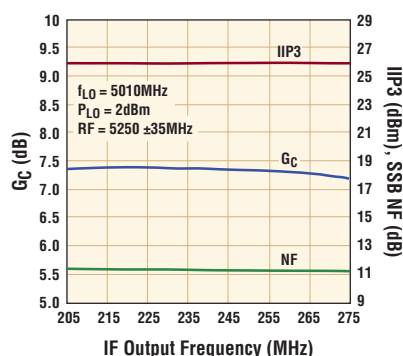
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27	28	29	30	31 Webinar: HetNets Sponsored by Agilent Technologies	1	2
						
27	28	29	30 Webinar: Signal Generation Fundamentals Sponsored by Agilent Technologies	31	1	2

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February 18-21, 2013 • Fort Worth, TX
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MICROWAVE & RF 2013
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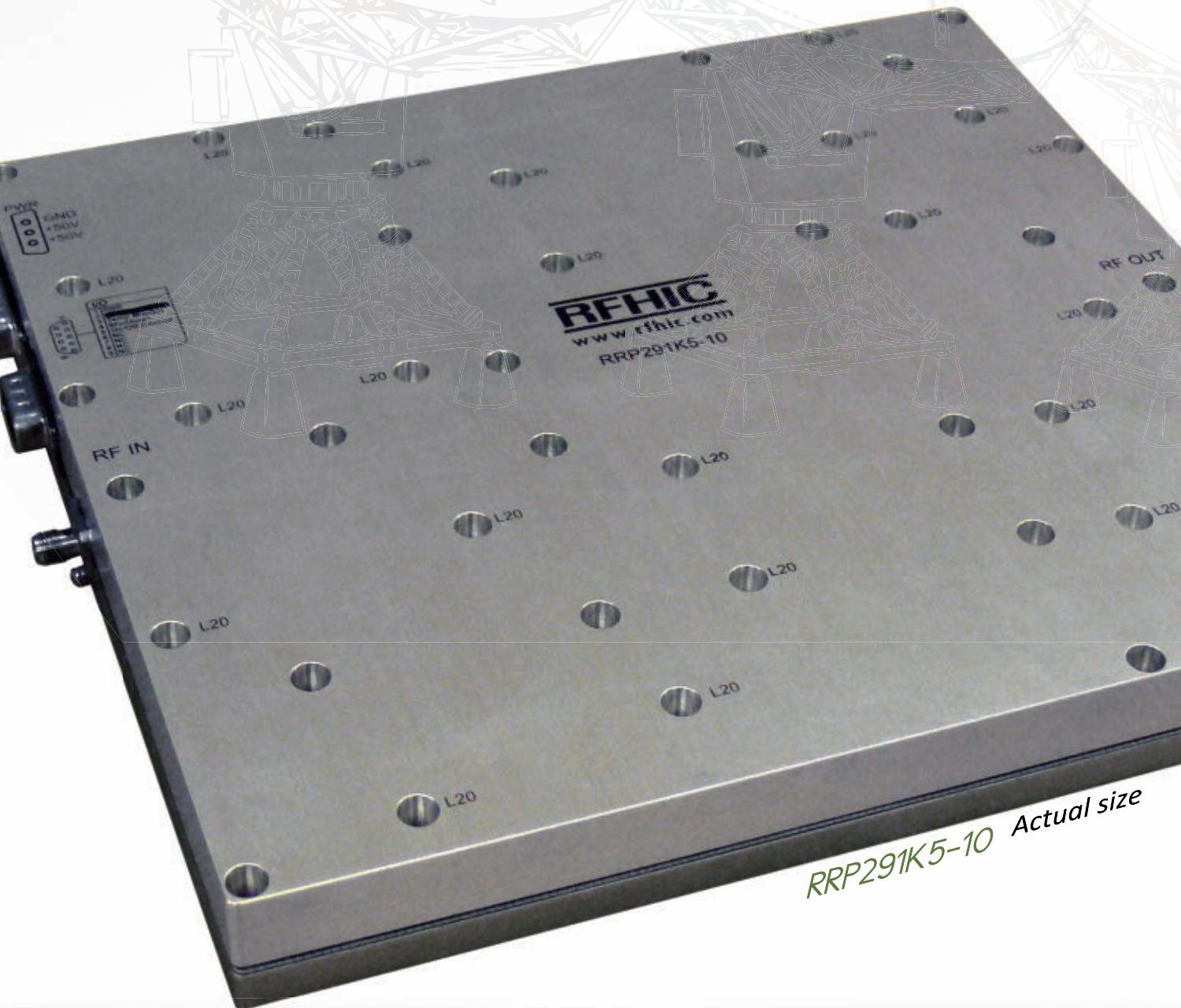
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RRP311K0-10	3.1	400	1000	60			32	
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The Year That Was...



DAVID VYE, *MICROWAVE JOURNAL* EDITOR

2012 was an Olympic year, a political year, a jubilee year (at least in the UK); a year of celestial aspirations and turmoil back on planet Earth. It was a year spent vacillating between tepid and propitious economic forecasts. In business, the year offered opportunities and challenges – and no lack of uncertainty thanks to the European debt crisis, a potential course-changing election and looming fiscal cliff. Altogether, the economical, political and global security issues of 2012 will undoubtedly impact the pace and direction of technology funding.

For microwave technology, it was a year in which GaN and CMOS devices (switches and power amps) increased their respective market penetration, DPD and envelope tracking techniques continued to gain interest and the need for spectral capacity provided opportunities for small cell data off-loading and carrier aggregation, while over-the-air testing became essential to validating the benefits of MIMO. And at the *Journal*, it was a year to advocate for global growth with the launch of *Microwave Journal China* and EDI CON (Beijing, 2013).

Reaching for the stars was a common theme in 2012. The United States set the bar high with a successful Mars rover landing, a challenging feat portrayed in a NASA video, “Seven minutes of Terror,” that went virile. For North Korea, the dream was slightly out of reach as its long-range Uhna-3 rocket carrying an observation satellite exploded 80 seconds after launch. The attempt was viewed by the U.S. and its allies as a poorly-disguised missile test.

Fairing considerably better, a Shenzhou-9 capsule carrying three Chinese astronauts successfully docked to an orbiting space module, which China had launched the previous year. The space module is to be replaced by a permanent space station around 2020 as China hopes to be the third country to send an independently manned space station into orbit. Returning from space in style, Austrian daredevil Felix Baumgartner

jumped from more than 24 miles above the Earth to break the speed of sound along with the record for highest free-fall. This interest in space bodes well for future commercial activity and the microwave industry.

Back on Earth, Global security continued to be a growing concern. One year after the Arab Spring, the region's democracy movement struggled to establish stable governments in Egypt and Libya, leading to attacks on American diplomats, while an escalating civil war in Syria, fighting in Gaza, and a belligerent and defiant Iran served to demonstrate the continuing need for embedded intelligence gathering and stealthy, rapidly deployable security forces to operate beyond the limits of defense systems designed for conventional warfare. Asymmetrical conflicts continue to drive the need for more sophisticated spectrum monitoring, cognitive and coherent radio technology, ad hoc communication networks, wireless sensors, miniaturization and low-power electronics.

Infrastructure, safety and security were put to the test in a number of circumstances from the blackouts in India that left over half a billion people without power, to the devastation left in the wake of Hurricane Sandy. Storm hardened infrastructure and a smarter electric grid should be the investors' take-away from these events. Meanwhile, the tsunami that hit Japan in 2011 and its impact on the Fukushima Daiichi nuclear power plant alerted many to the risks associated with natural disasters and potential disruption to the global electronics supply chain. Mitigating this risk with manufacturing centers in Germany, the United States and Singapore, GLOBALFOUNDRIES, a foundry business launched in 2009 through the integration of the former manufacturing arm of AMD and Chartered Semiconductor, became the fastest growing semiconductor company in 2012. GLOBALFOUNDRIES is poised to address the demand for outsourced semiconductor manufacturing and the high-volume pro-

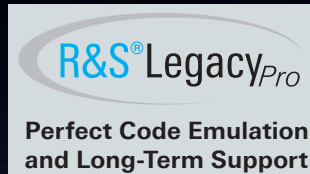
duction of wireless semiconductors.

With the prospect of future wireless connectivity exemplified in this month's cover story, and the ensuing need to drive down component and system costs, many companies took steps to strengthen their technology offerings. Considerable merger and acquisition activity took place in 2012. RFMD acquired Amalfi Semiconductor, a fabless semiconductor company specializing in CMOS RF, Gaas Labs acquired Nitronex to add to its portfolio of communication semiconductor companies that include M/A-COM Technology Solutions. Device modeling was on the minds of several test equipment manufacturers as Agilent acquired Accelicon Technologies (a device modeling company from Beijing) and National Instruments strengthened its position in RF design and active device modeling expertise by acquiring NMDG. ANSYS expanded its multi-physics simulation portfolio to include embedded software development with the acquisition of Esterel Technologies.

EMC emission and immunity testing system provider, Teseq Holding AG, added two leading amplifier manufacturers to its organization with the acquisitions of IFI and Milmega, while Teledyne made big news by acquiring LeCroy. Agilent expanded its vast array of test solutions with the acquisition of AT4 Wireless Test Systems and Centellax's test and measurement business (BER testers and signal generators), while Rohde & Schwarz addressed QoS testing in wireless networks with the acquisition of SwissQual. Dragonwave acquired Nokia Siemens Networks' microwave transport business, API Technologies entered into a definitive merger agreement with Spectrum Control, Mercury Computer acquired Micronetics and Thales acquired Tampa Microwave.

The industry continues to morph and grow in support of the systems that define our changing world. The editors at the *Journal* look forward to covering your achievements in 2013 and being among the first to say, “well done.”

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A 5G Wireless Communications Vision

Everybody acknowledges that wireless communications technology has developed rapidly. It empowers our modern life, enables modern societies to operate efficiently, and has had a major impact on modern politics, economy, education, health, entertainment, logistics, travel and industry. In the last 20 years, wireless technologies have changed the world we live in. It seems as if life without modern wireless communications, as it existed before 1990, is difficult to comprehend.

Major breakthroughs and advances in communications are heavily related to the basic interests of humans. Nature has empowered us to talk and listen, leading to the demand for telephony. We are interested in information and want to share, requiring data communications. We like to collect and hunt, driving the demand for monitoring and sensing. Also, we like to steer and control within our environment, demanding control communications. Today we enjoy the power of telephony and data communications. Machine type communication and control is yet to fully enter the market. This article provides a recollection of our current state for motivating and sketching a vision of our future.

When reviewing today's situation, we see a chronology of revolutionary applications and technologies that have shaped everyday life. First and foremost, the need for untethered telephony, and therefore wireless real-time communication, has dominated the success of cordless phones, followed by cellular communications. Soon thereafter, two-way paging implemented by SMS text messaging became the second revolutionary application. With the success of wireless local area network technology (i.e., the so-called "IEEE 802.11" standard), Internet browsing, and the widespread market adoption of laptop computers, untethered Internet data connectivity became interesting and ultimately a necessity for everyone. This phenomenon opened the market for wireless data connectivity. The logical next step was the shrinkage of the laptop and merging it with the cellular telephone, which evolved into today's smartphone. We now enjoy access to the world's information at our fingertips, in any situation and at any place.

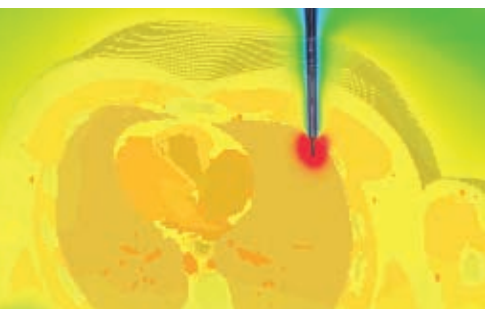
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CHANGING THE STANDARDS

The next wave is the connectivity of machines with other machines, referred to as “M2M.” During the past years we have seen a multitude of wireless M2M applications being deployed, for example information dissemination in public transport systems. However, the commercial success has been somewhat limited. Why? The previous revolutionary applications have been clearly driven by addressing a human need, whereas M2M, by nature, needs more analysis before we can understand the basic human need it serves. Identifying that need could cause a breakthrough.

Today it is accepted that M2M is developing, without knowing how to create the large market pull. This leaves us in a situation where a coarse analysis of driving forces behind data services over the last decades needs to be undertaken.

THE WIRELESS ROADMAP

Over the years it has become evident that wireless data rates are continuously increasing over time. This is mainly driven by the need to transfer files of ever increasing size, as well as the rapid adoption and growth of streaming/podcast services. In this section, a quick review of data rate increases of wireless data applications (non-voice) over time is given, as this is seen to be the main driver of wireless technology development.

The International Technology Roadmap for Semiconductors (ITRS) shows for flash memories a history, as well as projection, of a factor of 10× in memory increase every five years, as seen in **Figure 1**.

Flash memory is seen as the most important storage technology for the majority of “wireless gadgets,” which require broadband connectivity. Devices that use flash memory include cellular (smart) phones, game consoles, cameras, camcorders, subnotebooks and e-books, as well as modern laptops. Hence, the storage size increase of flash memory directly drives the size and amount of data stored. As stored data needs to be moved from one device to another, storage increase also drives the need for communications bandwidth. Perhaps another perspective is the use of cloud technologies for storage. As more businesses continue to take advantage of the cloud, the demand for wireless bandwidth could

potentially further accelerate wireless bandwidth and network capacity needs by several orders of magnitude over current usage.

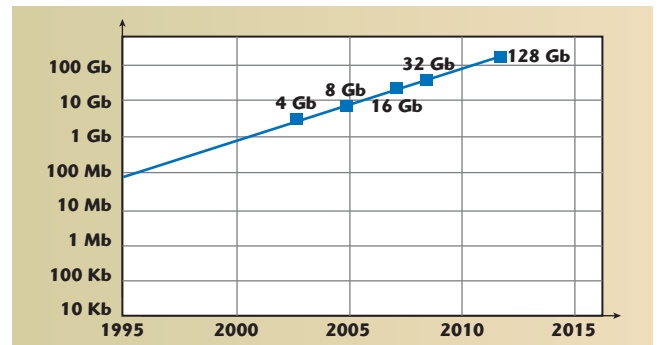
Wireless gadgets, as previously defined, also need connectivity at different levels. USB is the transport media of choice, being an easy way of moving data quickly between two devices that are closely positioned to each other (approximately 1 meter apart). From USB 1.0 at 2 Mb/s, data rates have now increased to 4.8 Gb/s with the introduction of first USB 3.0 interfaces in 2009. Wireless USB is often considered as an alternative, in particular for connecting devices that have their own power supply and do not need the 2 W powering capability via the USB cable. For example, when downloading pictures from a digital camera to a laptop, both have batteries for operations.

So far, however, wireless USB has not been economically successful. The main reason being that IEEE 802.11 wireless LAN (WLAN) standards have also been providing increasing data rates, as can be seen in **Figure 2**. So far the difference in data rates between wireless USB and 802.11 is not large enough to make a noticeable difference in user experience. In addition, the cost difference for a chip set is negligible and the 802.11 protocol

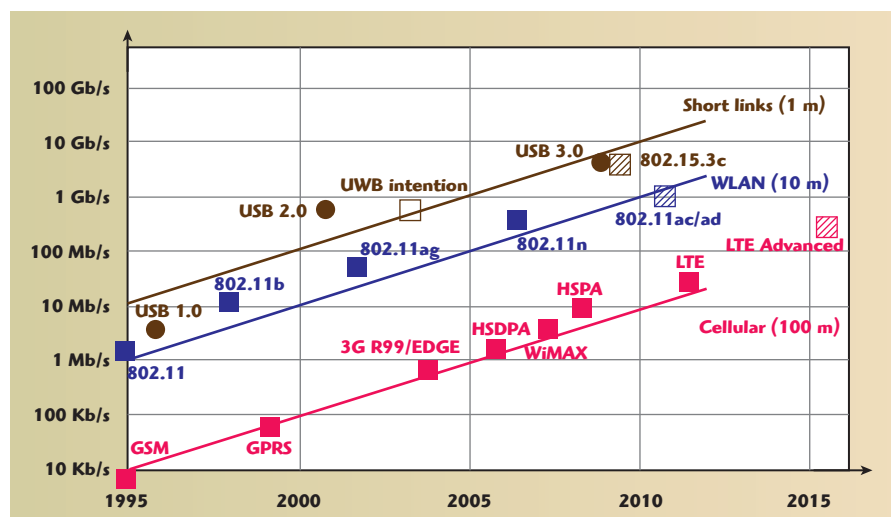
stack is well integrated into PC and cellular phone operating systems, whereas an 802.15 wireless USB protocol stack would require a whole new design effort with unknown engineering and debugging problems.

Therefore, even though WLAN systems are specified for a 10-meter range of operations and are intended for client-server applications in offices, hot spots or homes, they have also been able to eliminate the business case for wireless USB. The negligible speed difference between wireless USB and WLAN has virtually eliminated wireless USB's market viability.

Cellular, on the other hand, has a very different business. The most important feature of cellular is to provide coverage, meaning reliable connectivity no matter where a customer is located and/or positioned. Once connectivity is available and a connection is established, the speed of data communications becomes the next challenge. With coverage and reliability sufficiently addressed, consumers are demanding higher data rates for cellular, as can be

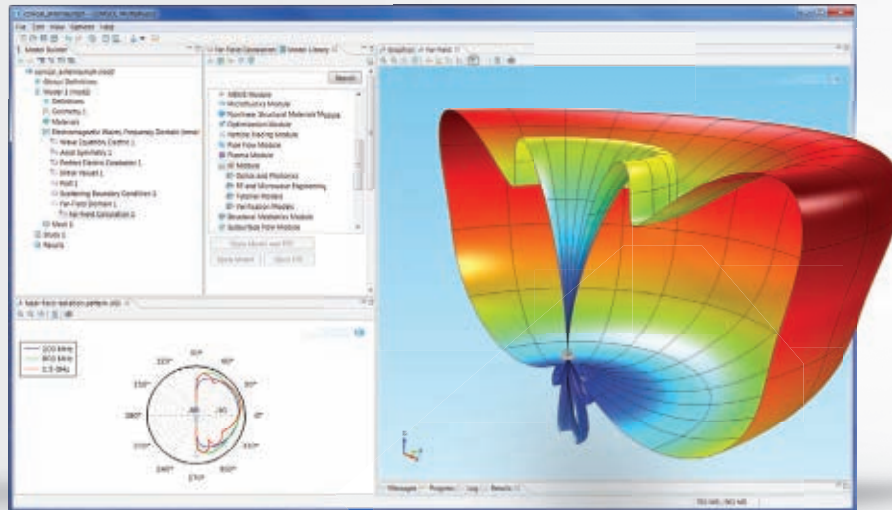


▲ Fig. 1 Moore's Law doubling single-chip memory capacity every 18 months leading to a 10× increase every five years.



▲ Fig. 2 The Wireless Roadmap.

ANTENNA DESIGN: Simulation of a broadband conical antenna. Results show the radiation pattern in the near-field for three different frequencies and in the far-field for 1.5 GHz.



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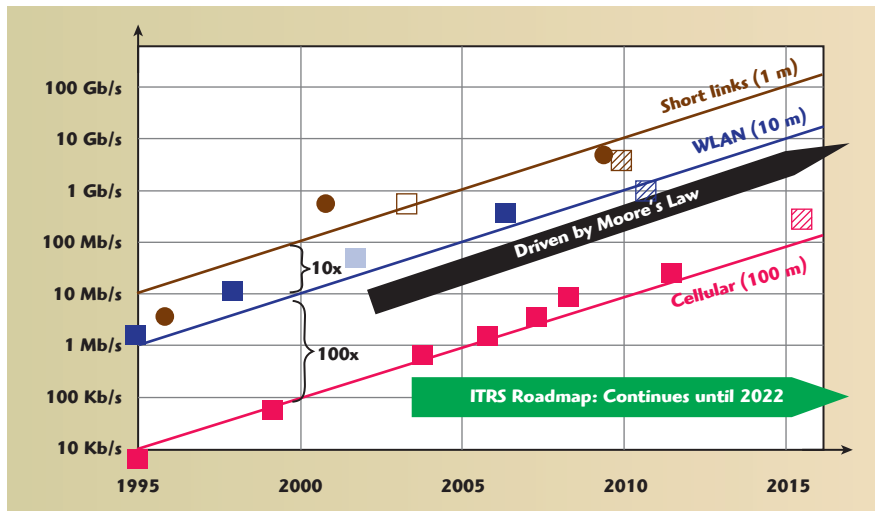
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▲ Fig. 3 The Wireless Roadmap matching Moore's Law.

seen. Currently the next generation cellular, LTE, is providing data rates in the order of 36 Mb/s. This clearly fits very neatly in the projected 10× data rate increase every five years mentioned previously. Remarkably, the data rates provided by USB, WLAN and cellular all increase by 10× every five years; exactly at the same rate as the increase in size of flash memories according to the ITRS roadmap.

The speed difference of 100× in data rates between cellular and WLAN (see **Figure 3**) has, so far, created a large enough differentiator for both technologies to be able to succeed in the market place (see Clay Christensen's "The Innovator's Dilemma," Harvard Business Press).

Cellular service providers now offer consumers femto base stations or "femto cells" in the home to improve cellular connectivity and coverage, ultimately providing access to a faster and more reliable cellular network. As small (femto) cells enter the home, and due to an improved link budget in this case, data rates in this heterogeneous network topology combined with future cellular technologies may deliver data rates approaching WLAN. This could create a situation where cellular may encroach upon the WLAN value proposition. However, due to the fact that cellular chip sets are typically more expensive than WLAN, in part because of the cellular technology high IP licensing costs, it is anticipated that WLAN will remain a dominant player in the market.

One question remains: "Is there a need for data rates beyond 100 Mb/s

in the future?" Today, more than 50 percent of the data volume measured in cellular networks is generated by users' increasing use of streaming applications. As high-definition 3D streaming with user-enabled vision angle control requires data rates in the order of 100 Mb/s, and users want quick downloads of typically above 100× real-time of multiple streams, we will see more than 10 Gb/s wireless connectivity as a future requirement. Obviously this does not lead to a need for a continuously sustainable very high bandwidth for one user over long periods of time. Instead, for example, 100 Gb/s data rates will be shared via the wireless medium.

SETTING THE STAGE FOR LTE AND BEYOND

Cellular technologies will continue to be driven by demands for not only reliable coverage but also high data rate access. Cellular service providers are introducing 4G LTE with a new Orthogonal Frequency Division Multiple Access (OFDMA) transmission scheme acting as a stepping stone for providing higher data rates with future improvements, which will enter the standardization process later. Initially, LTE networks will offer the same speed order as HSPA+, its predecessor. This repeats the case we have seen at the time of 3G UMTS introduction, which was also rolled out with data rates comparable with previous second generation enhancements of 384 kb/s EDGE. The new OFDMA air interface of LTE will provide the foundation for developing enhanced

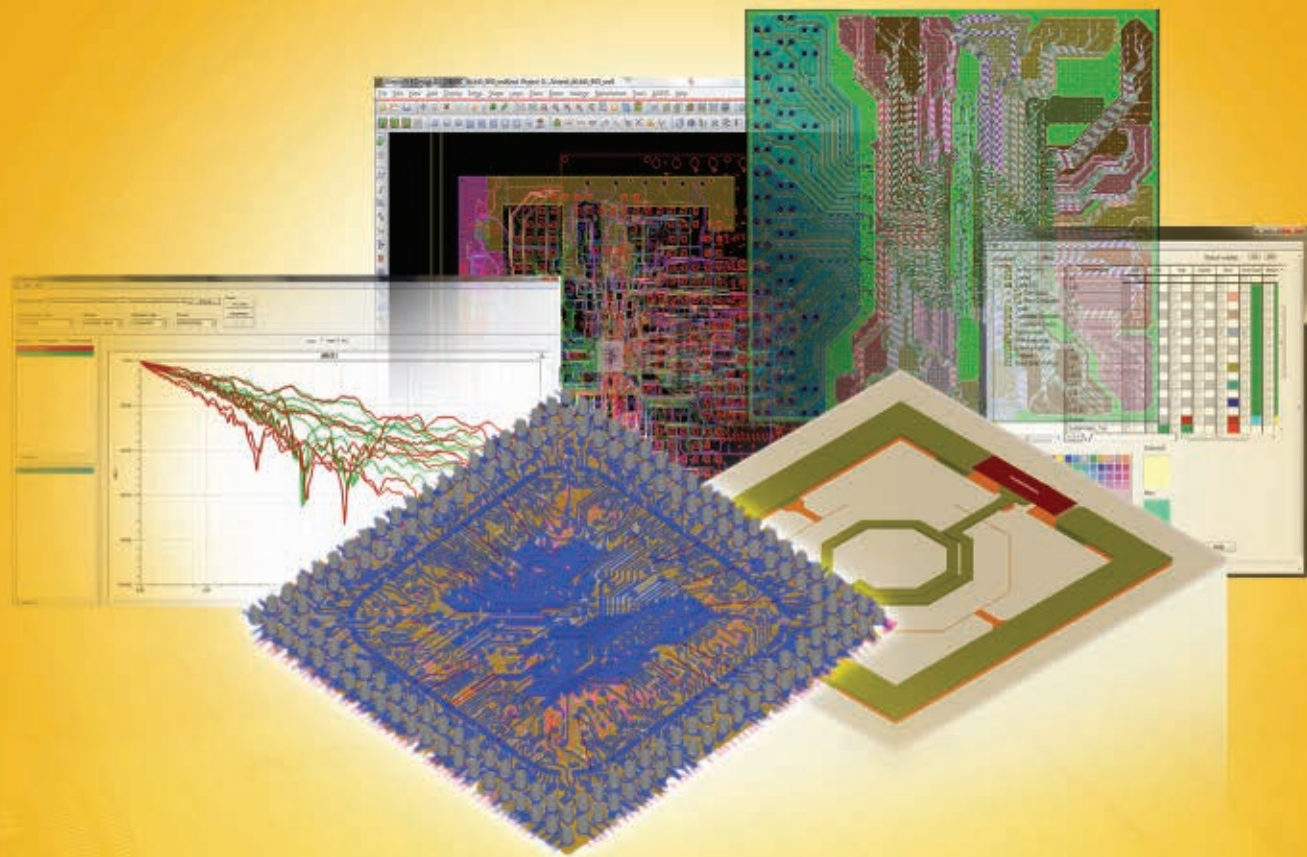
standards, what is currently referred to as LTE-Advanced. LTE-Advanced technologies therefore can be seen as a further stepping stone for cellular evolution along the data rate increases in the projections of Moore's Law and as required by the market.

Considering the technology and market forces in 10 years, we must be able to address speeds of 10 Gb/s or more. Current systems do not scale to this requirement. Using OFDMA for these data rates, the analog/digital conversion alone would represent a power consumption challenge that cannot be resolved with current technology projections. Hence, the power consumption determines that a new physical layer approach needs to be found for 5G cellular communications.

DRIVING TECHNOLOGY BY HUMAN NEEDS: SENSING, MONITORING, COLLECTING

One of human nature's greatest desires is to hunt and collect information in order to learn more about the status of our environment. This natural trait has found its way into a plurality of smartphone apps, which are available for tracing and tracking not only weather information, but the status of many different items and things. Obviously, this is not even a start when taking this to a more extreme view. For example, given that the status of every individual flower plant could be monitored and classified according to the kind of plant, we could ensure proper light and moisture for optimum growth and health. What is true in terms of desire for monitoring of flower plants is also true for many other applications. Examples are environmental status, traffic status, vehicle status, heating, ventilation, and air conditioning (HVAC) and its environmental status, and health monitoring. Clearly a large amount of monitoring can be achieved only if monitoring terminals can be designed to operate very simply, and for an extremely long duration.

An example of simple handling could be that such a sensing device would be activated by connecting the battery. The strip has a number or barcode which must be entered into a smartphone, initiating the download of an app and connecting the



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MODEL	FREQ. RANGE (GHz)	MAX. INSERT. LOSS (dB)	MAX VSWR	MAX LEAKAGE @ 25 W CW INPUT (dBm)
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LS0520P25A	0.5 - 2.0	0.6	1.4:1	+20
LS0540P25A	0.5 - 4.0	0.7	1.4:1	+20
LS0560P25A	0.5 - 6.0	1.3	1.5:1	+20
LS05012P25A	0.5 - 12.0	1.7	1.6:1	+20
LS1020P25A	1.0 - 2.0	0.6	1.4:1	+20
LS1060P25A	1.0 - 6.0	1.2	1.5:1	+20
LS1012P25A	1.0 - 12.0	1.6	1.6:1	+20
LS2040P25A	2.0 - 4.0	0.7	1.4:1	+20
LS2060P25A	2.0 - 6.0	1.2	1.5:1	+20
LS2080P25A	2.0 - 8.0	1.3	1.6:1	+20
LS4080P25A	4.0 - 8.0	1.3	1.5:1	+18
LS7012P25A	7.0 - 12.0	1.6	1.6:1	+18

Note: 1. Insertion Loss and VSWR tested at -10 dBm.

Note: 2. Typical limiting threshold: +6 dBm.

Note: 3. Power rating derated to 20% @ +125 Deg. C.

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app with the device. By repeating this procedure for any additional device of the same kind, it would be added automatically to the same app. This is true for large deployment of M2M, at very low data rates, but with very large numbers of devices. This vision can come true if the M2M devices are connected via cellular networks and not only via WLAN or ZigBee. The reasons are the availability of cellular coverage, combined with the simplicity of handling as users do not have to set up and connect to a ZigBee or WLAN hotspot. This makes it simple enough for every person to be able to buy M2M sensors and participate in the collection of data.

The vision is that of "Things 2.0." In Web 2.0, every person participates in social networks by disclosing personal information as well as their current status, documented in text, pictures, and relationships to others. In the world of Things 2.0, every M2M device participates by communicating its type and its status, and this information needs to be grouped in communities for aggregating and providing information. These communities could include hobby devices of the same class, for example, skis. If every ski communicated the current status of the run, you could instantaneously select the type of slope you are looking for considering elements such as ice for speed, moguls, powder, etc., and create "Skis 2.0." The same would be true for other activities, Surfing 2.0 for instance. The wave coming could be monitored and classified, not missing your chance for catching a great ride. Other M2M communities could be Cars 2.0, Homes 2.0 and Environment 2.0. Clearly, this vision could lead to a number of connected devices, which could easily cross the number 1 trillion.

TECHNOLOGY CHALLENGES: SENSING, MONITORING, COLLECTING

When addressing the need for M2M sensing, it must be translated into technical requirements specification, which serves as a design goal. As the M2M sensing requirements differ widely from one application scenario to another, a sensible specification must be developed that serves the needs of a dominating majority.

The best solution would be a device that could be activated, runs for 10 years on an AAA battery, and transmits, for example, 25 bytes of information in a duty cycle of every 100 seconds. This duty cycle could be an average, as it is moderated according to the instantaneous need. The skis from our previous example could be sitting in storage and would only be updated once a day, whereas on the slope a 1-second duty cycle might make sense. However, the question that needs to be answered is whether the power budget is reasonable. Taking the communication need of 25 B per 100 s, the resulting average data rate equals 2 b/s. Assuming a 2 MHz channel with a net capacity of 0.1 b/s/Hz (roughly GSM, and 5 percent of LTE) this results in an average of 100,000 M2M devices per cell. If every device would be billed by the operator with \$1 a year this would result in \$100k per cell addressable revenue.

Data rate 25 B/100s → 2 b/s average
2 MHz channel available at
2b/s/Hz → 100,000 devices per cell
\$1 revenue per device per year →
\$100,000 revenue per cell

Assuming 16-QAM modulation with net 2 bit/symbol (after error correction coding) results in 4 Mb/s within the 2 MHz channel. Each 25 B (200 bit) packet would then require a 0.5 ms duration; adding preambles and ramp-up/down of the transceiver, roughly 1 ms duration per packet can be assumed. For this case, 25 B for uplink as well as for downlink packets results in 2 ms transceiver up-time per duty cycle, or 2×10^{-6} .

16-QAM modulation → 0.5 ms packet duration → average on-time activity of 2×10^{-6}

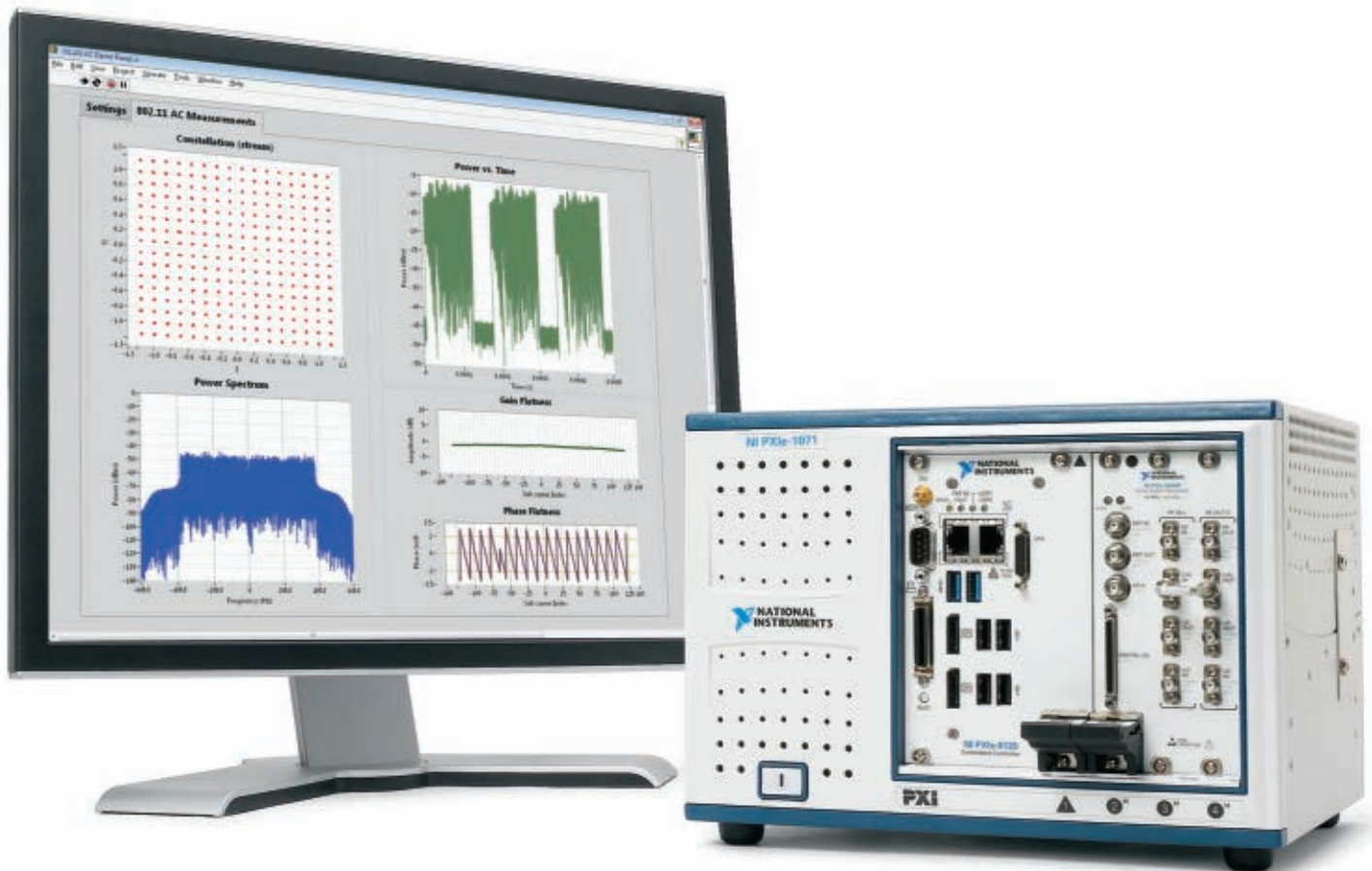
Considering an AAA battery with 1000 mAh @ 1 V and 10 years of M2M battery life operations, this leads to 10 μ W average power available. Dividing this average by 2×10^{-6} results in a power budget of 5 W during transmit and receive, allowing for 1 W transmit power. Even when taking a standby power of 1 μ W into consideration, the numbers only change marginally.

Average on-time activity of 2×10^{-6} → AAA battery allows for 10-year operation.

All the calculations above further improve when taking energy scaveng-

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ing into consideration. Scavenging energy is a term for generating energy through exploiting the low power from the environment, e.g., through solar power, or exploiting vibration power through piezo elements. Therefore, the good news is that this kind of M2M Things 2.0 vision is technically possible. However, this is not true with current cellular systems as their protocols require too much communications overhead for synchronization and channel allocation that 10 years of operations off an AAA battery is far more than one order of magnitude away. Hence, a new 5G standard is needed.

DRIVING TECHNOLOGY BY HUMAN NEEDS: TACTILE REAL-TIME CONSTRAINTS

The wireless roadmap clearly shows how technology continues to drive data rates. However, other forms of human interaction besides Internet browsing and multimedia distribution can be analyzed to understand basic needs, which will be serviced by drastically new innovations over the coming decades. For this, real-time experience can be analyzed in more detail. Obviously, real time is experienced whenever the communication response time is fast enough when compared with the time constants of the application system environment. There are four types of physiological real-time constants to consider: muscular, audio, visual, and tactile.

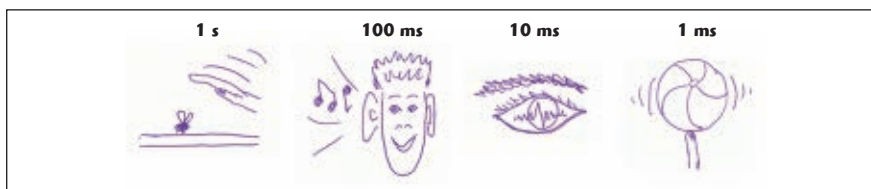
As humans we have the ability to react to sudden changes of situations with our muscles – for example, by hitting the brakes in a car due to an unforeseen incident, or by touching a hot platter on a stove. If unprepared, the sensing to muscular reaction time is in the range of 0.5 to 1 seconds. This clearly sets boundaries for technology specification in comparable situations. An example is Web browsing. The page buildup after clicking on a link has to be in the same order of time. Henceforth, real-time browsing in-

teraction is experienced if new Web pages can be built up after clicking on a link within 0.5 seconds. A shorter latency, that is, a faster reaction time of the Web is not necessary for creating a real-time experience. This reaction time has been serviced by initial 802.11b and 3G cellular systems.

The next shorter real-time latency constant is experienced when analyzing the hearing system. With humans, it is known that real-time interaction is experienced in conversations if the corresponding party receives the audio signal within 70 to 100 ms. This requirement means when standing more than 30 m (100 ft) apart, due to the speed of sound, real-time discussions cannot be carried out. This fact has led the International Telecommunications Union (ITU) to set this as a minimum latency requirement for telephony. Since the speed of light is 1 million times faster than sound, many applications have been designed that adhere to this restriction. For engineering system specifications, the impact has been that speech delays on telephone lines have to be in that order of magnitude. Also, lip synchronization between the video stream and the sound track needs to be within the same time lag, otherwise the sound seems disconnected to the moving image. The 4th generation cellular standard LTE meets this requirement, as well as modern 3rd generation systems, making Internet video conferencing (e.g., Skype) viable over cellular.

Our eyes, the visual sensing system of human beings, have a resolution slower than 100 Hz, which is why modern TV sets have a picture refresh rate in the order of 100 Hz. This allows for seamless video experience, translating into 10 ms latency requirement.

The toughest real-time latency is given by the tactile sensing of human bodies. It has been noted that we can distinguish latencies in the order of 1 ms accuracy. Examples are the reso-



▲ Fig. 4 Physiological real-time constants.

RFMD.

RFMD's New Highly-Integrated FEM for AMI/AMR Smart Meter Applications



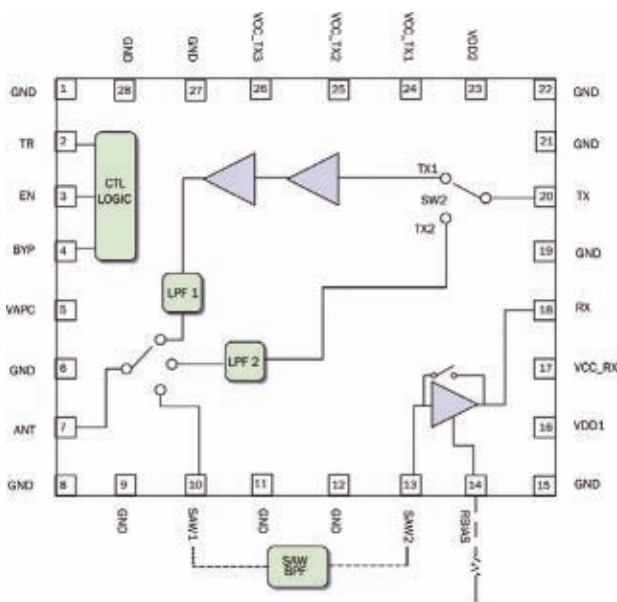
The RFFM6903 front end module meets or exceeds the system requirements for AMI/AMR Smart Meter applications operating in the 868MHz to 960MHz frequency band and supports multiple applications, including Smart Energy/advanced metering infrastructure (AMI), portable battery powered equipment, and general 868/915MHz ISM band systems.

This feature-rich FEM is ideal for advanced metering systems operating with high efficiency requirements and a minimum output power of 30 dBm. The fully integrated design approach shortens customer design time and accelerates time-to-market, while delivering industry leading product performance.

SPECIFICATIONS

Freq Range (Min) (MHz)	Freq Range (Max) (MHz)	PA Gain (dB)	P _{OUT} (dBm)	OP1dB (dBm)	V _{SUPPLY} (V)	PAI _{SUPPLY} (mA)	Efficiency (%)	Switch	Package	Part Number
868	960	21.0	30.0	30.5	3.6	800	36	SP3T	LGA, 28-pin	RFFM6903

RFFM6903 BLOCK DIAGRAM



FEATURES

- Integrated 50Ω input/output match
- Tx output power: 30dBm
- Separate 50Ω Tx/Rx transceiver interface
- Integrated PA, Tx filtering and LNA with bypass mode
- Transmit thru path

APPLICATIONS

- 868MHz/900MHz ISM bands
- Single chip RF front end module
- Wireless automatic metering
- Portable battery powered equipment
- Smart Energy

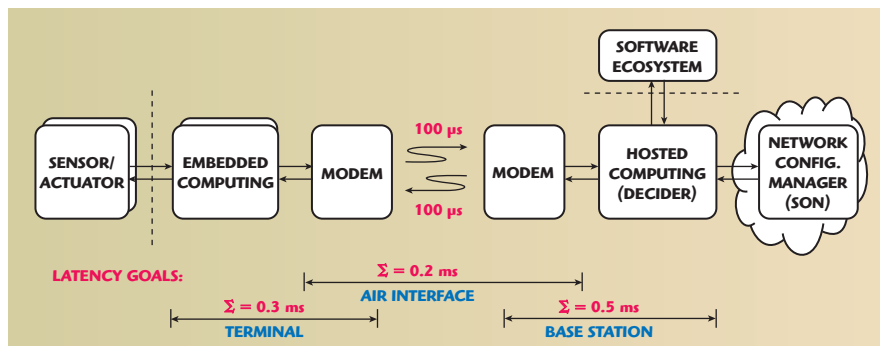
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▲ Fig. 5 The impact of breaking down the 1 ms roundtrip delay.

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lution of our tactile sensing when we move our fingers back and forth over a table with a scratch. By our high sensing resolution, we can experience the scratch in the same position. Also, tactile-visual control is in the same order of magnitude, when moving an object on a touch screen for example. If we move our hand at a rate of 1 m/s, at 1 ms latency the image follows the finger with a displacement of approximately 1 mm. A latency of 100 ms would create a 100 mm (4") displacement. A similar experience can be made by moving a mouse and tracking the cursor on the display. Since we see a differential signal over a static background, a screen update resolution finer than 10 ms is necessary. More extreme situations where the 1 ms latency requirement can be experienced are when moving a 3D object with a joy stick or in a virtual reality environment. A real-time cyber physical experience can only be given if the electronic system adheres to this extreme latency time constraint. This is far shorter than current wireless cellular systems allow for, missing the target by nearly two orders of magnitude (see **Figure 4**).

TECHNOLOGY CHALLENGES: REAL TIME

When a wireless engineer deals with latency restrictions, they need to consider the speed of light. In 1 ms, light travels 300 km. However to consider a 1 ms roundtrip latency constraint, see the possible distribution over the individual components depicted in **Figure 5**. It is a very rough distribution of latency within the chain of communication from the sensor through the operating system, the wireless/cellular protocol stack, the physical layer of terminal and base station including the latency of speed of light, the base station's protocol stack, the trunk line to the compute server, the operating system of the server, the network within the server to the processor, the computation, and back through the equivalent chain to the actuator.

Each and every element of this communications and control chain must be optimized for latency. Clearly, as the time budget on the physical layer is 100 μs maximum, LTE with OFDMA symbol duration of 70 μs is

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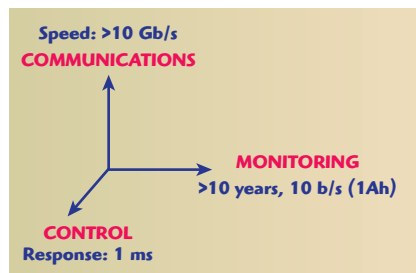
not going to be the solution. A completely new and revamped 5G cellular standard needs to be designed.

CONCLUSION

At Technical University of Dresden (TU Dresden), research on the new technologies of 5G wireless systems is being conducted using National Instruments (NI) RF and communications tools, including NI LabVIEW system design software and NI PXI

products. The TU Dresden 5G wireless lab is one of the first in the world that is comprehensively addressing these challenges. Research results will be used to influence and drive the global standards for the next phase of wireless communications.

The new challenges of 5G cellular communications can be derived from a user-centric perspective, requiring 10 Gb/s data rates to address network traffic constraints of today's 4G sys-



▲ Fig. 6 The wireless network moving from communications to monitoring to control.

tems, 10 years of operations for M2M sensing devices, as well as 1 ms real-time latency (see **Figure 6**). As all three dimensions may not need to be addressed simultaneously for any class of service, it can be assumed that it is feasible to design a new 5G system that can meet these differing requirements, and that it will clearly differ from 4G LTE.

- Data rates of 10 Gb/s will enable immersive virtual reality at levels not foreseen.
- Communicating sensors embedded in our environment will enable a new world of Things 2.0. We will move from cellular/wireless communications to a new level of wireless monitoring.
- And a roundtrip latency of 1 ms will move the world from enjoying today's wireless communication systems into the new world of wireless control systems. It will dramatically change our life, impacting all aspects of application areas such as health, safety, traffic, education, sports, games and energy.

The result will be that we will see revolutionary steps from today's wireless communication to future monitoring and to future control networks. The wireless opportunities lying ahead are larger than anyone can foresee. What we experience today is only the very first glimpse. Obviously, with challenges as pointed out here, 5G cellular communication will be the base for our future, impacting societies in ways which cannot be foreseen yet. ■

Gerhard P. Fettweis earned his Ph.D. from RWTH Aachen in 1990. Thereafter he was at IBM Research and TCSI Inc., California. Since 1994 he is Vodafone Chair Professor at TU Dresden, Germany, with main research interest on wireless transmission and chip design. He is an IEEE Fellow and an honorary doctorate of TU Tampere.

For more information about the NI platform that enabled this research, go to www.mwjjournal.com/tudresdenNI.

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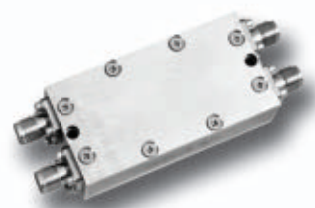
Mixers



Model Number	RF/LO Frequency (GHz)	IF Frequency (GHz)	LO Power (dBm)	Conversion Loss (dB) Typ./Max.	LO-to-RF Isolation (dB) Min.
DOUBLE-BALANCED VERSIONS					
DM0052(L)A2	0.5 - 2	DC - 0.5	7 - 13	6.5/8.5	25
DM0104(L)A1	1 - 4	DC - 1	7 - 13	5.5/7	30
DM0208(L)W2	2 - 8	DC - 2	7 - 13	7/8	30
DM0408(L)W2	4 - 8	DC - 2	7 - 13	5/6	30
DM0812(L)W2	8 - 12	DC - 4	7 - 13	4.5/6	30
DM0416(L)W2	4 - 16	DC - 4	7 - 13	7/8	30
DB0218(L)W2	2 - 18	DC - 0.75	7 - 13	6.5/8.5	22
DB0226(L)A1	2 - 26	DC - 0.5	7 - 13	9/10	20
DB0440(L)W1	4 - 40	DC - 2	10 - 15	9/10	20
TRIPLE-BALANCED VERSIONS					
TBR0058(L)A1	0.5 - 8	0.05 - 3	10 - 15	10.5/12.5	15
TB0218(L)W2	2 - 18	0.5 - 8	10 - 15	7.5/9.5	20
TB0426(L)W1	4 - 26	0.5 - 8	10 - 15	10/12	20
TB0440(L)W1	4 - 40	0.5 - 20	10 - 15	10/12	18

DYNAMIC RANGE OPTIONS		
(*) Add Letter	LO/IF Power Range	Input 1 dB C.P. (dBm) (Typ.)
L	10 - 13 dBm	+6
M	13 - 16 dBm	+10
H	17 - 20 dBm	+15

Image Rejection Mixers



Model Number	RF/LO Frequency (GHz)	Conversion Loss (dB) Max.	Image Rejection (dB) Min.	LO-to-RF Isolation (dB) Min.
IMAGE REJECTION MIXERS				
IRM0204(*)C2(**)	2 - 4	7.5	18	20
IRM0408(*)C2(**)	4 - 8	8	18	20
IRM0812(*)C2(**)	8 - 12	8	18	20
IRM1218(*)C2(**)	12 - 18	10	18	20
IRM0208(*)C2(**)	2 - 8	9	18	18
IRM0618(*)C2(**)	6 - 18	10	18	18
IR1826NI7(**)	18 - 26	10.5	18	20
IR2640NI7(**)	26 - 40	12	18	20

Model Number	RF/LO Frequency (GHz)	Conversion Loss (dB) Max.	Balance Phase (±Deg.) Typ./Max.	Balance Amplitude (±dB) Typ./Max.	LO-to-RF Isolation (dB) Min.
I/Q DEMODULATORS					
IRM0204(*)C2Q	2 - 4	10.5	7.5/10	1.0/1.5	20
IRM0408(*)C2Q	4 - 8	11	7.5/10	1.0/1.5	20
IRM0812(*)C2Q	8 - 12	11	5/7.5	.75/1.0	20
IRM1218(*)C2Q	12 - 18	13	10/15	1.0/1.5	20
IRM0208(*)C2Q	2 - 8	12	7.5/10	1.0/1.5	18
IRM0618(*)C2Q	6 - 18	13	10/15	1.0/1.5	18
IR1826NI7Q	18 - 26	13.5	10/15	1.0/1.5	20
IR2640NI7Q	26 - 40	15	10/15	1.0/1.5	20

IF FREQUENCY OPTIONS	
(**) Add Letter	IF Frequency Range (MHz)
A	20 - 40
B	40 - 80
C	100 - 200
Q	DC - 500 (I/Q)



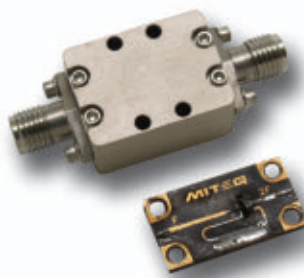
Mixer Products

Passive Doublers



Model Number	Input Frequency (GHz)	Input Power (dBm)	Output Frequency (GHz)	Conversion Loss (dB) Typ./Max.	Rejection (dBc) Typ. Fund. Odd Harm.
DROP-IN VERSIONS					
SXS01M	0.5 - 3	8 - 12	1 - 6	13/16	-20 -25
SXS04M	2 - 9	8 - 12	4 - 18	13/15	-20 -25
SXS07M	3 - 13	8 - 12	6 - 26	13/18	-18 -25
CONNECTORIZED VERSIONS					
SXS2M010060	0.5 - 3	8 - 12	1 - 6	13/16	-20 -25
SXS2M040180	2 - 9	8 - 12	4 - 18	13/15	-20 -25
SXS2M060260	3 - 13	8 - 12	6 - 26	13/17	-18 -25
MX2M130260	6.5 - 13	8 - 12	13 - 26	11/13	-15 -15
MX2M004010	0.02 - 0.5	8 - 12	0.04 - 1	10.5/13	-25 -25

SSB Upconverters or I/Q Modulators



Model Number	RF Frequency (GHz)	Conversion Loss (dB) Max.	Carrier Suppression (dBc) Min.	Carrier Suppression Carrier - Fundamental IF (dBc) Min.
IF DRIVEN MODULATORS				
SSM0204(*)C2MD(**)	2 - 4	9	20	20
SSM0408(*)C2MD(**)	4 - 8	9	20	18
SSM0812(*)C2MD(**)	8 - 12	9	20	20
SSM1218(*)C2MD(**)	12 - 18	10	20	18
SSM0208(*)C2MD(**)	2 - 8	9	20	18
SSM0618(*)C2MD(**)	6 - 18	12	20	18

For full data sheets on the products shown, please visit www.miteq.com/mixers
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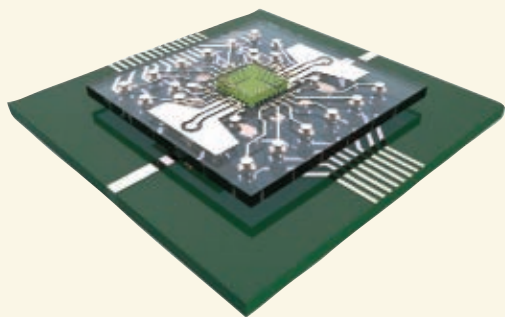
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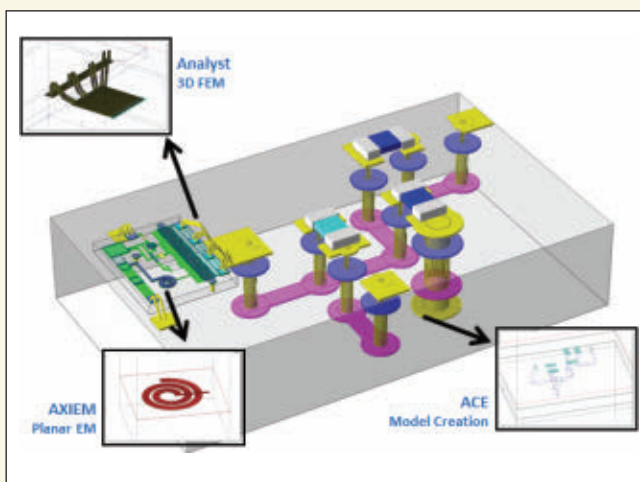


Most Valuable Product



Analyst: Fully Integrated 3D EM Simulation

Analyst™ is a full featured, 3D electro-magnetic (EM) industry-standard finite element method (FEM) simulator that is completely integrated into AWR's Microwave Office™ circuit design environment (see **Figure 1**). It is the first software to give designers the ability to use 3D EM simulation when needed from within their circuit design software, without having to work in a third party/CAD drawing and simulation environment.



▲ Fig. 1 Analyst is part of the AWR Design Environment™ integrated workflow.

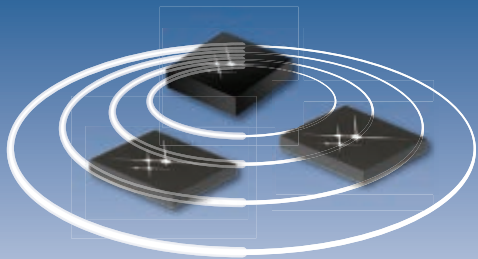
Analyst benefits those circuit designers who need to rely upon 3D FEM EM analysis for both the design and verification of their designs prior to manufacture. For RF/microwave designers of on-chip passive components, monolithic microwave integrated circuits (MMIC), microwave integrated circuits (MIC), RF printed circuit boards (PCB), modules and packaging, and hierarchical designs such as system-on-chip (SoC) and system-in-package (SiP), ease-of-use and minimal simulation setup time coupled with the elimination of manual drawing means maximum EM accuracy with minimal overhead.

3D EM TOOL FOR THE PRACTICAL CIRCUIT DESIGNER

The underlying philosophy of Analyst is to give the designer the power of 3D simulation in an easy-to-use circuit environment. This premise is made possible in two ways.

First, Analyst gives designers the ability to use 3D simulation in their normal design environment. Most circuit designs are planar, whether developed for ICs, modules or boards; consequently, 3D EM simulators are really only needed in the few places where planar EM simu-

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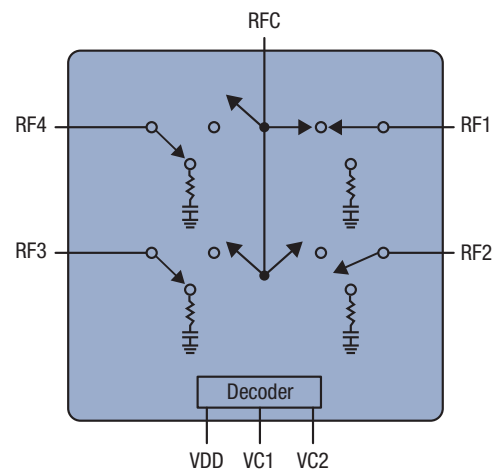


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SKY13392-359LF Functional Block Diagram

Part Number	Description (Absorptive / Reflective)	Frequency (GHz)	Typ. IL (dB)	Typ. Isolation (dB)	Typ. IIP3 (dBm)	Typ. IP _{1dB} (dBm)	Package (mm)
SKY13347-360LF	SPST (A)	0.1–3.0	0.7	35	40	21	QFN 8L 2 x 2 x 0.9
SKY13372-467LF	SPDT (A)	0.1–6.0	0.8	65	45	26	QFN 16L 4 x 4 x 0.9
SKY13373-460LF	SP3T (R)	0.1–3.5	0.4	35	70	39	QFN 12L 2 x 2 x 0.55
SKY13384-350LF	SP4T (A)	0.02–4.0	0.7	45	50	30	QFN 16L 3 x 3 x 0.75
SKY13392-359LF	SP4T (A)	0.02–4.0	1.0	55	47	30	QFN 16L 4 x 4 x 0.9
SKY13415-485LF	SP5T (R)	0.1–3.0	0.4	32	70	38	QFN 14L 2 x 2 x 0.55
SKY13416-485LF	SP6T (R)	0.1–3.0	0.4	30	69	39	QFN 14L 2 x 2 x 0.55
SKY13417-485LF	SP7T (R)	0.1–3.0	0.65	30	69	38	QFN 14L 2 x 2 x 0.55
SKY13418-485LF	SP8T (R)	0.1–3.0	0.5	30	69	38	QFN 14L 2 x 2 x 0.55

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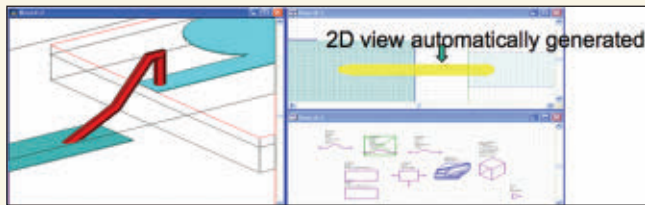
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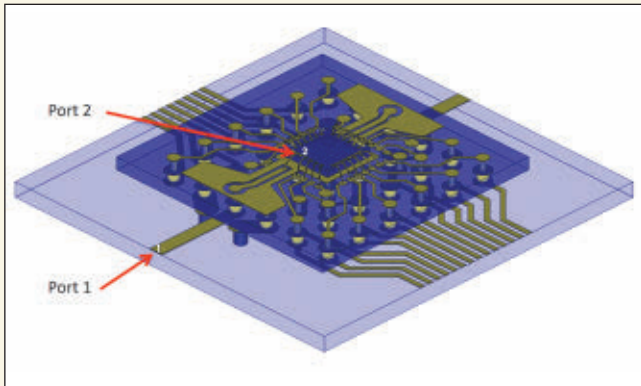


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▲ Fig. 2 Analyst automatically generates parameter controlled layout cells (Pcells).



▲ Fig. 3 The performance of the transition from Port 1 on the board to Port 2 on the chip is analyzed.

lators are not practical, for example, a gap in the dielectric substrate from a recessed chip on a board. Therefore, it makes complete sense to provide 3D EM simulation capabilities directly and seamlessly within a circuit design environment.

Second, Analyst comes preconfigured with settings (boundary, ports, mesh, modes) that are tailored to the class of problems specific to these IC, module, and board designs. Prior to Analyst, designers had to define, specify, and ship their 3D problems to an external EM tool, set up and simulate them, and then import the results back into their circuit environment. The first issue with this method is one of time and potential error in carrying out the export/import of the project. The second is that these simulators require many esoteric settings of ports and solver options that the average designer can feel uncomfortable with and overwhelmed by and therefore less confident with the end result. In the Analyst approach, the settings are already optimized for the typical problems designers are likely to encounter, therefore the manual interactions are minimized, reducing potential user error and increasing confidence in results.

ANALYST IN THE DESIGN FLOW

Microwave Office has traditionally

given designers the flexibility to easily use EM simulation in a variety of ways. This use model has been evolving for a number of years, including the concept of extraction, where the layout can be automatically selected, EM simulated, and the results included into the circuit.

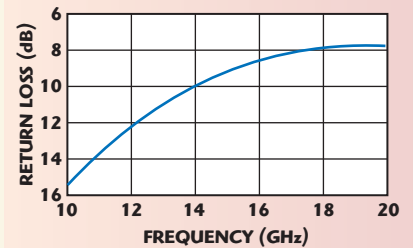
AWR continues to improve the functionality of the EM environment (Extraction flow/EXTRACT block) within Microwave Office by now offering 3D FEM EM analysis via Analyst. Even before Analyst, layouts could be

controlled by variables, allowing the creation of models with swept parameters. For example, a custom model of a discontinuity like a notched tee is easy to create. Designers can tune the parameters of the model, and can even run optimizations. Layouts can also take advantage of preconfigured layout cells (Pcells), as shown in **Figure 2**, the shapes of which are controlled by parameters. And now with Analyst, the EM environment has been enhanced to handle 3D structures common to planar circuit topologies. For example, Pcells now automatically create 3D bond wires, ball grid arrays (BGA), tapered vias, and bond straps. Common 3D discontinuities like finite sized dielectric bricks and package walls can also be easily included.

REAL-WORLD CHIP/PACKAGE/BOARD EXAMPLE

The key advantage of Analyst is its tight integration within AWR's Microwave Office circuit design and simulation environment. To demonstrate the real-world value of this unique feature, let's look at an example: the optimization of a board-to-module-to-chip signal path.

Figure 3 shows the board, module and periphery of the chip being investigated. The signal goes from Port 1 on a trace on a PC board, onto a module by means of a BGA, along a trace on top



▲ Fig. 4 The return loss is shown from 10 to 20 GHz before optimization.

of the module, and over to Port 2 on the chip by means of a bond wire. The design goal is to have a return loss of better than 20 dB over the frequency range of interest, 10 to 20 GHz.

Analyst simulation results, shown in **Figure 4**, for the layout of the product photo indicate that the design goal is not yet being met. To remedy this, Analyst is used within the Microwave Office design environment to enable easy design optimization via a three-stage approach:

- Isolate specific area(s)
- Identify electrically their behavior
- Modify the layout to bring behavior into spec

Analyst has a number of features that designers can take advantage of as the design is modified. The tool has the ability to simulate only portions of the layout, thereby reducing problem size and increasing simulation flexibility (Step 1). The Analyst results are inserted into a schematic, capacitors are attached to the ports, and their values tuned and optimized (Step 2). The layout is then augmented to give the desired extra capacitance or inductance (Step 3). Again, only the portion of the layout of interest is simulated. In this manner, Analyst has been designed to minimize the amount of setup time required for a simulation. The final solution that results from this three-stage approach is one in which the bond wire has been doubled and shortened to reduce inductance, the gap between the bond wire pad and side grounds has been decreased to increase capacitance, and the ground vias on the board have been moved away from the ground balls to increase the loop inductance and compensate for the ball capacitance. The entire structure is then simulated as a final verification check to ensure the design meets with success. The resulting data is shown in **Figure 5**.

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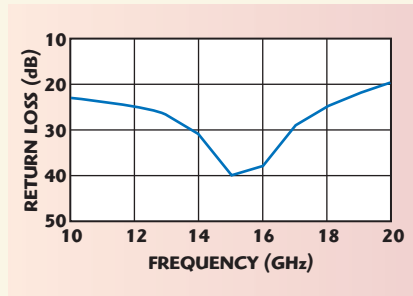
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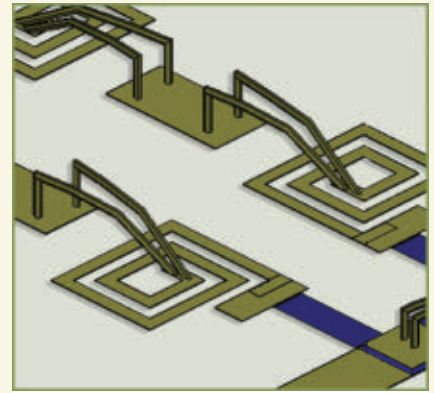
Analyst is specifically designed with the knowledge that RF/microwave designers need to perform analysis on interconnects commonly found within high-frequency packages, boards and modules.

- Die-level interconnect: Analyst enables designers to simulate and accurately capture the electrical behavior resulting from die-level interconnects (see **Figure 6**) such as air bridges, spiral inductors, capacitors and tapered vias within gallium arsenide (GaAs), gallium nitride (GaN), silicon germanium (SiGe), or bipolar junction complementary metal oxide semiconductor (BiCMOS) ICs so that IC design performance can be fully optimized.
- IC/package/board/module interconnect: Analyst is equally capable of solving the challenges of IC packaging and chip/package/board and module interconnect (see **Figure 7**) that include bond wires, bumps, ribbons and/or solder balls. Analyst accurately accounts for each interconnect and its associated parasitics.

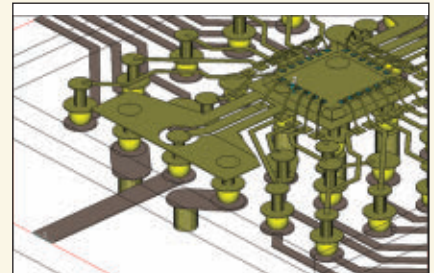


▲ Fig. 5 The entire signal path is simulated — the return loss meets the specification of being less than 20 dB over the desired frequency range.

Electromagnetic simulators are commonly used to help designers gain a more accurate understanding of the physical layout and interconnect common to ICs, PCBs, modules and associated packaging. The main advantage of Analyst is its tight integration into the AVR Microwave Office circuit design environment. With Analyst seamlessly embedded into the Microwave Office environment, circuit designers save time (fewer mouse clicks and menu options) while gaining greater EM-insight into design performance. For example, layout setup and drawing are



▲ Fig. 6 Die-level interconnect.



▲ Fig. 7 IC/package/board interconnect.

simplified by preconfigured 3D Pcells for the bond wires and BGA balls. Hierarchy is supported in the EM layout, making for easier design reuse. Tuning, optimization and sensitivity and yield analysis can be quickly implemented through the use of parameterized layout, without having to leave the Microwave Office environment. Since Analyst is optimized for RF and microwave designers, the designer is not required to become an expert on EM simulation software settings. It is now possible to seamlessly include 3D EM simulation in critical circuit simulations such as optimization, tuning of circuits like filters, sensitivity and yield analysis, and even nonlinear circuit simulation using harmonic balance. The designer can fully concentrate on his/her design, easily using 3D EM simulation when needed, without having to spend time learning a complex EM point tool. The key point is that designers can now focus more of their time on circuit designs/behavior and less on the nuances of using a 3D EM point tool.

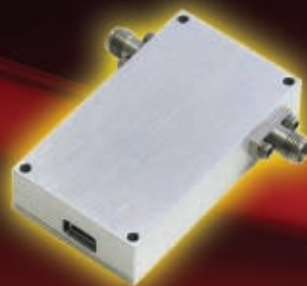
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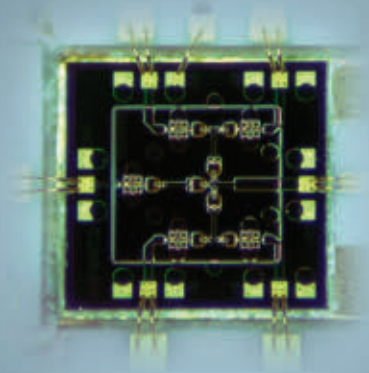


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THEODORE S. RAPPAPORT, *Director of NYU WIRELESS, New York, NY*

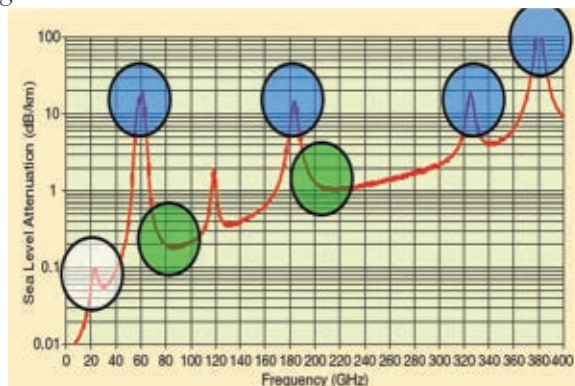
As the cellular industry rolls out fourth-generation Long Term Evolution (LTE) across the world, one has to believe that we are witnessing the dawn of an amazing new era, where wireless becomes so pervasive and intertwined with everything we do in life, just as the pen and paper are today. We are at the dawn of the Wireless Renaissance. Since I wrote “The Wireless Revolution” article for the *IEEE’s Communications Magazine* in 1991¹, we have witnessed the transition from first generation analog FM cellular phones, operating at carrier frequencies of 850 MHz, to today’s 4G LTE devices and smartphones with download speeds that will, in a year or two, approach 500 Megabits per second at carrier frequencies of approximately 2 GHz. With multi-gigabit per second, 60 GHz Personal Area Networks (PAN) now available under the IEEE 802.11ad standard and the WiGig and Wireless HD labels, the ability to retrieve from the cloud all of the content in our lives within seconds is now a reality. What is more, the required engineering know-how needed to catapult wireless to its renaissance is being born in these new LTE and 60 GHz technologies. But as awesome as the capabilities of LTE and 60 GHz Wireless LAN are, these are simply cumbersome first steps toward what the future holds in the coming decade.

Truth be told, our modern wireless technologies are only a shell of what we should expect, given the past advances of the computing and semiconductor industries and the abundance of untapped spectrum above 3 GHz. In 1991, many of us were learning about the new field of wireless mobile communications, while the PC industry

offered personal computers with clock speeds of approximately 10 MHz and memory sizes of 10 megabytes. Today, when considering the parallelization of multi-core processors, both the equivalent clock speed and memory size of a mid-range PC have increased by three orders of magnitude – a factor of 1000 – and the consumer pays less than half the price for today’s more powerful PC, adjusting for inflation. Yet, over the same 22 year period, the carrier frequencies used by the cellular industry across the globe have advanced from 850 MHz to only about 2 GHz, not even approaching one order of magnitude increase in frequency. Today’s low-cost CMOS circuitry can be made to operate with an f_t of 1 THz, meaning that cellphones and WLAN devices can now operate at many tens or hundreds of GHz, orders of magnitude greater in carrier frequency than today’s commercial devices. Such an increase in carrier frequency brings with it a similar increase in useable bandwidth, thus allowing future mobile or PAN services to have many orders of magnitude greater raw bandwidth (and capacity), as well. By proportionally increasing the carrier frequency (that is, decreasing the wavelength) and increasing the spectrum bandwidth available for future mobile devices, these future millimeter-wave systems will exploit new high gain, electrically steered, integrated antennas to find the best signals in a mobile environment, while being physically no larger than a fingernail or

as small as a human freckle, as carrier frequencies approach a few hundred GHz.

Consider this — the contiguous spectrum of every commercial wireless service known to man (such as satellite, cellular, Wi-Fi, broadcast television, FM radio, amateur radio, etc.) easily fits within the bandwidth of today’s 60 GHz unlicensed band. It is hard not to be giddy about the emerging impact of such massive transfer rates, as carrier frequencies begin to ramp up to take advantage of today’s semiconductor capabilities³ (see **Figure 1**). As this Massively Broadband® era is reached, incredible bandwidth and spatial steering of radio waves will be new dimensions that can be traded with power to yield unparalleled flexibility and power efficiency, allowing revolutionary form factors for everything we enjoy today, such as laptops (where the magnetic or electronic hard drive will become a high speed tetherless device you can carry in your wallet or clothing), vehicles (where the control wiring harnesses and connections in cars are replaced with broadband wireless interconnec-



▲ Fig. 1 Carrier frequencies will ramp to take advantage of semiconductor capabilities and natural attenuation characteristics.³

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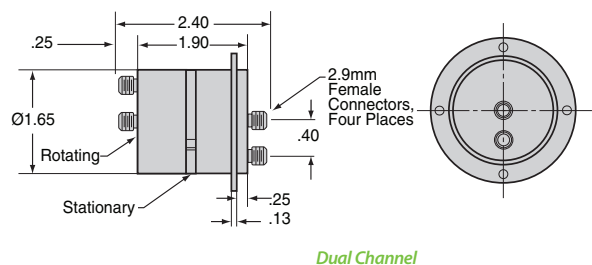
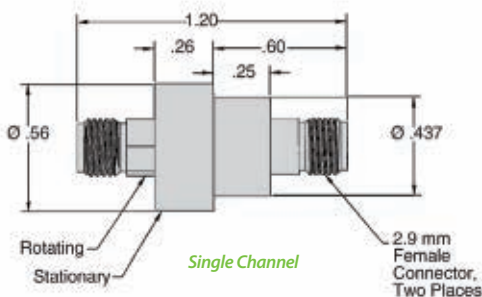
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	10 - 26 GHz	1.35 : 1 MAX.
	26 - 40 GHz	1.75 : 1 MAX.
WOW	1.05 MAX.	
INSERTION LOSS	DC - 10 GHz	0.2 dB MAX.
	10 - 26 GHz	0.4 dB MAX.
	26 - 40 GHz	0.6 dB MAX.
PEAK POWER	Equal to connector rating	

DUAL CHANNEL SPECIFICATIONS:

ELECTRICAL

	Channel 1	Channel 2
FREQUENCY	7.0 - 22.0 GHz	29.0 - 31.0 GHz
VSWR	1.50:1 MAX.	1.70:1 MAX.
WOW	0.15	0.25
INSERTION LOSS	0.5 dB MAX.	1.0 dB MAX.
ISOLATION	Channel to Channel	50.0 dB MIN.



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tions operating in the “whisper radio” band of 380 GHz (see Figure 1), making cars less expensive to build and lighter weight with better gas mileage), to data centers (where today’s expensive optical or fiber interconnects are replaced with wireless transceivers to enable unprecedented deployment flexibility with less cost and power). This unparalleled spectrum will unleash revolutionary uses of our cellphone, and will enable new concepts in the home, such as the “information shower,” where all of your past and present content in your life is downloaded to you as you walk from the living room to the bedroom. This wireless “peace dividend” spawned by investments and advances in the semiconductor and computing industries, and new advances in miniature on-chip and in-package antennas, integrated beam formers and continued advances in spatial processing, will bring about the renaissance of wireless communications, as the copper wire is relegated to the important job of carrying power to increasingly efficient devices that are wirelessly interconnected. This renaissance will also bring the cloud to

our cellphones, wireless into the operating room of hospitals, medical and patient care, homes and vehicles, and telepathy (yes, telepathy, where wireless monitoring of the brain has been shown to deliver 3 bits/second telepathy rates today — and we expect these rates to ramp dramatically, following in the footsteps of cellular). To study these areas and more, a new research center called NYU WIRELESS has been created at NYU and NYU-Poly (formerly known as Brooklyn Poly and now the engineering college of NYU). At NYU WIRELESS, a focus on wireless communications, computing and medicine combined with nearly \$10 million in investment, has brought together researchers and students in an unparalleled collaborative environment, with access to the world’s leading wireless, computational and medical researchers. Our recent pioneering work on urban multipath propagation at NYU WIRELESS shows that at the millimeter-wave frequencies of 28 and 38 GHz², cellular phones using adaptive antennas will actually be more reliable than today’s 2 GHz systems, with data rates that are

orders of magnitude greater than LTE’s greatest plans. Our work also shows that for cell radii of two hundred meters in New York City and Austin, Texas, neither urban propagation nor rain is an issue whatsoever. Other universities, such as MIT and the University of Surrey have also recently launched centers to investigate aspects of future wireless networks.

For the renaissance of wireless to take hold, the first step will be to enable ubiquitous multi-gigabit per second data rates to cellphones of the future. Carriers using LTE will not realize this in today’s low microwave bands that are currently the focus of spectrum regulators, but 5G will enable this, if the millimeter-wave bands are opened up to mobile usage. Governments around the world should make this millimeter-wave spectrum available without delay, and should begin to contemplate much larger spectrum allocations, on the order of several GHz bandwidths as shown in Figure 1. While governments attempted to do this with LMDS spectrum at 28 and 38 GHz in the late 1990s, the spectrum availability at that time was far ahead of the capabilities of semiconductors, and electronics were too costly. Today, however, the world is different, as the move to 60 GHz PAN and 77 GHz automotive electronics are creating the reservoir of technical experts needed to bring wireless into its renaissance. As massive spectrum allocations in the mmWave bands begin to provide a playing field for the modern capabilities of wireless devices using state-of-the-art CMOS circuit designs, computing and signal processing, all of us will soon experience such amazing data transfer rates and new wireless applications that promise to transform our lives in ways that few could have imagined in 1991.

NOTE: *Massively Broadband* is a registered trademark of the author: ■

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1. T.S. Rappaport, “The Wireless Revolution,” *IEEE Communications Magazine*, 29 (11), November 1991, pp. 52-71.
2. T.S. Rappaport, Y. Qiao, J.I. Tamir, J.N. Murdock and E. Ben-Dor, “Cellular Broadband Millimeter Wave Propagation and Angle of Arrival for Adaptive Beam Steering Systems,” *IEEE Radio and Wireless Symposium (RWS) 2012*, pp. 151-154.
3. T.S. Rappaport, J. Murdock and F. Gutierrez, “State-of-the-Art in 60 GHz Integrated Circuits and Systems for Wireless Communications,” *Proceedings of the IEEE*, August 2011, Vol. 99, No. 8, pp. 1390-1436.



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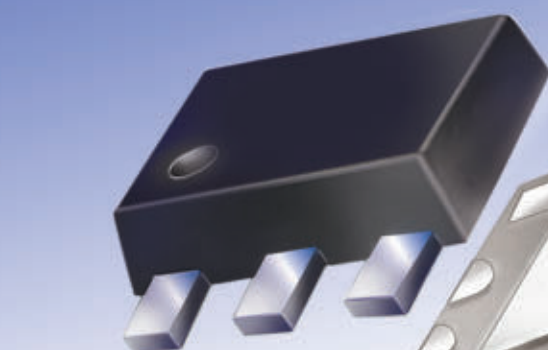
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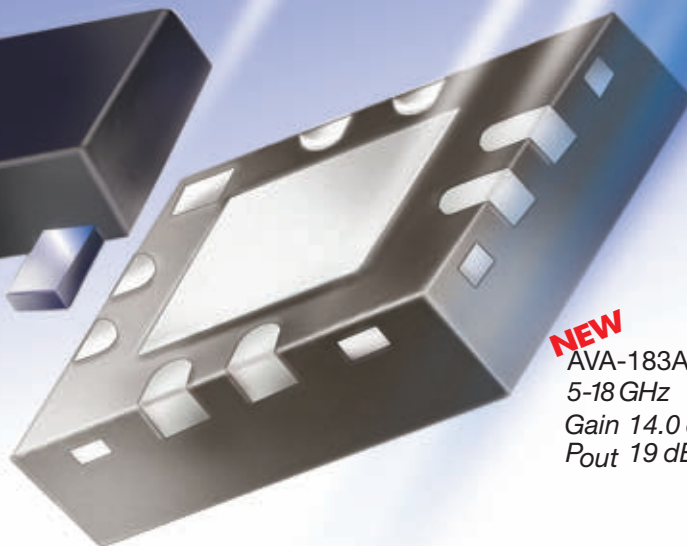
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OCTAVE BAND LOW NOISE AMPLIFIERS

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

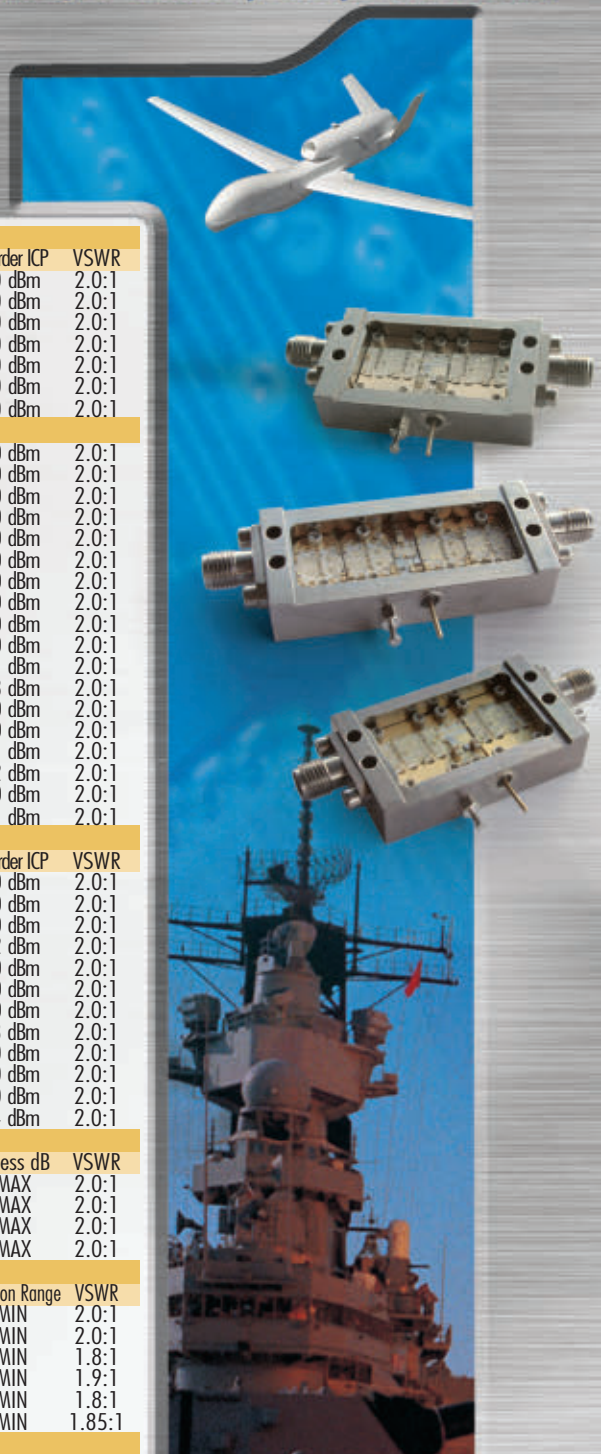
Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 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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Raytheon Co.'s new-production Patriot Air and Missile Defense System has received the U.S. Army's final stamp of approval after undergoing stringent testing. During the testing, Patriot's performance was outstanding when subjected to challenging climatic and electromagnetic environments.

"This approval validates the modernized Patriot system's readiness to counter evolving threats and protect warfighters and allies in a combat situation," said Sanjay Kapoor, vice president for Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business. "This will only build on the confidence that our Patriot partners have in the system's performance and reliability, a confidence we look forward to extending to the partners who join the Patriot family."

Patriot performance consistently exceeded expectations in all eight flight tests in a variety of terrain and weather conditions.

Since last year, the Patriot system has undergone the U.S. Army's rigorous testing of every component of the modernized system. Patriot performance consistently exceeded expectations in all eight flight tests in a variety of terrain and weather conditions.

dergone the U.S. Army's rigorous testing of every component of the modernized system. Patriot performance consistently exceeded expectations in all eight flight tests in a variety of terrain and weather conditions.

Harris Team Selected for Global Tactical Advances Communications Systems

A team led by Harris Corp. has been selected for the Global Tactical Advanced Communication Systems (GTACS) contract, which was awarded by the U.S. Army's Program Executive Office — Command Communications and Control.

Harris was one of 20 prime contractors selected to compete for work under the five-year, \$10 billion Indefinite Delivery/Indefinite Quantity contract, which enables both defense and civilian federal agencies to quickly and cost-effectively procure a wide range of tactical communications products, systems and engineering services.

Under GTACS, the Harris team will pursue opportunities to supply the Department of Defense, as well as U.S. government agencies such as Homeland Security, with advanced communications solutions that range from wireless networking to tactical satellite communications and handheld JTRS-compliant radios.

"The GTACS contract vehicle makes it very efficient for customers to acquire a comprehensive mix of products and services from the Harris team," said Sheldon Fox, group president, Harris Government Communications Systems.

"Harris and its partners will work together to provide advanced, networked communications systems that meet the critical needs of our warfighters and security agencies."

Lockheed Martin Submits Final Proposal for Medium-Range Ballistic Missile

Lockheed Martin announced that it has submitted its final proposal revision for the Medium-Range Ballistic Missile (MRBM) Targets contract. The Lockheed Martin team delivered its final offer to the U.S. Missile Defense Agency's (MDA) Targets and Countermeasures Program Office in Huntsville, AL.

The contract will provide MRBM targets to support Ballistic Missile Defense System element and system flight tests. Requirements include development and manufacturing of MRBMs, integrated logistics support to include inventory storage and maintenance, pre- and post-mission analysis, launch preparation and execution and engineering services. The final proposal revision responds to amendments to the request for proposals made by the MDA following Lockheed Martin's submission of its proposal in June. The MDA anticipates contract award in 2012.

"Lockheed Martin is dedicated to developing reliable and affordable Medium-Range Ballistic Missile Targets that will meet the Missile Defense Agency's requirements for tests of the nation's Ballistic Missile Defense System," said John Holly, vice president of Missile Defense Systems and deputy for Strategic and Missile Defense Systems, Lockheed Martin Space Systems Co. "Our offer represents the next step in cost-efficient systems engineering that will maintain the quality required to produce and launch these next-generation ballistic missiles."

To meet the government's requirements, Lockheed Martin will apply more than 15 years of experience as a leading provider of target missiles for missile defense testing. Lockheed Martin has achieved an unmatched 98-percent success rate in 43 out of 44 target missions since 1996, including legacy and next-generation ballistic missile targets. Target reliability contributes to the overall affordability of a flight test, due to costs associated with the weapon system and sensors. Lockheed Martin has implemented innovations in next-generation target production and operations that focus on cost effectiveness without sacrifices in reliability.

Northrop Grumman Begins Sampling GaN MMIC Product Line for the Military

Northrop Grumman Corp. has developed a line of GaN MMICs for military and commercial uses. These devices represent the first commercial availability of GaN-based components from the company.

Initial engineering evaluation sampling is underway with quantities of three GaN MMIC products. They were

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developed for defense and commercial ground satellite communication terminal markets and the commercial wireless infrastructure market, said Frank Kropschot, general manager of the Microelectronics Products and Services (MPS) business unit of Northrop Grumman Aerospace Systems.

"We have been producing gallium nitride-based devices since 2002 at Northrop Grumman's dedicated wafer fabrication facility in Redondo Beach, which the Department of Defense has designated as a Trusted Foundry," Kropschot said. "We have achieved outstanding performance and reliability from our high-frequency gallium nitride process and are extremely confident that these GaN MMICs will improve performance, efficiency and bandwidth for military and commercial users."

The initial set of three MMICs has these performance characteristics:

- The APN149 is a GaN high electron mobility transistor (HEMT) MMIC power amplifier chip that operates between 18 and 23 GHz. This power amplifier provides 20 dB of linear gain, +36 dBm (4 W) of output power at 1 dB gain compression and +38 dBm (6.3 W) in saturation with physical address extension (PAE) of greater than 30 percent.
- The APN180 is a GaN HEMT MMIC power amplifier chip that operates between 27 and 31 GHz. This

power amplifier provides 21 dB of linear gain, +38 dBm (6.3 W) of output power at 1 dB gain compression and +39 dBm (8 W) in saturation with PAE of 30 percent at midband. For less demanding applications, the APN180 can be operated from a drain voltage as low as +20 V while still producing +37 dBm (5 W) of saturated output power.

- The APN167 is a GaN HEMT MMIC power amplifier chip that operates between 43 and 46 GHz. This power amplifier provides 20 dB of gain, +35.5 dBm (3.5 W) of output power at 1 dB gain compression and +38.5 dBm (7 W) in saturation with PAE of 19 percent at midband.

"These new products are the first of several we plan to introduce into the marketplace during the next few months as we roll out a new family of products using Northrop Grumman's 0.2 μ m GaN HEMT process developed partially under the Defense Advanced Research Projects Agency's (DARPA) Wide Band Gap Semiconductors for Radio Frequency program (WBGSRF)," Kropschot said. He added the DARPA program was the first of several key GaN technology development contracts awarded to Northrop Grumman beginning in 2002. He noted that GaN devices are key components the new low-cost terminals recently introduced by an industry team consisting of Northrop Grumman, Lockheed Martin Space Systems and Telecommunication Systems.

GaN Power Amplifiers

Model Number	Freq (GHz)	Gain (dB)	Psat (Watts)	PAE	VDC (V)	CW/Pulsed	Size - LxWxH (inches)
DM-HPMB-25-102	0.5-6	30	25	20%	50	CW	2.5 x 2.75 x 0.45
DM-HPLS-50-101	1-3	50	50	25%	28	CW	2.5 x 2.75 x 0.45
DM-HPLS-100-101	1-3	50	100	25%	28	CW	5.0 x 5.4 x 1.0
DM-HPSC-25-101	2-6	50	25	30%	28	CW	2.5 x 2.75 x 0.45
DM-HPSC-50-101	2-6	50	50	30%	28	CW	2.5 x 2.75 x 0.45
DM-HPMB-10-101	2-18	40	10	15%	32	CW	2.5 x 2.75 x 0.45
DM-HPMB-25-101	6-18	50	25	20%	28	CW	2.5 x 2.75 x 0.45
DM-HPMB-50-101	6-18	50	50	20%	28	CW	2.5 x 2.75 x 0.45
DM-HPX-140-101	7.8-9.6	55	140	30%	40	Pulse*	3.6 x 3.4 x 1.0
DM-HPX-25-101	8-11	45	25	30%	28	CW	2.5 x 2.75 x 0.45
DM-HPX-50-102	8-11	50	50	30%	28	CW	2.5 x 2.75 x 0.45
DM-HPX-100-101	8-11	50	100	30%	28	Pulse*	3.6 x 3.4 x 1.0
DM-HPKU-20-101	14-16	50	20	20%	28	CW	2.5 x 2.75 x 0.45
DM-HPKU-40-101	14-16	50	40	20%	28	CW	2.5 x 2.75 x 0.45
DM-HPKU-80-101	14-16	50	80	20%	28	CW	3.6 x 3.4 x 1.0
DM-HPKA-10-101	29-31	45	10	20%	28	CW	2.5 x 2.75 x 0.45

*Pulse width 100 μ s, 10% duty cycle

Delta Microwave power amplifiers employ GaN devices for high efficiency, high power density, and high reliability.

Delta Microwave specializes in the design and manufacture of commercial, military, and space grade RF components and integrated microwave assemblies from 1MHz to 45 GHz.



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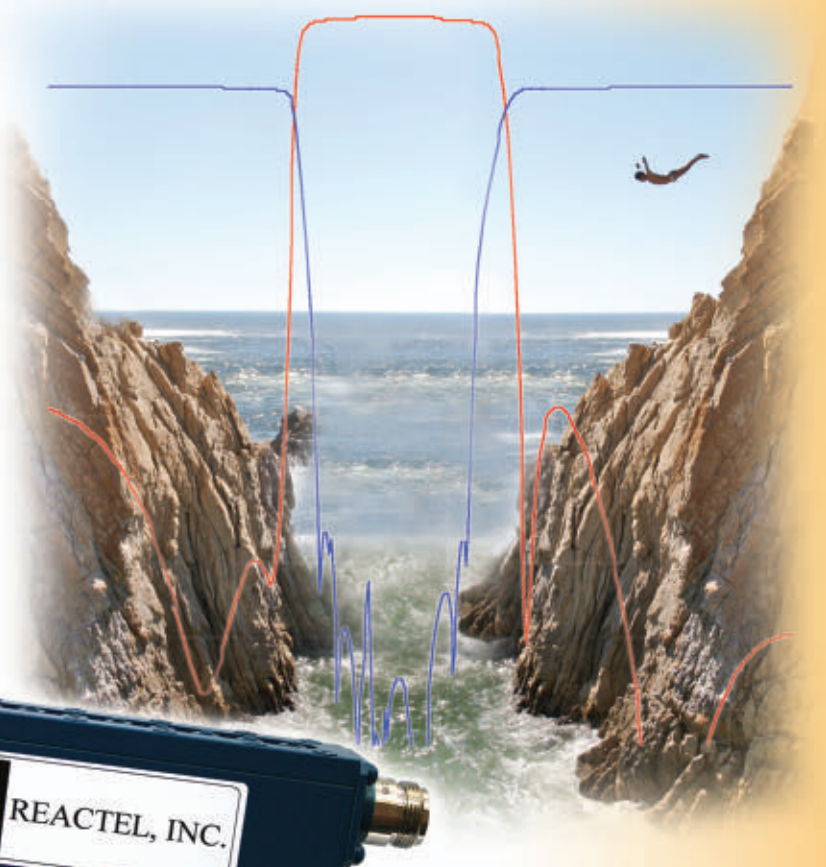
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Galileo IOV Satellites 3 and 4 Deployed

The second pair of in-orbit validation (IOV) satellites forming part of Europe's Galileo navigation system, developed and manufactured by Astrium, has been launched aboard a Soyuz rocket from the European Space Centre in French Guiana.

This initial constellation of four IOV satellites marks an important milestone in putting the core of the Galileo system in place. The two latest IOV satellites will soon enter service in orbit alongside IOV satellites 1 and 2 and the constellation will be activated in order to validate the Galileo system. With these four satellites, launched into two

"...we have accomplished our task of laying the foundations for the European navigation system."

different orbit planes, Galileo will prove it can deliver ultra-precise three-dimensional positioning.

Galileo is Europe's first global satellite navigation system under civilian control. It will supply ultra-reliable and precise positioning

data worldwide. The Full Operational Capability phase of the Galileo programme is managed and fully funded by the European Commission.

The Galileo IOV satellites were designed and built by an Astrium team led from Ottobrunn, Germany. The state-of-the-art navigation payload was designed, integrated and tested at the company's payload centre of excellence in Portsmouth, UK.

Astrium Satellites' CEO Evert Dudok said: "Astrium's teams have been providing their unique know-how and experience to the Galileo programme for more than ten years, since the initial definition of the system and the entry into service of the GIOVE experimental satellites. With the successful launch of the four IOV satellites, we have accomplished our task of laying the foundations for the European navigation system. And our involvement does not end here: Astrium and its subsidiaries will be contributing half of the workshare for the next satellites, delivering the Ground Control Segment (GCS), taking part in system support activities and adapting Ariane 5 for the launch of 4 Galileo satellites at a time."

Harmonized 79 GHz Frequency Band Sought for Automotive Radars

In November, the International Telecommunications Union (ITU) hosted a workshop in Geneva, Switzerland to demonstrate the progress made over the past year in developing short-range high-resolution automotive radar systems in the 79 GHz frequency band that will contribute to increased transport efficiencies and road safety. The developments have been made within the automotive indus-

try, working together with international bodies such as the ITU and the European Commission.

The workshop organized by the industry-based 79 GHz Consortium in coordination with the ITU's Radiocommunication Bureau focused on the use of automotive radars for future Intelligent Transport Systems and featured a live demonstration of automotive short-range high-resolution radar operations in the 79 GHz frequency band.

The 79 GHz Consortium, in partnership with ITU's Radiocommunication Sector, aims to establish a harmonized worldwide frequency allocation for vehicular radars in line with the frequency range allocated by the European Commission in 2004. This standardization process is in the framework of the upcoming ITU World Radiocommunication Conference in 2015 (WRC-15).

...to establish a harmonized worldwide frequency allocation for vehicular radars...

UK Adds £60 M to Europe's Space Programme

The UK's £9 billion space sector is about to become even bigger after the government pledged an extra £60 million to Europe's space programme. Industry has already identified projects to the value of £1 billion that should follow in train from this additional funding.

The investment through the UK Space Agency will also secure the future of the ESA facility in Oxfordshire, including transferring ESA's telecoms satellite headquarters to the UK and creating over 100 new high-tech jobs. This will put Harwell at the centre of space technology and development, reinforcing the work of the Satellite Applications Catapult Centre and RAL Space. The hub will work with partners in the UK, across Europe and around the world to drive an ever-increasing range of exciting new opportunities for industry and academia.

The new resources will be focussed on projects that will bring economic growth to the UK. One example is a new generation platform for telecommunications satellites. This will provide a 20-year horizon for new satellite sales that are competitive in the global market. Another is the next generation of weather satellites, where a UK contribution to ESA programmes will bring significant business through future orders.

UK Minister for Universities and Science, David Willetts said: "This increase will bring the UK's total investment in the European Space Agency to an average of £240 million per year over the next five years. This will allow the UK to play a leading role in the next phase of European space collaboration. It will drive growth, create extra skilled jobs and help the UK to realise its ambition to have a £30 billion space industry by 2030."



“...UK to play a leading role in the next phase of European space collaboration ...”

European space sector by developing space capacities in the UK. In addition to the increased use of UK industry, our commitment to growing ESA's facility here in Harwell confirms that the UK Space Agency is taking up more of a leadership role in key parts of the space sector.”

Jean-Jacques Dordain, director general of the European Space Agency said: “With this substantial increase in investment, the UK is helping to promote competition in and encourage the growth of the

BoF Group Investigates Sensor Integration in Mobile Systems

The Mobile Industry Processor Interface (MIPI®) Alliance has formed an open ‘Birds of a Feather’ (BoF) group that will investigate the requirements related to integrating sensors into mobile systems. The group will address current challenges facing the sensor and wireless markets including a fragmented digital interface land-

scape, rapidly expanding sensors per device, varied signals per device and non-scalable architectures.

“The massive proliferation of sensors in diverse applications is driving the trend toward standardization of sensor interfaces,” said MEMS Industry Group® (MIG) managing director Karen Lightman. “With MEMS playing a major role in the adoption of sensors worldwide, we recognize the importance of investigating the requirements needed to address this rapidly growing space. We are excited to work with MIPI Alliance as they explore the issues at stake in sensor-interface standardization.”

“MIPI Alliance members – from semiconductor manufacturers to mobile device OEMs – have been considering this issue for some time,” said Joel Huloux, chairman of the board of MIPI Alliance. “The Sensor BoF gives us an opportunity to talk with key sensor stakeholders, and insures we develop technology that the market truly wants and needs.”

As one of the group's first efforts, MIPI Alliance joined with MIG to conduct member-based market research. While the need for a sensor interface standard was not immediately apparent, there was a clear gap between the technology of today and the needs of the future. Closing that gap will be a primary focus of the Sensor BoF group.

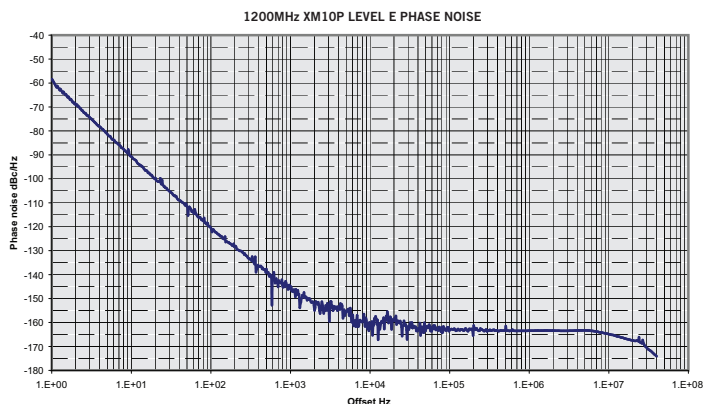
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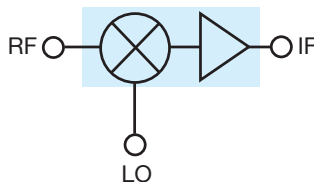
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MRA-42LH+	10	1.0-4.2	10-800	12	8.95
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The Microwave Tube is Still Strong at Nearly \$1 B

While microwave and millimeter wave high-power vacuum electron devices (VED) remain “below the radar” of many industry observers, the total available market (TAM) for this segment is nearly \$1 billion in 2012. Despite its size, and although these tubes remain essential elements in specialized military, scientific/medical and space communications applications, this market is generally under-reported and poorly understood by those not directly involved in it.

This is now a stable industry after several rounds of consolidation in recent years. There is potential for some further consolidation, but there are no signs of that happening yet.

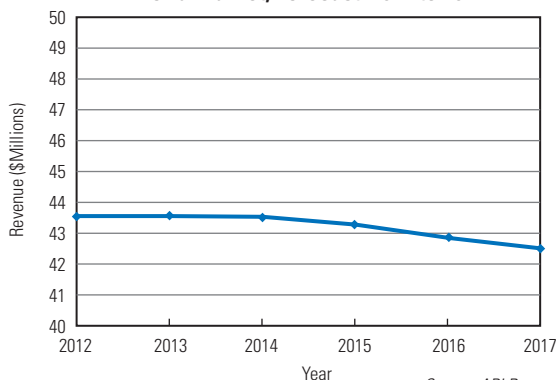
GaN will continue to be a threat to some aspects of the microwave and millimeter wave VED marketplace.

However, one new RF semiconductor technology – gallium nitride (GaN) – may change the landscape but has not yet done so to any meaningful scale. While it is not yet near monopolizing the RF/microwave power industry, GaN is advancing steadily and is a technology that should be closely watched, as it will continue to be a threat to some aspects of the microwave and millimeter wave VED marketplace.

Lance Wilson, research director says, “The size of this historic market continues to surprise everyone and its longevity and firm resistance to RF power semiconductor encroachment is as surprising.”

“These specialized vacuum electron devices may at first seem anachronistic,” Wilson adds, “but in some cases there is no other way to generate such high levels of RF power within an acceptably small space. Certain microwave and millimeter wave VEDs can generate megawatts, and it would take tens of thousands of transistors to do that.”

**Total Crossed-Field Amplifier Device Revenue
World Market, Forecast: 2012 to 2017**



Source: ABI Research

Close to 80% of Base Station Silicon Will Be SoC Based by 2017

ABI Research expects sales of base station processors to grow at 17 percent annually and reach \$1.1 billion in 2017, driven by the growth in compact format femto-, pico- and microcell small cell base stations, which will account for the majority of the processor market in 2017. With macrocells declining at 13 percent per year over the next 5 years and microcells growing at a modest 7 percent, the large growth in picocells and outdoor femtocells will consume the majority of next generation base station processors.

As the number of these compact femtocells and picocells grows, the penetration of system-on-chip basebands will grow at 108 percent annually to reach almost 80 percent of the total market in 2017.

With a capacity shortfall looming, service providers are deploying Heterogeneous Networks (HetNets) with small cell underlays in dense urban areas and using distributed Radio Access Networks (RAN)

to narrow the gap between capacity and demand, and all of these techniques are driving integration into the next generation base station baseband.

“These next generation baseband processors are heterogeneous multicore SoC devices including both DSP and CPU cores for control and data plane processing, along with hardware acceleration and connectivity for backhaul and radio interfaces,” says Nick Marshall, principal analyst, mobile networks.

Merger and acquisition activity is high in this segment – Broadcom’s acquisition of ProVigent, Pericello and NetLogic, Mindspeed’s purchase of Picochip, Wavesat’s sale to Cavium, Xilinx’s acquisition of Modesat, and Qualcomm’s purchase of DesignArt, all indicate that there are significant revenue opportunities for baseband SoCs in the evolving distributed RAN and HetNet segments and that vendors are positioning themselves to challenge current leaders Freescale Semiconductor and Texas Instruments.

“With the latest SoCs available or becoming available over the next 6 to 9 months in 28 nm silicon technology, these will be some of the most advanced baseband ICs ever produced and raise the bar in terms of complexity,” continued Marshall.

“With the latest SoCs available or becoming available over the next 6-9 months in 28 nm silicon technology, these will be some of the most advanced baseband ICs ever produced and raise the bar in terms of complexity.”



Wiping Off Download Bots Pulls iPhone's Share of Smartphone App Downloads

The iPhone's share of quarterly global smartphone app downloads stood at 29 percent in the second quarter of 2012, significantly below the 47 percent attributed to Android smartphones, shows new market data from ABI Research.

Senior analyst Aapo Markkanen comments, "The iPhone's download share tends to see a lot of seasonal

The main reason for the declining market share is Apple's clampdown on download bots earlier this year, which some developers utilized to manipulate their charts positions.

fluctuation, but over the past year or so it has stayed surprisingly resiliently between 30 and 37 percent of the total. In our estimates the second quarter represented the first time the iPhone dipped below 30 percent. The iPhone 5 will most likely cause a second-half hike to the download count, but that may be of a rather temporary nature."

The main reason for the declining market share is Apple's clampdown on download bots earlier this year, which some developers utilized to manipulate their charts positions. For example, app-marketing firm Fiksu has published data indicating that, at the high end of the download chart, the bot squeeze may have alone wiped off even one-fourth of daily volumes. For Android, the bots have not been as big a factor to begin with, owing to Google's different app-ranking methods, as well as to the fact that in its app economy there is still far less money changing hands than on iOS.

As another reason, Markkanen points to the growing prominence of the iPad, adding, "It is notable that, among the iOS apps, the momentum is also shifting up the value chain and towards iPad applications and this change is happening definitely faster than what Google is experiencing. We estimate in the first half of this year the iPad saw over five times more app downloads than all Android tablets combined."

These findings are from ABI Research's Mobile Application Markets Research Service, which focuses on distribution and the economics of mobile apps, providing data-driven insights on areas such as download volumes, revenues and business models and trends within different applications categories.

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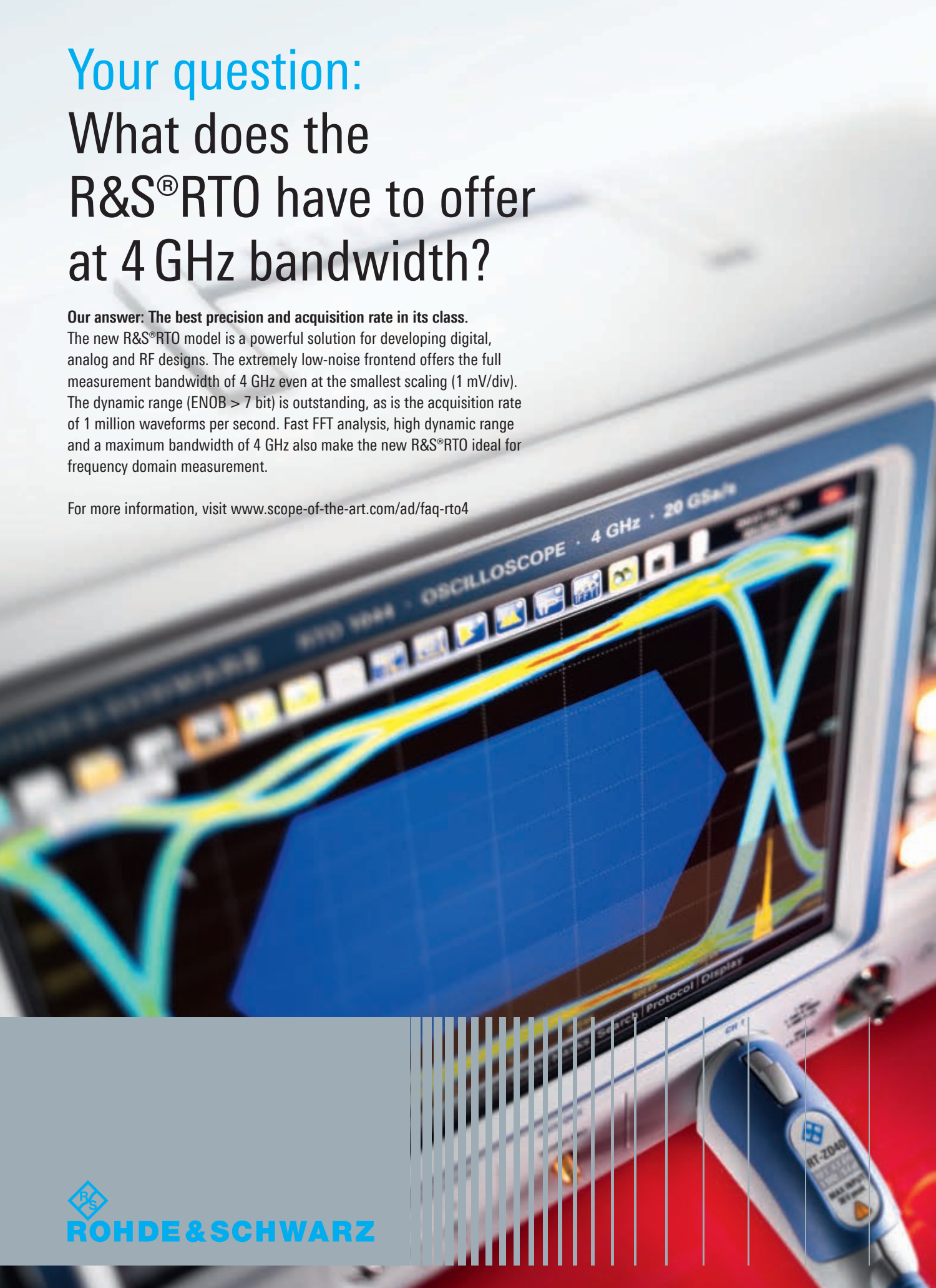
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Around the Circuit

Laura Glazer, Staff Editor

INDUSTRY NEWS

RFMD announced a definitive agreement to acquire **Amalfi Semiconductor**, a fabless semiconductor company specializing in cost effective, high performance RF and mixed-signal ICs for the entry-level smartphone market. RFMD intends to accelerate the market adoption of Amalfi's RF CMOS and mixed-signal ICs. Under the terms of the agreement, RFMD will acquire Amalfi with cash on hand for total consideration of approximately \$47.5 million, net of cash received.

National Instruments (NI) announced the acquisition of **NMDG**, a company with more than 20 years of experience and technology in high-frequency stimulus-response and large-scale network analysis measurements. The new team serves as the foundation to establish a Network Analysis Center of Excellence located in Brussels, Belgium to work worldwide with NI partners, lead user programs and develop measurement and modeling architectures on NI's platform, influencing the future product roadmaps of NI.

Teseq Holding AG acquired **Instruments for Industry (IFI)**, a designer and manufacturer of solid state and traveling wave tube amplifiers. The acquisition expands Teseq's model range from an upper limit of 6 up to 40 GHz and power levels from an upper limit of 1 to 10 kW. The IFI brand remains the same, while the company's product range will be harmonized with the ones of Teseq and MILMEGA and offered in a new price list valid as of January 1, 2013.

AML Microtechnique Lorraine S.A. of Metz, France joined with **Diamond Antenna and Microwave Corp.** of Littleton, MA to form **Diamond Antenna Europe BVBA**. The new entity combines AML Microtechnique's capabilities as a manufacturer of high precision components with Diamond Antenna and Microwave's capabilities in micro-wave rotary joint design and production.

Cobham plc established a new strategic business unit – **Cobham SATCOM** – that combines all of the group's satellite communications businesses into one organization, following the successful acquisition and integration of Danish SATCOM company **Thrane & Thrane** earlier this year. Headquartered in Denmark, Cobham SATCOM is led by Thrane & Thrane CEO Walther Thygesen with assistance from a multinational management team. Thrane & Thrane will trade as Cobham SATCOM from November 2012. Rebranding of Thrane & Thrane will begin immediately and is expected to be complete during 2013.

Space Data Corp. and **Lemko Corp.** announced the successful deployment of the world's first satellite-based commercial LTE network. The network was deployed in Atkasuk, Alaska and offers subscribers mobile broadband data speeds of over 70 Mbps. LTE over satellite is enabled

by Lemko's patented DiMoWiNe software solution. This allows commercial carriers to economically deploy LTE using satellite in areas where it was not previously practical or possible to connect cell towers with fiber.

Colt Technology Services, in partnership with **NEC**, is conducting the first ever live trials of small cells using Femto-as-a-Service with a leading, large-scale European mobile operator, using a multi-operator small cell (Femto) gateway. This breaks down the investment barrier for mobile operators to start their own small cell service.

ON Semiconductor has joined the multi-partner, industrial research and development program at **imec**, a leading nanoelectronics research center, to collaborate on the development of next-generation GaN on silicon (Si) power devices. Imec's broad-scale research program is focused on developing GaN-on-Si technology on 200 mm wafers, as well as reducing the cost and improving the performance of GaN devices.

The U.S. Patent and Trademark Office has issued **SRC Inc.** a patent for the "Interleaved Beam Coherent Radar Apparatus and Processing Method," an advanced radar scanning and processing technique that improves a radar's ability to detect very slow moving targets with a very high scan rate.

Anritsu Corp. announced the opening of an India subsidiary in Bangalore. The new office brings together marketing, sales, engineering, services and support. By co-locating all the departments, the company expects to accelerate the rate of delivery of new products and provide better support to its growing customer base in India.

M/A-COM Technology Solutions recently moved its Torrance, CA operations into a new facility in Long Beach, CA. The new building is ISO 9001 certified and has 23,000 square feet, of which 7000 square feet is for manufacturing and 4000 square feet for engineering.

I.F. Engineering announced the opening of its newly constructed world class manufacturing and engineering development facility. The company moved from a previous 6700 sq. ft. building in Fabyan, CT to its new 20,000 sq. ft. facility in Dudley, MA. This new facility provides the needed manufacturing space for the production of the company's increasing line of components and subsystems.

CONTRACTS

Raytheon Co. received a \$349 million five-year contract to provide heavy anti-tank, wireless precision-assault missiles for the **U.S. Government**. Raytheon received the award during its third quarter. Under this contract, Raytheon will deliver 6676 of the new wireless tube-launched, optically

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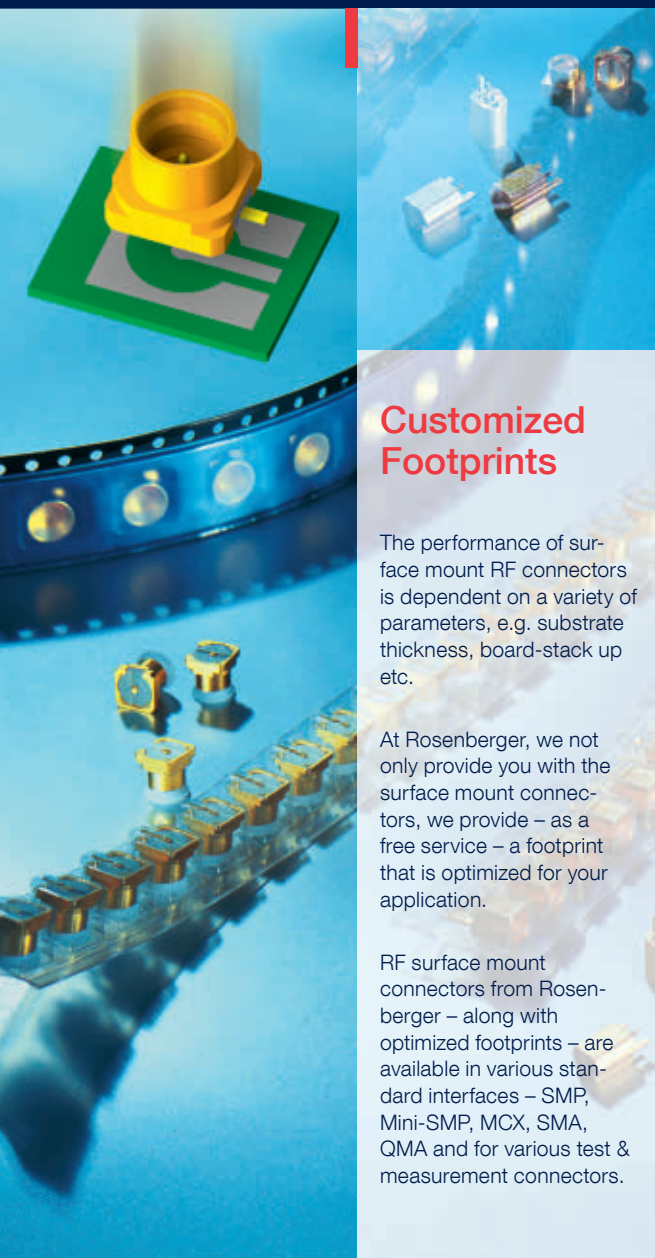
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Around the Circuit

tracked, wireless-guided (TOW) missiles that receive commands from the gunner through a wireless guidance link.

ITT Exelis has been awarded an indefinite delivery, indefinite quantity (IDIQ) contract from the **U.S. Army** to provide Generation 3 aviation night vision systems, spare parts and accessories. The contract allows Exelis to compete for deliveries of the AN/AVS-6 aviator night vision goggle and spare aviation image intensifiers during a five year period. The contract is valued at up to \$217.5 million.

Cobham has reached an agreement with the **Australian Customs and Border Protection Service** to extend the existing Sentinel aerial maritime surveillance contract by two years. This £105 million contract extension secures the contract until the end of 2021.

Communications & Power Industries LLC (CPI) has received initial orders totaling more than \$5 million from a prime contractor for high-power, Ka-Band satellite communications amplifiers. These SATCOM amplifiers will be used in a U.S. military communications program intended to provide worldwide communications connectivity to tactically deployed forces.

RFMD has been awarded a \$2.1 million contract from **DARPA** to enhance the thermal efficiency of GaN circuits used in high power radar and other military systems. The award is in association with the Near Junction Thermal Transport (NJTT) effort of DARPA's Thermal Management Technologies program. The goal of the NJTT initiative is to achieve a 3x or greater improvement in power handling from GaN power amplifiers through improved thermal management of the near junction region.

Harris Corp. received \$7 million in orders to deliver public safety and tactical communications systems to the **U.S. Department of Homeland Security (DHS)** and its component agencies; the Federal Emergency Management Agency (FEMA); and the U.S. Coast Guard. The orders were awarded through the five-year, \$3 billion DHS Tactical Communications IDIQ contract vehicle.

Eutelsat Communication selected **Thales Alenia Space** to build the EUTELSAT 8 West B satellite, which will boost satellite broadcasting resources in the Middle East and North Africa. It will be equipped with 40 operational Ku-Band transponders designed primarily to serve DTH markets in North Africa and the Middle East.

NEW MARKET ENTRY

Rakon, a provider of frequency control solutions, announced MEMS technology is being utilized to develop new products to further broaden its oscillator product portfolio and capabilities. The addition of MEMS products supports Rakon's growth in telecommunications, smart wireless devices and high reliability markets, as well as fuels growth in networking, storage, servers, portable electronics, consumer and computing applications. Rakon has begun sampling oscillators using MEMS to select customers, with volume production ramping up in the fourth quarter of 2012.

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SM-20M3G-8X8	0.02 - 3.0	8 / 8	14	60	45	100	2.0:1	20
SM-20M3G-16X16	0.02 - 3.0	16 / 16	16	60	45	100	2.0:1	20
SM-20M3G-32X32	0.02 - 3.0	32 / 32	19	60	45	100	2.0:1	20
SM-2G18G-4X4	2.0 - 18.0	4 / 4	14	60	45	100	2.0:1	20
SM-2G18G-8X8	2.0 - 18.0	8 / 8	16	60	45	100	2.0:1	20
SM-2G18G-16X16	2.0 - 18.0	16 / 16	19	60	45	100	2.0:1	20
SM-2G18G-32X32	2.0 - 18.0	32 / 32	23	60	45	100	2.0:1	20
SM-18G40G-4X4	18.0 - 40.0	4 / 4	16	60	45	100	2.0:1	20
SM-18G40G-8X8	18.0 - 40.0	8 / 8	18	60	45	100	2.0:1	20
SM-18G40G-16X16	18.0 - 40.0	16 / 16	22	60	45	100	2.0:1	20
SM-18G40G-32X32	18.0 - 40.0	32 / 32	25	60	45	100	2.0:1	20



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Frequency Matters.

Around the Circuit

PERSONNEL



▲ John Croteau

John Croteau will be joining M/A-COM Tech as its president and will be reporting to Charles Bland, CEO. As president, Croteau will assume responsibility for worldwide sales, operations, R&D, marketing and business unit management. Croteau joins M/A-COM Tech with nearly 30 years of global semiconductor experience.



▲ Alan Hallberg

RFMD announced the appointment of **Alan Hallberg** as the company's corporate vice president and CMO. In the role of CMO, Hallberg will oversee RFMD's global marketing activities and will be based in RFMD's growing Silicon Valley, CA location. He will report to RFMD's president and CEO Bob Bruggeworth. Hallberg is a seasoned industry veteran with extensive experience in marketing and branding.

SenarioTek, a leading designer and manufacturer of RF and microwave products, named **Stephen Pettis** as its new aerospace and defense business development manager. This is a new position that focuses on expanding SenarioTek's growing defense ATE business. Prior to joining SenarioTek, Pettis spent over 30 years working with Hewlett-Packard and Agilent Technologies.

REP APPOINTMENTS

Delta Microwave announced the appointment of **Component Solutions**, San Jose, CA, as the company's exclusive representative in northern CA and northern NV.

Hirose Electric has signed a worldwide distribution agreement with **Mouser Electronics** that expands its product availability and customer support.

L-com Inc. has signed an agreement to have its products distributed by **Carlton-Bates Co.** (CBC), a subsidiary of WESCO Distribution Inc.

NuWaves Engineering announced it has increased its international presence by adding authorized resellers in Europe, Southeast Asia and the Middle East. **MEDs Technologies** will represent NuWaves in several Southeast Asia countries, including Indonesia, Malaysia, Thailand and Singapore. **Mel Sivan Technologies** will represent NuWaves in Israel. Two European companies join NuWaves' reseller network as well: **Tech-Inter** of France and **Medeos Srl** of Italy.

Pasternack Enterprises Inc. announced that it has appointed **Medición y Electrónica S.A. de C.V.** (MESA) as its exclusive distributor for Mexico, Guatemala and Honduras. The company has also appointed **Altaix Electronica S.A.** as its exclusive RF distributor for Spain and Portugal.

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Armored (APC)	DC-18	N	6.0-15	-55/+105
Low Loss (KBL-xx-LOW)	DC-40	2.92	1.5-6.6	-55/+85
Phase Stable (KBL-xx-PHS)	DC-40	2.92	1.5-6.6	-55/+85

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[†] Custom lengths available by special order.

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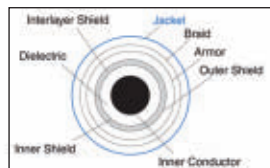
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A Four-Element “Clover” Transceiver Array for 3 Tesla Cardiac MRI

The design of radio frequency (RF) coils is of paramount importance to the quality and safety of Magnetic Resonance Imaging (MRI). Being the signal generator and detector of MRI, RF coils are required to generate a uniform excitation in the target during transmission and high signal-to-noise ratio (SNR) during reception.¹ In the meantime, RF coils must not cause subject overheating in in-vivo human studies.² This requires that RF energy deposited inside the human body and coupled to receivers should be minimized.

With the advent of clinical high-field MRI systems, that is $B_0 = 3$ Tesla or higher, the much improved SNR enables the development of fast and effective diagnostic and therapeutic techniques.³ However, electromagnetic wave effects appear as an issue that challenges the conventional MR imaging methodology. Because the size of human torso is approximately several wavelengths at the MR resonant frequency, that is 123 MHz at 3 Tesla, standing waves appear and sufficient RF excitation is no longer guaranteed in the target region.⁴ The volume-coil-induced eddy currents that circu-

late in the human body also make the use of a body transmit coil less appealing, for safety reasons, when a specific organ, such as the heart, is imaged.² Last but not least, the RF energy coupled to receiver cables and detuned circuits is a persistent concern of subject burning.^{1,2}

As a feasible means of solving the above issues, the interest in surface transceiver arrays has been growing rapidly in high-field MRI.⁴ Taking cardiac imaging as an example, a well-designed transmitter array positioned above the heart guarantees that a strong excitation field is inside the heart with less RF energy deposition than a volume body coil would deposit. Since transmitters and receivers are not separate in a transceiver array, there are no detuning circuits and energy pick-up issues involved.

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Nevertheless, the design of transceiver arrays is more challenging than conventional receive-only arrays. In receive-only array design, high-impedance pre-amplifiers are extensively applied to help decouple neighboring coils.⁵ Thus an array can be designed to accommodate various non-RF requirements, such as parallel imaging performance,^{6,7} without much concern about mutual coupling. But this does not apply to transmitter arrays, which must be designed with sufficient field coverage and mutual decoupling at the same time.

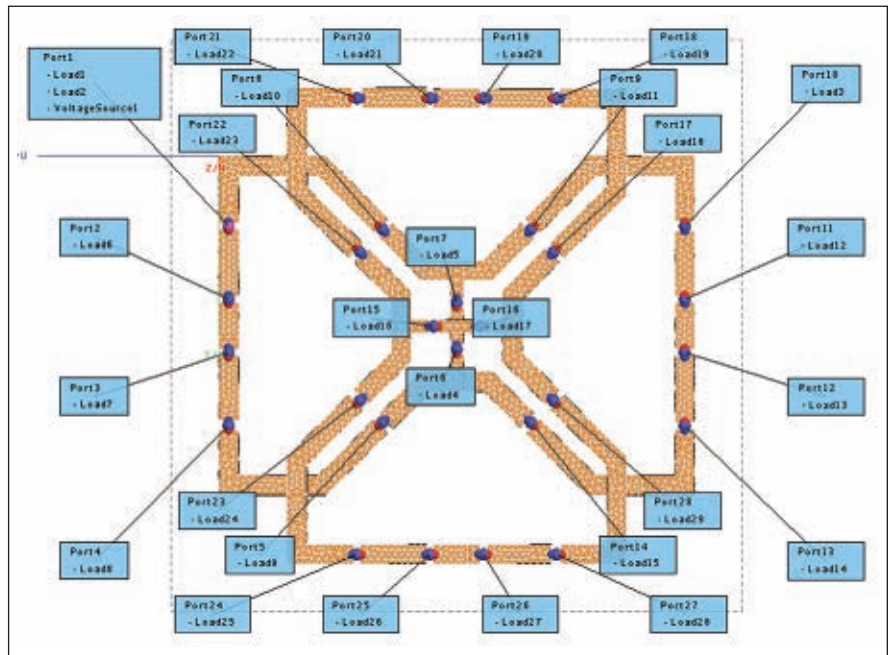
In this article, a detailed workflow is presented for the design of a four-element transceiver array for 3 Tesla cardiac MRI. It will be demonstrated that by employing a “clover” layout, all coils can be arranged to achieve good field coverage and element mutual decoupling simultaneously.

TRANSCIVER DESIGN

Figure 1 shows the numerical model of the four-element cardiac transceiver array in the commercial software package FEKO.⁸ The four coils were positioned in a rotational symmetric manner so that a geometric center can be uniquely defined. Aligning this center with the center of the heart helps to localize the transceiver to achieve the maximum transmit efficiency and receive sensitivity. The side-to-side dimension of the array was 5 inches, in order to provide a good field penetration into the heart.

Eight capacitors were used on each coil element. Six of them were for tuning a coil to the desired resonant frequency, that is 123.2 MHz for Siemens’ 3 Tesla scanners. The number of capacitors was determined by the following criteria: 1) Each capacitor should be large enough (> 10 pF) to minimize the electric coupling with the human body; 2) The distance between adjacent capacitors should be no more than $1/10$ of a wavelength to ensure current uniformity; 3) The capacitor values should be available from off-the-shelf vendors.

The six capacitors were positioned in a mirror-symmetric manner to create a virtual ground along the symmetry axis. By soldering the ground of RF feeding point to the virtual ground, the amount of parasitic currents induced on cable shields is minimized.¹

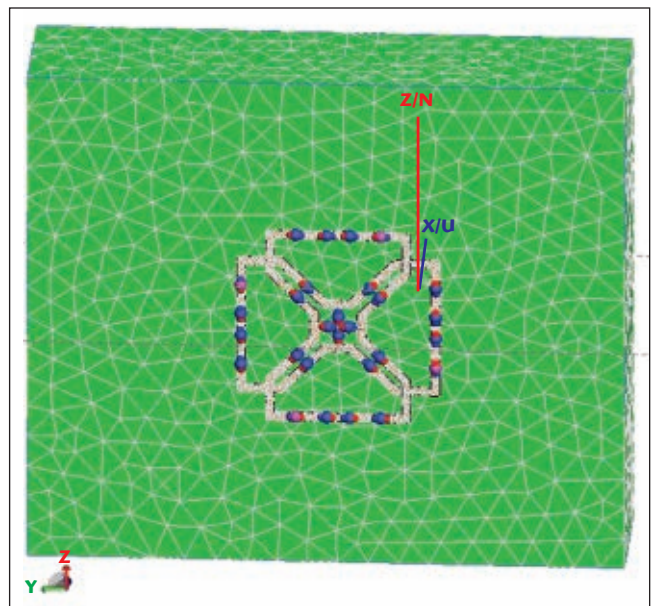


▲ Fig. 1 Numerical model of the four-element cardiac transceiver array.

This is a very useful mechanism for reducing mutual coupling caused by shield currents. For the same reason, all capacitors were adjusted pair-wise in order to keep the mirror symmetry.

The capacitors on the edge shared by two opposite coils are in charge of decoupling the associated coils.¹ They introduce a voltage drop that is negative to the mutually induced electromotive force (EMF). For each pair of adjacent coils, decoupling was accomplished by adjusting the overlap size so that the magnetic flux produced by one coil goes through the other coil from two opposite directions canceling out.⁵ It should be mentioned that applying two different decoupling methods in one array design is not common. In this case, this strategy brought great convenience for achieving good field coverage and mutual decoupling.

Numerical tuning and decoupling were performed with a large phantom model which has a relative permittiv-



▲ Fig. 2 The transceiver array positioned on top of a phantom.

ity of 63.8 and conductivity of 0.72 S/m (see **Figure 2**). These resemble the properties of human muscle at 123.2 MHz. The following procedure was applied:

1. Turn on each coil in turn and adjust all eight capacitors so that S_{11} reaches a minimum at 123.2 MHz.
2. Turn on the two opposite coils simultaneously and adjust the two decoupling capacitors so that S_{21} is less than -25 dB.
3. Readjust the six tuning capacitors of each coil to bring the resonant

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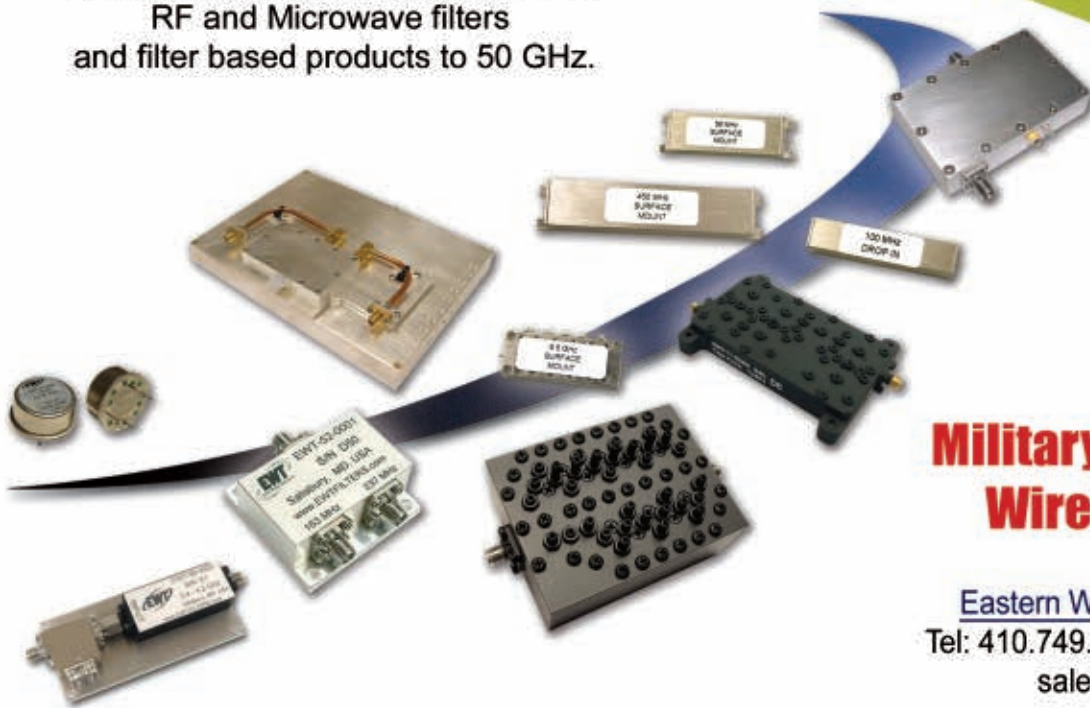


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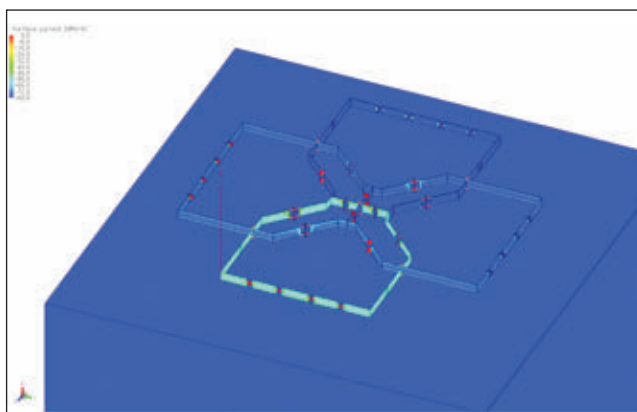


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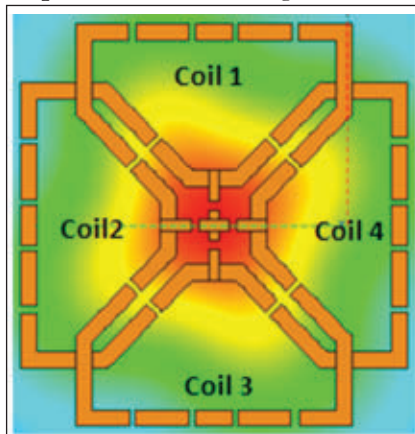
Technical Feature



▲ Fig. 3 Current distribution in four coils when one coil is excited and the three other coils are in perfect load matching condition.

- frequency back to 123.2 MHz.
- Check S_{21} by turning on two opposite coils simultaneously. If they are coupled again, readjust the two decoupling capacitors.
- Check S_{21} of two adjacent coils by turning them on simultaneously. Adjust the overlap size so that S_{21} is less than -25 dB.
- Readjust the six tuning capacitors of each coil to bring the resonant frequency back to 123.2 MHz.
- Check the S_{21} by turning on two adjacent coils simultaneously. If they are coupled again, readjust the overlap side. Since overlap decoupling is broadband, this readjustment is seldom needed.
- Check the tuning of each coil and the decoupling of each pair of coils. Readjust if needed.

In numerical simulations, the coil cross-section was discretized into at least five triangles to ensure sufficient accuracy. **Figure 3** illustrates the current distribution when one coil was turned on and three other coils were in perfect load matching conditions.

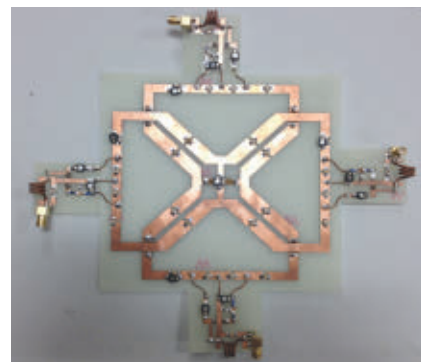


▲ Fig. 4 Simulated RF magnetic field distribution when all coils are tuned on with phases prescribed in Table 1.

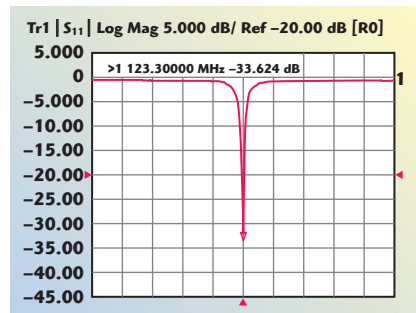
As can be seen, the currents induced in other coils are nearly invisible. This serves as further proof that good decoupling was achieved.

In MRI, a circularly polarized magnetic field is required on planes perpendicular to the transceiver surface, in order to generate a transverse magnetization.⁹ If the

foot-to-head direction is defined as the z-direction, the polarization should be left-handed in a right-hand coordinate system. This can be accomplished by RF excitations with the phases listed in **Table 1**. When the first and the third coils are excited in-phase, a magnetic field pointing out of the paper plane is generated. When the second and the fourth coils are excited out-of-phase, a right-to-left magnetic field is gener-



▲ Fig. 5 The four-element transceiver array with matching boards.



▲ Fig. 6 Measured $|S_{11}|$ of one coil when other coils are terminated with a 50 Ω load.

TABLE I				
THE PHASE OF EACH COIL IN FIGURE 4				
Coil	1	2	3	4
Phase	0°	90°	0°	-90°

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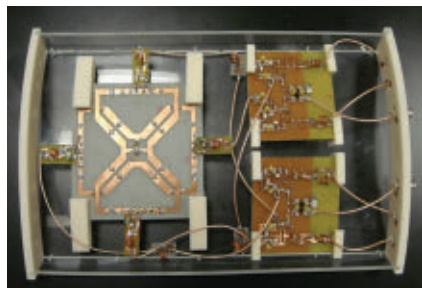
Part Number	MRI Application	Power Rating [Watts]	Amplitude Balance [±dB max]	Insertion Loss [dB max]	Footprint		Phase
					inches	[mm]	
HD064M3F	1.5T Rx	10	0.10	1.00	0.56 x 0.35	[14.22 x 8.89]	90°
BD064M3F	1.5T Rx	10	0.10	1.50	0.56 x 0.35	[14.22 x 8.89]	180°
HD128M3F	3.0T Rx	10	0.20	0.80	0.56 x 0.35	[14.22 x 8.89]	90°
HG064M2F	1.5T Tx	300	0.25	0.20	2.00 x 1.50	[50.80 x 38.10]	90°
HE128MF	3.0T Tx	300	0.10	0.23	1.00 x 1.00	[25.40 x 25.40]	90°
HE298MF	7.0T Tx	300	0.10	0.23	1.00 x 1.00	[25.40 x 25.40]	90°
BE298M2F	7.0T Tx	300	0.40	0.20	1.00 x 1.00	[25.40 x 25.40]	180°
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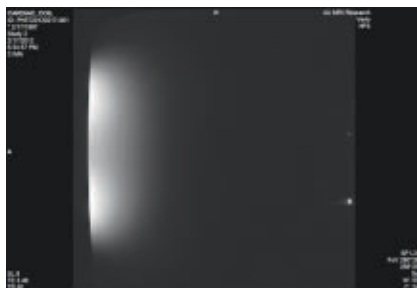
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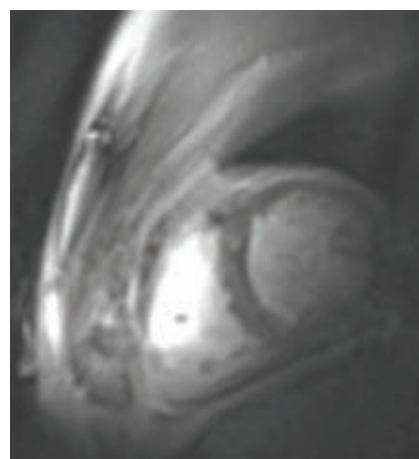





▲ Fig. 7 The complete transceiver array with power dividers and baluns.



▲ Fig. 8 MR image of a bucket of saline water.




▲ Fig. 9 Actual image of a subject's heart.








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ated. By introducing a 90° phase difference between these two groups of coils, a left-hand polarized transverse magnetic field can be generated.

Figure 4 shows the magnetic field distribution when all coils were turned on simultaneously with the phases prescribed in Table 1. Since all coils were sufficiently decoupled, a strong focus appears near the geometric center of the array. This is highly desired, since aligning this center with the center of the heart will result in optimized transmission efficiency and receive sensitivity. This will be demonstrated in the experimental results in the next section.

HARDWARE IMPLEMENTATION AND EXPERIMENT RESULTS

The transceiver array was fabricated on a 1/32" FR-4 printed circuit board (PCB) with 1 oz copper (see **Figure 5**). The capacitance in simulations was directly applied for tuning and decoupling. Readjustment that follows the same procedure as in simulations was required. It was found that the actual capacitance differed from simulation results by 10 to 20 percent. Since the bought capacitors have a 10 percent tolerance, this agreement was considered to be very good.

Each coil was matched to 50 Ω by a standard highpass L-network. **Figure 6** shows the measured S_{11} of one coil when all other coils were matched to a 50 Ω load. In this measurement, a bucket of saline water that mimics the loading of the human body was applied. A sharp resonant curve (<-30 dB) was observed, which indicates that good matching and decoupling were achieved at the same time.

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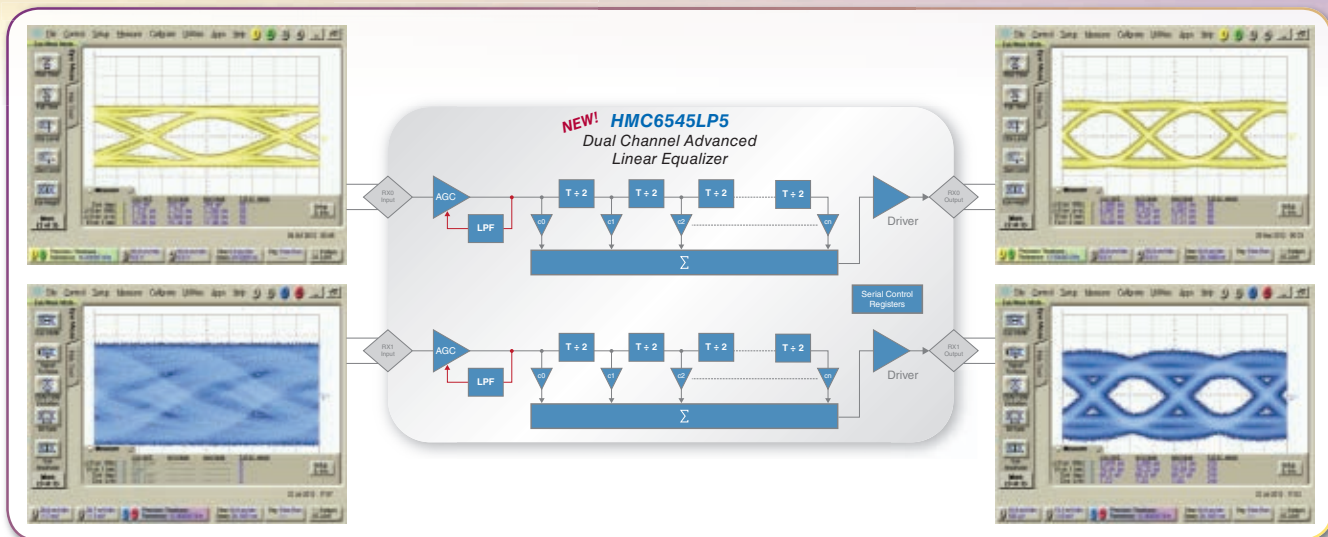
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Technical Feature

Baluns made of wound semi-rigid coaxial cables were connected to each coil to choke unwanted shield currents.¹⁰ Each coil was then connected to a T/R switch tuned with an insertion loss between 0.2 and 0.3 dB and an isolation less than -40 dB.¹⁰

On the transmit side, three Wilkinson power dividers were constructed to split a single RF input from the scanner equally four ways. Appropriate phases were implemented by

phase shifters according to Table 1. Four receiver channels were connected to an interface box custom made by Stark Contrast Inc., Erlangen, Germany. Finally, the interface box was connected directly to a Siemens' 3T scanner. The complete transceiver array is shown in **Figure 7**.

MR images were acquired with gradient echo sequence on the 3T scanner. The acquisition matrix size was 280×280 , slice thickness = 8 mm,

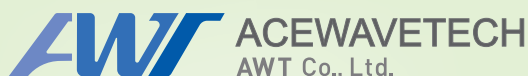
TE = 3.68 ms and TR = 10 ms. In the first experiment, the same bucket of water used in bench measurement was imaged. The result is shown in **Figure 8**. As can be seen, a bright region appears underneath each coil due to the fact that image intensity is strongly modulated by receiver sensitivity profile. However, at the depth where the heart should be, peak image intensity locates near the symmetry axis. Thus aligning the geometry center of the coil with the heart should yield optimal image quality. This was confirmed in the second imaging experiment, in which the transceiver array was tested on the first author. As shown in **Figure 9**, the image intensity in the heart is the strongest.

CONCLUSION

A complete design workflow for a four-channel transceiver array is detailed in this article. By employing a four-element clover layout, sufficient mutual decoupling and good transmit field coverage were achieved at the same time. Experimental results show that with careful hardware implementation, satisfactory signal intensity can be acquired in the heart. ■

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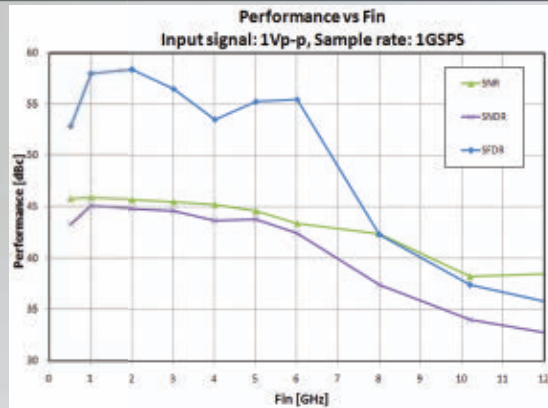
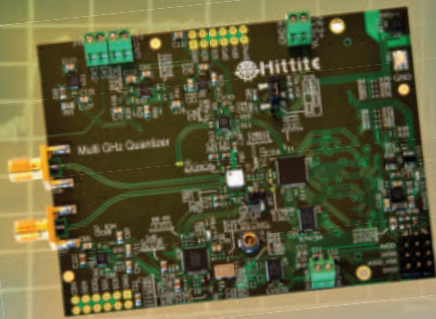
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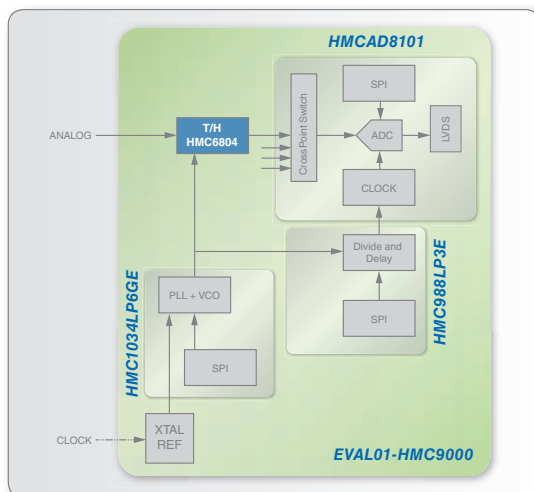


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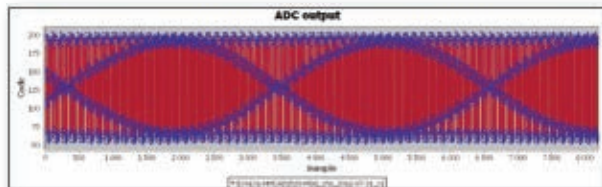
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Ultra Low Noise Amplifiers Improve Cell Coverage and Reduce Costs

Mobile data communication utilization is increasing rapidly, outpacing voice communication utilization due to the increasing number of mobile data consumers. New radio access networks (RAN) are currently being developed and tested to accommodate this growth in data capacity and mobile data users. For instance, long term evolution (LTE) RANs are now being tested and deployed globally. This raises the corresponding demands on radio transceiver performance, such as a lower noise figure (NF), a high input intercept point of second/third order (IIP2/IIP3) and operation over a wider bandwidth (BW). Better immunity against large unwanted signals is also desired.

Yet a cellular base transceiver system (BTS) can be deployed in such a way that the total number of BTSs in a given region can be reduced, while still maintaining optimal cell coverage. From an operator perspective, this yields opportunities to reduce CAPEX and OPEX.

A low NF is not the only RF parameter that matters for an LNA. The number of interference signals increases when the number of users in one cell is increased. To cope with high levels of interfering signal levels, the linearity of the LNA needs to be increased while maintaining the lowest possible NF. Finally, the NF and linearity should be flat over frequency to support wideband RANs.

NF LINK TO CELL DISTANCE

In order to link the LNA's NF to cell distance, some intermediate steps have to be made first. Two classical formulas are used, one for the receiver sensitivity and the other for the propagation model. The receiver sensitivity P_{sens} is expressed as:

$$P_{sens} = kT \cdot B \cdot F_{sys} \cdot P_G \cdot \frac{E_b}{N_o} \quad (1)$$

where k is Boltzmann's constant, T is the device temperature, B is the signal bandwidth (in case of UMTS 3.84 MHz), F_{sys} is the system noise factor, P_G is the processing gain (in case of WCDMA), and E_b/N_o is the bit energy to noise energy ratio.

The radio link budget assumes a minimum signal level to be received at the cell edge, usually expressed in terms of a maximum allowable path loss together with a link margin to provide a specified level of Quality of Service (QoS). A statistical analysis of the radio signal measurements exposes that the path loss (PL) at any particular location between the base station and mobile stations at any distance (d) can be expressed as a random variable, which follows a log normal distribution around the median path loss value. The propagation model that is used here is the COST Okumura-Hata model:

$$PL = 46.3 + 33.9 \log_{10} f_c - 13.82 \log_{10} h_B - a(h_R) + [44.9 - 6.55 \log_{10} h_B] \log_{10} d + C \quad (2)$$

And in the case of urban areas:

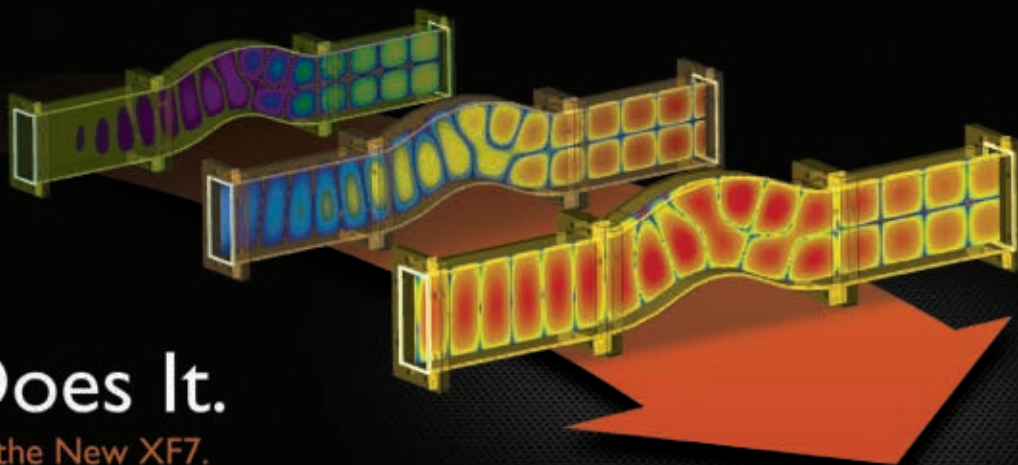
$$a(h_R) = (1.1 \log_{10} f_c - 0.7) h_R - 1.56 \log_{10} f_c - 0.8$$

$$C = \begin{cases} 0 \text{ dB for medium cities and urban areas} \\ 3 \text{ dB for metropolitan areas} \end{cases}$$

with $1500 \text{ MHz} < f_c \leq 2000 \text{ MHz}$, $30 \text{ m} < h_B \leq 200 \text{ m}$,
 $1 < h_R \leq 10 \text{ m}$ and $1 \text{ km} < d \leq 20 \text{ km}$

where PL is the median path loss (dB), f_c is the radio frequency (MHz), h_B is the base station antenna effective height (m), d is the link distance (km), h_R is the mobile station antenna effective height (m) and $a(h_R)$ corresponds to the mobile station antenna height correction

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factor (dB). In suburban areas, 8 dB standard deviation is subtracted to deal with shadowing. The total medium path loss (PL) is obtained from the total link budget as shown in **Appendix 1** (view online at mwjournal.com/NXPappendix).

In addition, other parameters have to be included in the link budget. These are:

Soft hand over (SHO) gain, which is gain against slow fading (log normal fading) by reducing log normal fading margin. Soft hand over is the ability to exploit the macro diversity between different Node Bs. All cellular systems use multi-antenna diversity at the base station receiver and transmit antenna diversity at the base station transmitter. However, these 'micro diversity' techniques are mainly aimed at mitigating the effects of multipath fading and have very little impact on the larger scale like shadow fading.

If a mobile device can establish simultaneous links to different Node Bs, then, given the spatial separation of the Node Bs, each link is likely to experience a different shadow fading characteristic. By combining the information received on each individual link, the effects of shadow fading can be mitigated to some degree and this is termed macro diversity.

Uplink noise rise: There is a trade off between intended uplink coverage and uplink total received interference power. The total received power increases due to the addition of a user in the cell and depends heavily on the uplink noise rise (NR). This is defined as the ratio of total received interference power to background noise power, $NR = C/N$. It represents the direct relationship between total interference power increase and current noise increase, as opposed to current total received interference power. This is the reason why uplink noise has to be included in the link budget. Noise rise is also often described by means of the cell load η : $10 \log(1/(1 - \eta))$. In this article, a cell load of 0.7 (or 5.23 dB) is used.

Log-normal fade margin: Slow fading is caused by events such as shadowing, where a large or tall obstruction such as a hill or a tall building obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modelled using a log-normal distribution with a

standard deviation according to the log-distance path loss model. In this example, a standard deviation of 5 dB is used with a confidence probability of 90 percent.

Voice communication is the most critical consideration in cell planning, due to the fact that no retransmission is allowed compared to data transmission. For this reason, the link budget is based on voice communication. The lowest voice data rate using adaptive multi-rate audio speech (AMR) codec is 12.2 kbps. In UMTS, the chip rate is 3.84 MC chips/s, which results in a spreading gain or processing gain of 25 dB.

The total base station transmission power is chosen to be 40 dBm or 10 W into 50 Ω , measured at the output of the final stage amplifier. The output power level is attenuated by cable and connector losses before it arrives at the antenna connector. The 40 dBm power is conducted power and needs to be converted to radiated power or effective isotropic radiated power (EIRP). An isotropic radiator radiates power equally in all directions. However, a perfect isotropic radiator is only theoretical. All realizable antennas will concentrate the power in a certain direction. For instance, a half wave dipole has an antenna gain of 2.15 dBi. In this article, the antenna gain of the base station is assumed to be 18 dBi, which gives a total EIRP of 55.5 dBm or 355 W radiated power.

The radiated power is further attenuated by free space loss and absorption by materials like trees, concrete buildings, etc. Moreover, not only attenuation takes place but also reflection, refraction and diffraction. For diffraction, an additional margin, called fading margin, should be included in the link budget and here a 5.1 dB lognormal fading margin is assumed.

At the UE side, the antenna receives the multiple replicas of the wanted and unwanted signals. The radiated power received at the antenna is converted into conducted power where an antenna gain of 0 dBi is assumed. In addition, an extra body loss of 3 dB should be accounted for in the link budget. This reflects the fact that antenna gain is measured in free space, whereas in practice the handheld device is close to the human head, which reduces the antenna gain.

Via the duplex filter, the received signal enters the input of the LNA, af-

ter which it will be further processed toward the base band. This concludes the downlink Node B (transmit) to UE (receive). In fact, the return path UE to node B is of greater importance for a base station.

In the uplink from transmitting UE to receiving Node B, the maximum transmit power at the UE is limited, due to battery operation lifetime. Here, a conducted power of 21 dBm or 126 mW into a 50 Ω termination is assumed. Likewise for the downlink, the antenna gain is set to 0 dBi and a body loss of 3 dB is assumed. The conducted power is converted to EIRP at the UE antenna and equals 21 dBm. It is assumed that the radio channel is equal for the downlink and the uplink.

At Node B, the receive antenna gain is again 18 dBi. Additional losses (antenna connector, cable and duplex filter) should be subtracted from the received conducted power. For the sake of simplicity, diversity gain is not used in this link budget calculation. After the receive antenna, connector and cable losses, the received signal arrives at the input of the duplex filter. This filter has an insertion loss of 0.6 dB. To meet the receiver sensitivity level, the total front end noise figure should not exceed 3.1 dB.

This 3.1 dB can be decomposed into several contributions, duplex filter losses (0.6 dB), baseband processing noise (0.5 dB) and front end noise. The front end noise includes ADC noise and, given the duplex filter noise and baseband noise, the overall front end noise figure (NF) is 1.9 dB, assuming that the LNA contributes most of it and is chosen to be 0.6 dB. Knowing the total system noise figure NF_{sys} , the receiver sensitivity can then be calculated. Given the thermal noise density and the total system noise, the total noise density can be calculated as -170.7 dBm/Hz. Next the minimum signal strength, or sensitivity level, for a given bit error rate can be calculated.

This level is defined by the required E_b/N_o , the bit energy divided by the noise energy, which is often provided in the standard and depends heavily on the radio channel propagation conditions. In this article, using a voice call at 12.2 kbps and a pedestrian channel the E_b/N_o is specified as 11.9 dB. Adding the total noise density, the required E_b/N_o and processing gain and converting from power density to power

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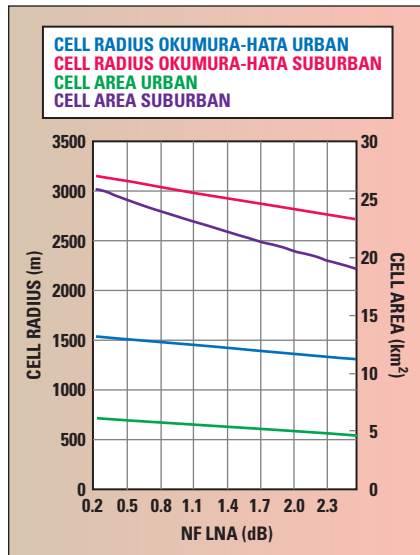
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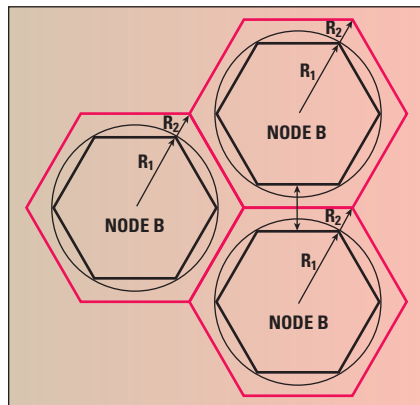
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level by adding the bandwidth logarithmically, the receiver sensitivity is obtained (−112 dBm). Finally, after inclusion of all of the aforementioned effects, the total path loss (PL) [dB] can be calculated as:

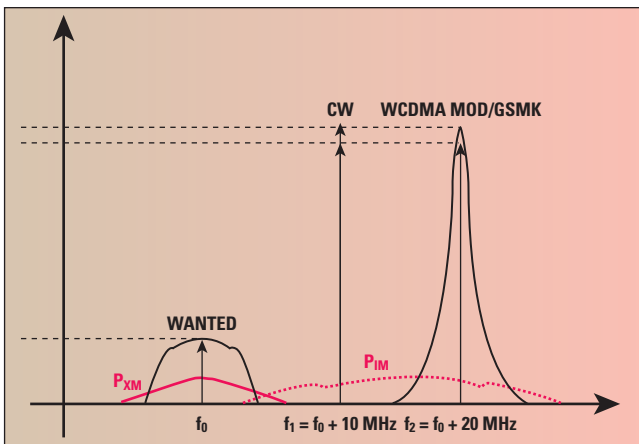
$$PL = \text{EIRP Tx power} + \text{Rx antenna}$$



▲ Fig. 1 Cell radius and cell area as a function of LNA NF.



▲ Fig. 2 Cell coverage increase by lowering LNA NF.



▲ Fig. 3 Intermodulation requirement for WCDMA wide area base station.

gain - body loss - noise rise + Rx diversity gain - cable/connector loss - receiver sensitivity + SHO gain (dB).

Knowing the total path loss (= median path loss) from the link budget and the path loss channel model from Okumura-Hata path loss model for urban and suburban areas, the cell radius can then be calculated. In the case of the pedestrian channel, the cell radius is assumed to be 1.3 km for urban areas and 2.6 km for suburban areas. Suppose that the shape of a cell is a regular hexagon with a cell radius of 1.3 km or 2.6 km, then in the case of an urban area the covered area is 4.4 km² and 17.6 km², respectively. If the NF of the LNA is swept from 0.2 to 2 dB, the cell radius gain and cell area gain can be plotted as shown in **Figure 1**. Reducing the NF of the LNA by a factor of 2 increases the cell area by more than 7 percent. Therefore, the usage of an LNA with an NF of 2.0 dB instead of having an NF of 0.4 dB increases the operator's coverage by 26.5 percent. **Figure 2** illustrates the cell coverage improvement achieved by lowering the LNA's NF.

CROSS AND INTERMODULATION CHARACTERISTICS

There are two basic nonlinear distortion mechanisms, one is the intermodulation and the other is the cross-modulation. Intermodulation may produce an additional amount of noise in the wanted frequency channel, called PIM, (see **Figure 3**). The cross-modulation characteristics are a measure of the immunity of the base station receiver against interferers that produce a spurious response within the wanted assigned channel frequency. This specification sets

the cascaded input referred third-order intercept point (IIP3) of the base station receiver. Cross-modulation distortion is the most significant distortion mechanism in WCDMA receivers, where the modulated transmitter signal in the receiver path cross-modulates with a close-in jammer to produce in-band distortion.

Normally the static reference performance of the wanted signal is defined 3 dB above the reference sensitivity level. Two interfering signals with specific cross-modulation performance requirements are added. **Figure 3** shows the intermodulation and cross-modulation requirements in the case of a WCDMA wide area base station non-narrow band cross-modulation. The red line (P_{XM}) represents the result of cross-modulation from the CW tone with the WCDMA modulated signal and falls in the wanted frequency.

In order to calculate inter-modulation requirements, two more parameters are needed: the required E_b/N_o to meet the reference BER and the maximum allowed receiver desensitization X. The reference BER for voice speech is $E_b/N_o = 8.3$ dB and the power levels of the two interferer signals are for $P_{cw} = -48$ dBm and for the $P_{wcdma} = -48$ dBm/3.84 MHz. Accordingly, the IIP3 can be calculated using the equation:

$$IIP3 = P + \frac{P - \left(P_{ref} - \frac{E_b}{N_o} + 10 \log 10 \left(10^{\frac{X}{10}} - 1 \right) \right)}{2} \quad (3)$$

where $P = P_{cw} = P_{WCDMA}$ are the interference power levels, P_{ref} is the reference sensitivity level, E_b/N_o is the level to meet the reference BER and X is the receiver desensitization factor. Where X is set to 3 dB, the cross-modulation noise (P_{XM}) is equal to the thermal noise floor (N_o) and the receiver is desensitized by 3 dB, thus P_{ref} is increased from −115 dBm to −112 dBm. In the 3GPP standard, a 3 dB receiver desensitization is specified.

However, since there are more distortion components that will desensitize, the receiver base station manufacturers apply a lower value. Here, a receiver desensitization of X = 3 dB is taken, due to intermodulation specifications according to the 3GPP standard. **Table 1** shows the IIP2 and IIP3 numbers for WCDMA wide area base station.

BLOCKING CHARACTERISTICS

The blocking characteristics are a measure of the receiver's ability to receive a wanted signal at its assigned frequency channel in the presence of an unwanted interferer on frequencies other than those of the adjacent channels. Distinction is made between adjacent channel blocker, in-band blockers (IBB) and out-of-band blockers

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(The development of this equipment was assisted through funding by the Technology Strategy Board)

TABLE I

IIP2 AND IIP3 FOR WCDMA CROSS-MODULATION CASES FOR WIDE AREA BASE STATION

All	Pref (dBm)	PCW (dBm)	PMOD (dBm)	PW (dBm)	E_b/N_o (dB)	Rate	Max Rx Dense(dB)	IIP3 (dBm)	IIP2 (dBm)
Wide Area BS	-115	-48	-48	-115	8.3	12.2 kbps	3	-10.34	27.320624
Band II, III, IV, V, VII, X, XII, XIII, XIV									
Wide Area BTS	-115	-47	-47	-115	8.3		3	-8.84	29.320624

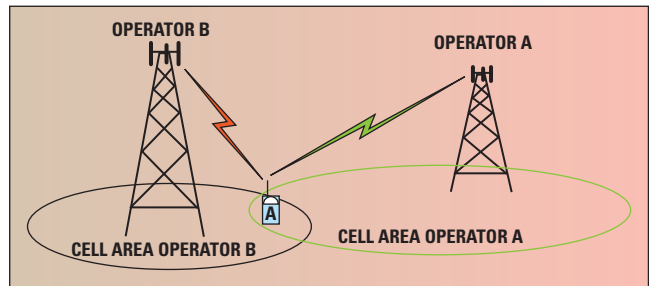
(OOB). This can better be explained by referring to **Figure 4**. When node B from operator B is receiving a strong (IBB) signal from a mobile device linked to operator A, but working in operator B adjacent carrier, then node B from operator B can be blocked. Operators have to deal with this so-called near-far problem. The signal strength of the blocking signal depends on many aspects such as cell size and position. A worst case situation will occur when the sites of operator B are allocated at the cell borders of operator A.

ADJACENT CHANNEL BLOCKER

In the test specification of the 3GPP standard, the adjacent channel selectivity (ACS) is a measure of the receiver's ability to receive a wanted signal

at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the center frequency of the assigned (wanted) channel. ACS is the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel(s). The adjacent channel blocker can be linked to adjacent channel leakage ratio (ACLR) by the following empirical formula:
ACLR =

$$2(P \pm IIP3) - 20.75 + 1.6\xi \quad (4)$$



▲ Fig. 4 Graphical blocking description in case of two operators working in the same area.

where P is the blocking power, IIP3 is the input inter-modulation of third order, the 20.75 is a constant that depends on CCDF statistics of the WCDMA signal, and j is the peak to average ratio (PAPR). Note that this formula is only valid in cases where an adjacent channel has only a single carrier. ACLR itself can be written as PIM3-P (note that ACLR results in a negative dBc number). Including the receiver desensitization factor X, the IIP3 can be expressed as:

$$IIP3 = P - \left(P_{ref} - \frac{E_b}{N_o} + 10 \log_{10} \left(\frac{X}{10^{10}} - 1 \right) + 20.75 - 1.6\xi \right) \quad (5)$$

The PAPR factor j is set to 11 dB (worst case). For a wide area base station, the interfering signal mean power level P is -52 dBm at a frequency offset of 5 MHz (the adjacent channel). The reference sensitivity level mean power is -115 dBm (for voice rate of 12.2 kbps). **Figure 5** shows the blocking characteristics for WCDMA.

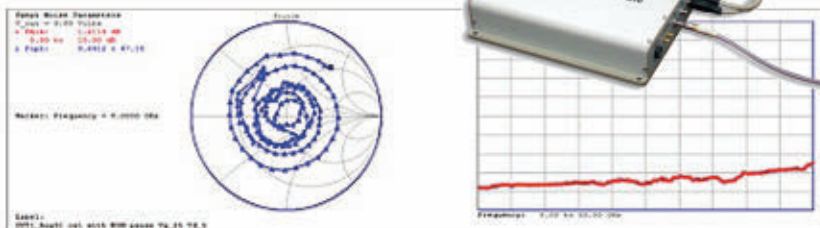
Substituting the values in Equation 5 gives the IIP3 due to adjacent channel blocking as -6.61 dBm.

IN-BAND BLOCKERS

In-band blocking characteristics are a measure of the receiver's ability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer on frequencies other than those of the adjacent channels (alternate channel). This is shown in **Figure 6** as $F_0 + 10$ MHz – since these interferers are beyond 5 MHz,

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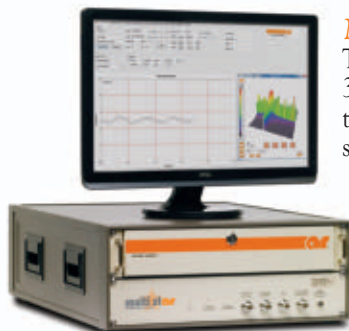
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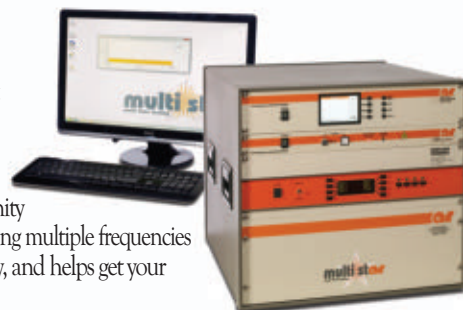
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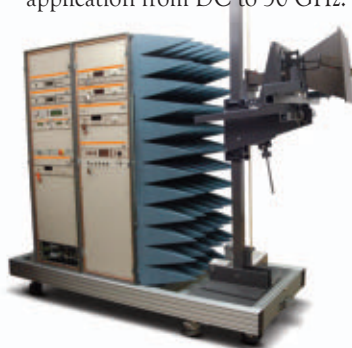


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the ACLR requirement is not of interest. It is assumed that intermodulation is responsible for the distortion.

The center frequency of the interfering signal (band I) is between 1920 and 1980 MHz. For a wide area base station, the interfering signal mean power is -40 dBm, where the static reference performance is met with -115 dBm wanted signal mean power. Equation 5 is not applicable for alternate channels, therefore Equation 3 will be used here. Substituting the power values and the receiver desensitization factor X of 0.1 dB, the required IIP3 due to alternate channel blocking equals 9.81 dBm.

OUT-OF-BAND BLOCKERS

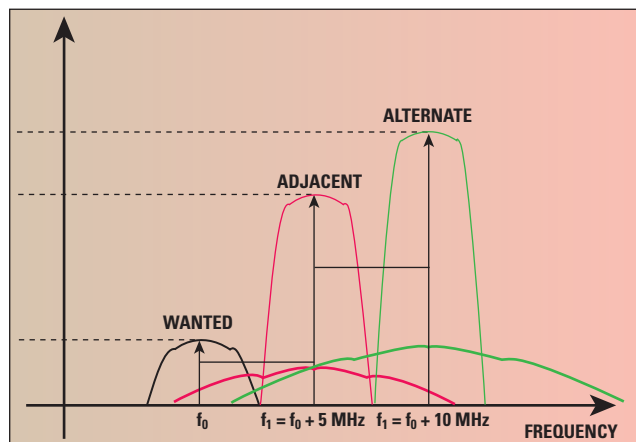
Referring to 3GPP band I blocking performance, there is also a requirement for out-of-band interference from 1900 to 1920 MHz and 1980 to 2000 MHz bands. These frequency ranges are just outside the wanted receive band from 1920 to 1980 MHz. Using wide area base station requirements, the interfering signal mean power is -40 dBm

in this OOB case (1900 to 1920 MHz and 1980 to 2000 MHz). The static reference performance is met with -115 dBm wanted signal mean power. This results in the same IIP3 as in the IBB case 9.81 dBm since the types of blocking signals are the same.

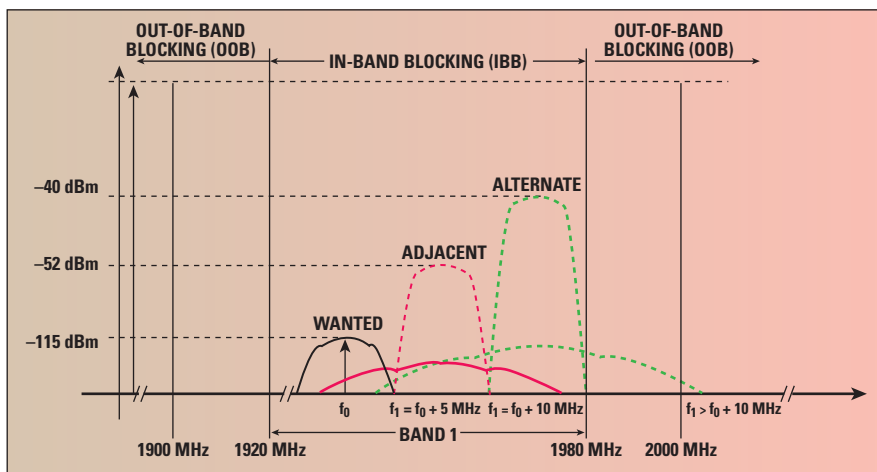
Finally there is a requirement for 1 to 1900 MHz and 2000 to 12750 MHz, where the interferer is a CW having a power level of -15 dBm. The frequency offset is 20 MHz away from the Band I frequency edges. It is assumed that this part of OOB can be partly filtered. For instance, suppose that the interferer can be attenuated by 30 dB worst case (typical 40 dB attenuation). In this case the IIP3 equals 2.3 dBm when dominated by intermodulation.

More important is the Tx (2110 to 2170 MHz) leakage into the receive band (1920 to 1980 MHz). In the case of a FDD system, the Tx-Rx separation is 190 MHz and a commercial available duplex filter has 40 dB attenuation. Suppose that the average transmit power is 49 dBm/3.84 MHz (80 W/3.84 MHz in 50 V) then the Tx signal

that leaks into the Rx band is 9 dBm/3.84 MHz. The requirement for a wide area base station that limits spurious emissions for protection of the base station receiver is -96 dBm measured in 100 kHz, or -80 dBm/3.84 MHz. Fortunately the Tx and Rx time slots have a certain delay so that during the Rx slot, the Tx leaked signal is sufficiently ramped down.



▲ Fig. 5 Blocking WCDMA characteristics (adjacent and alternate channels).



▲ Fig. 6 In-band adjacent and alternate channel WCDMA blockers.

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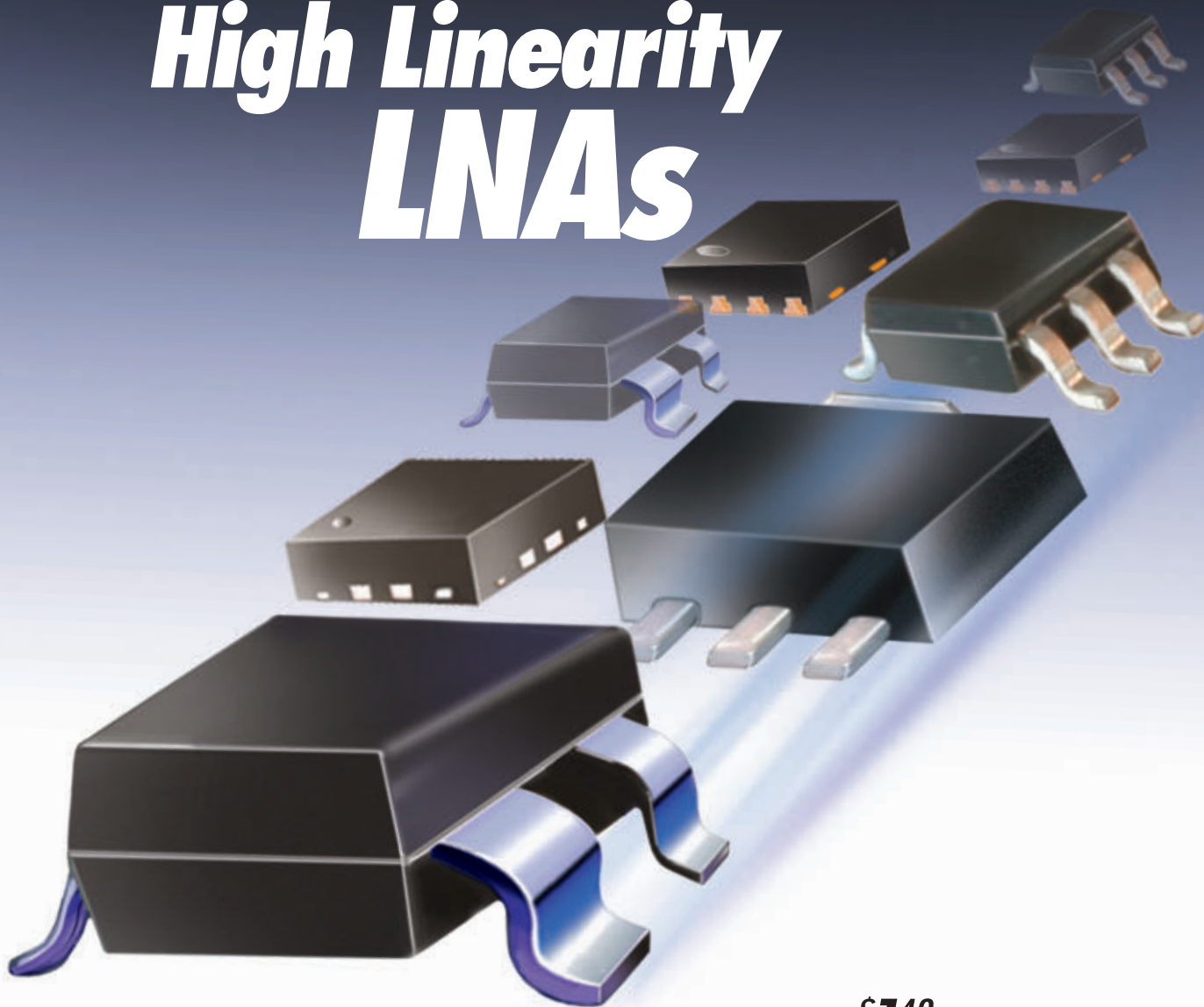
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PMA2-162LN+	700-1600	22.7	0.5	30	20	55	2.87
PMA-5452+	50-6000	14.0	0.7	34	18	40	1.49
PSA4-5043+	50-4000	18.4	0.75	34	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	0.8	33	19	40	1.49
PMA-5451+	50-6000	13.7	0.8	31	17	30	1.49
PMA2-252LN+	1500-2500	15-19	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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Part No.	Freq. (GHz)	Gain (dB)	NF (dB)	OIP3 (dBm)	Package
ASL51T8	0.9	18	0.37	38	TDFN8
ASL41S9	0.9	18	0.55	38	SOT89
ASL52T8	2.0	21	0.65	34	TDFN8

LNA w/o extra component

Part No.	Freq. (GHz)	Gain (dB)	NF (dB)	OIP3 (dBm)	Package
ANM1730	1.7~3.0	25	0.5~0.8	35	MCM3P

Wideband PA

Part No.	Freq. (GHz)	Gain (dB)	P1dB (dBm)	OIP3 (dBm)	Package
AWB459	DC~3	19	24	41	SOT89
AWB589	DC~1	20	27	44	SOT89
AWB688	DC~1	21	30	44	SOIC8

GPS LNA

Part No.	Vd/Id (V/mA)	Gain (dB)	NF (dB)	OIP3 (dBm)	Package (mm)
ASL22N	3/8.5	29	1.1	16	UQFN6 (1x1)

CATV

Part No.	Vd/Id (V/mA)	Gain (dB)	Pout (dBm)	CSO/CTB (dBuV)	Package
ASL39D2	5/300	19	105	60/66	SOIC8
ASL59D4	6.5/390	20	108	60/63	TSSOP24
ASL882	12/520	22	110	60/66	TSSOP24

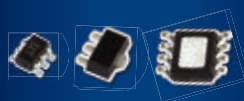
Optical Receiver

Part No.	Vd/Id (V/mA)	Photo.Pin (dBm)	Pout (dBuV)	CSO/CTB (dBc)	Package
ASA306C	4/210	-10~+2	85	60/62	QFN24

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Digital Attenuator (LSB 0.5 dB, 6-bit)

Part No.	Freq. (GHz)	Atten. Range (dB)	Typ. IL (dB)	IIP3 (dBm)	Package (mm)
AAT530B6	0.5~3.0	31.5	2.0	45	QFN16 (4x4)



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TABLE II

IIP3 DERIVED REQUIREMENT FROM A STANDARD SUMMARY TABLE INCLUDING GSM

GSM IIP3 Due to Blocking				
	GSM400, TGSM810, P-, E-, RGSMB900	DCS1800 & PCS1900	GSM900, EGSM900 BTS	
Inband	IIP3 BTS Except MC	Multi Carrier BTS	BTS incl. Multi Carrier BTS	
600 kHz $\leq f-f_0 < 800$ kHz	16.01	2.51	2.51	10.01
800 kHz $\leq f-f_0 < 1.6$ MHz	31.01	26.64	17.51	-4.99
1.6 MHz $\leq f-f_0 < 3$ MHz	31.01	26.64	17.51	-4.99
3 MHz $\leq f-f_0 $	35.51	26.64	17.51	-4.99
Out-of-Band				
(a)	7.01	7.01	-4.99	7.01
(d)	7.01	7.01	-4.99	7.01
UMTS IIP3 Due to Blocking				
	1920-1980 MHz	1900-1920 MHz 1980-2000 MHz		1-1900 MHz 2000-12750 MHz
	1.66	1.66		-5.84
IIP3 Due to X-Modulation			IIP3 Due to ACS Blocking	
GSM900 Normal BTS	UMTS Wide Area BTS		GSM900 Normal BTS	UMTS Wide Area BTS
-9.49	-10.34		-23.34	-14.76

Table 2 shows the IIP3 derived requirement summary for GSM and WCDMA. It can be concluded that GSM sets the demanding IIP3 requirements. Note that these values are obtained from the values written in the GSM and WCDMA standard (3GPP). In the case of single carrier GSM, a sharp bandpass filter is required to attenuate the blocking signals, while for multicarrier GSM, a band pass filter is only applied where multiple carriers are passed through.

According to Table 2, using the blocking requirement from R-GSM MC BTS standard results in an IIP3 of 26.64 dBm and includes relaxation for multicarrier GSM. But the likelihood that a blocker has a level beyond the power level is limited. Today's LNAs achieve an IIP3 between 17 and 19 dBm at a fixed gain of 18 dB.

distribution is taken to be 70 percent, 30 percent.

The annual costs for one base station are as follows. Assume one base station consumes 800 W and the price for electricity is €0.20/kWh, then the price for one year is €1397.76. Further assumptions are O&M €3000 per unit and average site lease costs of €5000 per year.

Initial costs include equipment purchase and site build out, including installation, which are €40,000 and €80,000 per unit. Adding all costs together and working them out across the Netherlands gives a total cost savings of €34.3 million, which is significant. If divided among the number of operators, this represents substantial savings per operator. In terms of the number of base stations, the savings is 4.4 percent and CAPEX and OPEX is reduced by 4.5 percent.

REDUCING BASE STATION NUMBERS

Besides the improvement in cell coverage due to low NF, there is an additional financial benefit for the operators. Take for example two LNAs with two different noise figures of 0.9 and 1.2 dB. Given the LNAs' NFs, the cell size is known and the area of the country – in this case the Netherlands with an area of 41,526 km². Assume also that there are more urban base stations than suburban base stations. In this calculation, the

CONCLUSION

This article has shown that the noise figures of LNAs can be linked to the distance of the cell coverage via link budget calculations. On the other hand, the number of interference signals increases when the number of users in one cell is increased. To cope with high levels of interfering signal levels, the linearity of the LNA needs to be increased while maintaining the lowest possible NF. More important for network operators, lowering the LNA NF yields savings in CAPEX and OPEX (4.5 percent). ■

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CT-3877-S	2.5 Kw Pk 250 W Av	"Drop-in"	2.7–3.1 GHz
CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
CT-1739-D	20 Kw Pk 1 Kw Av	DIN 7/16	128 MHz Medical

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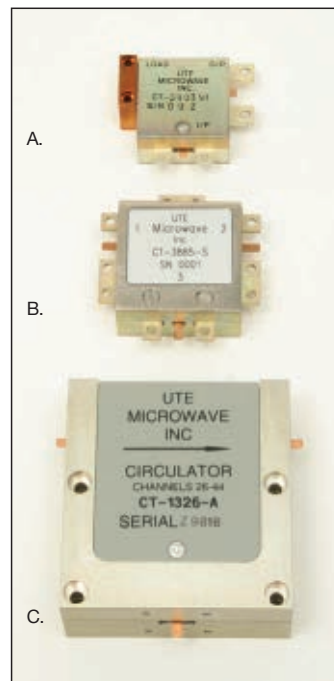
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Dr. Weinschel came to the United States as an eighteen-year-old genius with the equivalent of a Bachelor's degree in physics and a wealth of hands-on mechanical training. Studying under Nobel Prize winners Isidor

Rabi and Enrico Fermi at Columbia University Graduate School, Dr. Weinschel was first exposed to microwave measurements when he was tasked with building a 1300 MHz source for investigating the magnetic moment of molecules. Accepting a job as a supervisory engineer at Bell Labs (1943-44), the German-born physicist found himself designing microwave test equipment side-by-side with American engineers possessing a minimal understanding of microwave theory. Dr. Weinschel's physics background proved invaluable in designing equipment for precise attenuation measurements and industry standards. As chief engineer at Industrial Instruments (1944-48), and then section chief at the National Bureau of Standards (1949-52), Dr. Weinschel convinced his management to let him work on coaxial attenuators, advancing the work he had started at Bell Labs. Developing attenuator technology for the Army's ordnance development, he was responsible for a classified contract working on techniques to measure the microwave reflections used to trigger proximity fuses. Dr. Weinschel's engineering passion and drive to improve the performance of his attenuator technology eventually led him to set up a pri-

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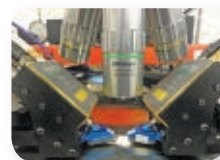
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Model Number	Frequency (MHz)	Pout (Watts)
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RCA0525H44D	500-2500	25
RCA002053H50D	20-530	100

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Model Number	Frequency (MHz)	Pout (Watts)
RSW002050H50F	20-500	100
RSW0525H50F	500-2500	100
RSW1030H52C	1000-3000	160
RSW1020H54D	1000-2000	200
RSW2030H54D	2000-3000	200

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Special Report

vate laboratory and to discover a market for precision attenuators. To avoid any perceived conflict of interest, he left the NBS to form Weinschel Engineering and continue developing the technology that is so critical to today's RF and microwave signal control and measurement systems. Dr. Weinschel received the National Medal of Science under President Regan. He also served as IEEE president in 1986 and the chairman of the Committee on U.S. Competitiveness (1988) for the IEEE.

Thriving through multiple ownership and name changes, including Lucas Industries PLC and Lucas Weinschel (1986), Sierra Networks and Sierra Weinschel (1995), MCE Technologies Inc. and Weinschel Corporation (1995), and the Aero-flex purchase of MCE / Weinschel which created the current Aero-flex / Weinschel (2003), the company has emerged as an industry benchmark in quality products and service. "The company formed as Weinschel Engineering, Co. in 1952, has changed ownership seven times, having successfully transitioned from a privately held company, to a division of a foreign-owned corporation, to a division of a publicly traded company. The company has managed to survive multiple recessions, various war-driven economies and national budget-constrained times, and through it all, remained a market leader, continuing to re-invent itself with new products that provide solutions to today's market needs," says Robert L. Stephens, Aero-flex / Weinschel president and general manager.

In the early 70s Dr. Weinschel saw the demand for fixed RF attenuators grow rather fast, beyond the test and measurement applications of the laboratory. He wanted to improve on the RF connector design. At the time the insulators and center contacts were pressed into a jack or plug body and held together with epoxy, injected from a side hole. This made the connectors inherently leaky to RF waves. Dr. Weinschel wanted to address this leakage problem while moving to higher volume manufacturing, so he invested heavily in injection mold machines from Germany.

Every connector type, either SMA or type N, needed a complicated mold fixture to get the desired final con-

necter, with the support insulator, the center contact and the jack/plug body all neatly molded in one piece without the need for any epoxy. Weinschel was the first company to supply Injection molded RF connectors into its commercial product line. Today the same process has been extended beyond SMA and type N connectors. Type SMK (2.92mm) and 2.4mm connectors are also molded in a multi-cavity mold. Injection molded connectors are rugged and reliable, have a consistent pin recession and offer the lowest RF leakage.

In conjunction with the attenuator development and other resistive base components, the need arose to make accurate insertion loss measurements. This need resulted in the development of precision measurement and calibration instruments. These instruments were originally designed for their own use, but the demand for this type of equipment by other laboratories was so great that Weinschel decided to make their calibration instruments available industry wide. This effort produced several products such as attenuator calibrators (BA-5 & VM-3), differential null detectors, double stub tuners, AF-substitution attenuators, modulated RF sources and other test and calibration of instruments. Weinschel's engineering and calibration staff has received over 40 patents and had over 70 technical articles published. This innovation has aided in their development of precision measurement and calibration equipment. In November 1997, this instrument line was sold to Tegan where they still manufacture these products today.

Look no further than its list of patents, past and present, which set the foundation for Weinschel's technical history. Its patents in attenuation measurements and design, connectors, detectors, frequency control, impedance measurement, power measurement, RF sources, step attenuators and tuners paved the way for the company's current business strategy. The evolution and success of Weinschel lies in its ability to adapt to changing market conditions and customer demands while simultaneously maintaining the core technologies, product development, processes and procedures. Innovation at Aero-flex / Weinschel is reflected in its ever-expanding

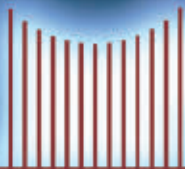
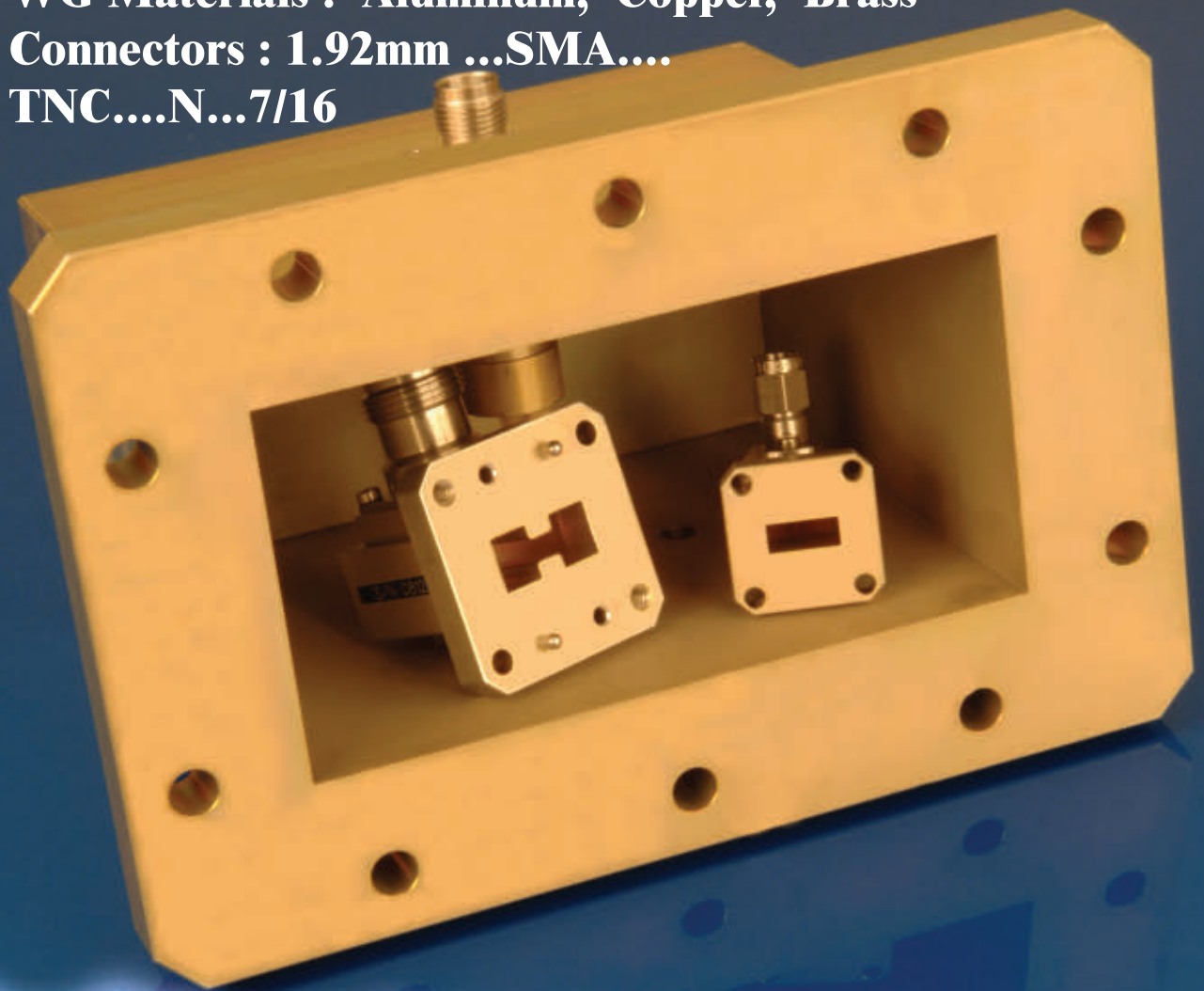
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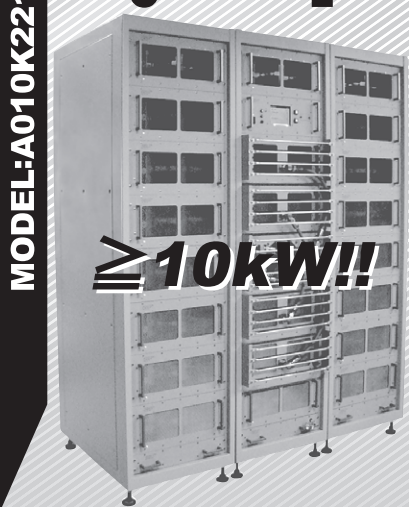


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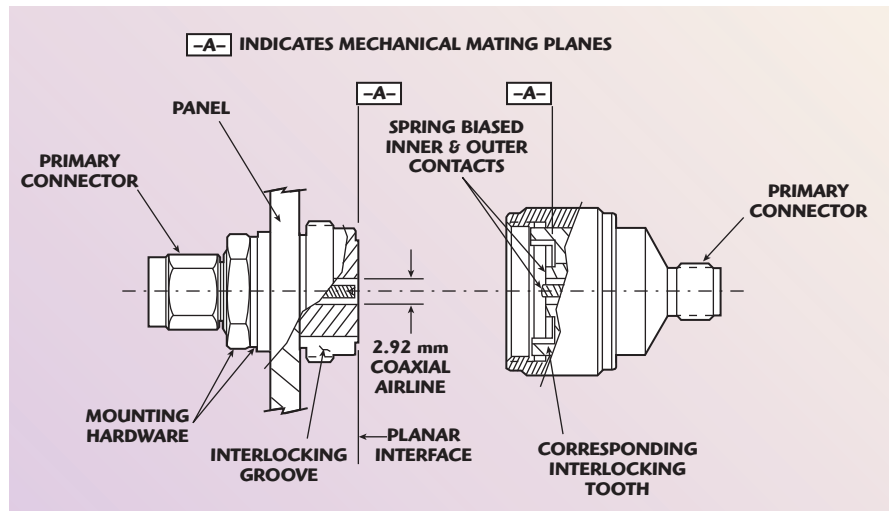
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Special Report



▲ Fig. 1 Cross section of Planar Crown® Universal Connector System.

line of RF and microwave components and subsystems. From the company's very first DC to 1 GHz tee attenuator came the technology that fostered the design of the industry's very first 500 W, DC to 10 GHz and 20 W, DC to 40 GHz attenuators, to name just two. These planar distributed resistor elements, form the basis for most all attenuators manufactured today from DC to 65 GHz.

Aeroflex / Weinschel utilizes both a thick film process, for DC to 3 GHz programmable attenuators, and a thin film process for the development of its resistors. The company utilizes a proprietary chemical vapor deposition (CVD) where a tin oxide (SnO) film doped with antimony (Sb) is sprayed onto a ceramic and the deposition takes place at a very high temperature. This technology and process gives Aeroflex / Weinschel's thin film products extreme ruggedness and high power handling capability at very high surface temperatures. Doping the film with Antimony results in an industry standard setting attenuator performance with low power and temperature coefficients, long term stability and endurance under high power. It also allows Weinschel to offer a wide variety of low intermodulation (IM) attenuators and terminations. Today Aeroflex / Weinschel offers the broadest frequency and power handling performance envelope in the industry.

In the late 70s Weinschel obtained a patent on a 2 GHz relay based programmable attenuators. They used relays from Teledyne and were built

on alumina with thick-film circuitry providing a patented scheme for tuning each individual attenuator. The result was a flat frequency response over DC to 2 GHz, quite unmatched in those early days. This attenuator formed the foundation of today's long list of programmable attenuator products spanning from DC to 6 GHz to DC to 26.5 GHz. The various programmables use either microstrip or edge-line as the transmission medium. Electromechanical relays, Edge line Reed Switches, PIN diodes, FETs or MMICs provide the programmability and the switching function, depending on the application.

As customer demand for faster switching speed within the telecommunications industry increased during the mid 90s, mainly for simulation and handover testing of mobile phones, Weinschel saw the need to develop its own line of solid-state GaAs and PIN switched programmable attenuators for its own attenuation matrices. New requirements from end-users to reduce cost and provide portability has produced a line of MMIC switched digital attenuators that are low profile and operate to 6 GHz up to 95 dB. Control for these devices was also an important consideration, which led Aeroflex / Weinschel to incorporate both built-in TTL and USB 2.0 interfaces. This device is programmed to auto select the type of control that is connected to the device. Included attenuation control center software makes it even easier to operate whether the device is in a bench or field application. In a majority of its



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Special Report

wide product line, including high-reliability products, Weinschel does not use any solder, either to launch onto the substrate or for RF grounding. Every product has a unique gold-plated spring mechanism to provide RF and thermal grounding. Each product also has a spring loaded connector end launch onto the RF circuitry. These two features make the products virtually immune to mechanical shocks and thermal extremes, a very important requirement of high-reliability products being launched into space.

Industry demand for high performance connectors led Weinschel to develop an innovative specialized planar connector systems. The Planar Crown® Universal Connector System, which is comprised of two connector halves/subassemblies, has a common mating interface referred to as the Planar Interface (see **Figure 1**). The first connector half is called the Planar Bulkhead which readily mounts into instrument front panels, components and cables. One end of this bulkhead has a 2.92mm (SMK) male/female primary connector. The other end has a combination of grooves, external threads and a coaxial Planar Interface with a 2.92mm (SMK) airline geometry. The bulkhead operates mode free beyond 40 GHz. The second, replaceable connector half, called the Planar Crown, has corresponding projections which interlock with slots on the bulkhead and a coupling nut which secures the two connector halves, resulting in a non-rotational, torque independent electrical connection.

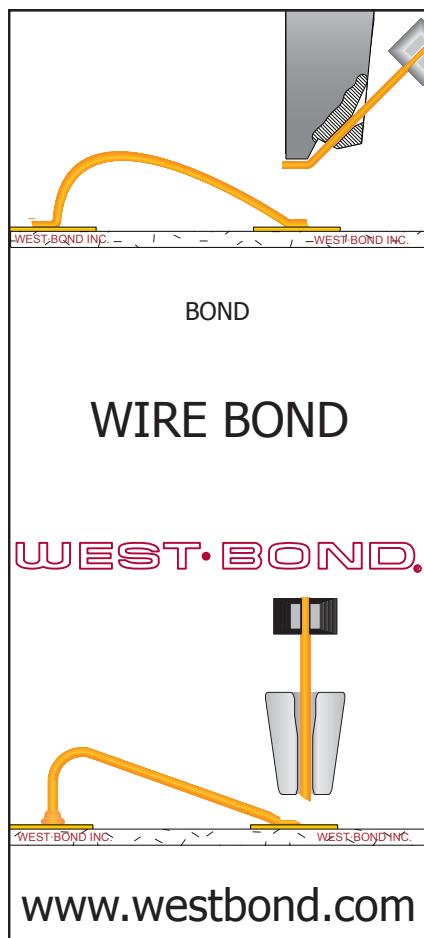
The spring biased inner and outer contacts eliminate the need for specifying proof torque and no tools are required to mate or unmate the connection. The primary end of the Planar Crown is offered in a variety of primary coaxial connector configurations such as SMA, Type N, GPC-7, TNC, 3.5mm, 2.92mm (SMK) and 2.4mm (under development), thus providing an extremely versatile connector system wherein a connector can be replaced in a matter of seconds.

The Planar Blind-mate Connector Series was designed for threadless connector mating that is useful when mating an array of connectors from one RF module to another in seconds. This design provides a “forgiving” mechanical interface that can permit

a 0.02 mis-alignment. These connectors offer DC to 40 GHz operation, a contact life of 1.0 m cycles and a repeatability of 0.05 dB typical per connection. Other features of this connector series include pressurized and unpressurized designs, SMA and SMB connector options and a space saving and rugged construction.

Today Aeroflex / Weinschel builds products for a host of customers, including leading aerospace and defense contractors, commercial wireless network providers and test equipment manufacturers. The company's subsystem development activity focuses on custom products employed in telecommunications, radar and CNI, satellite and ground communication systems, base station and mobile unit software conformance verification, signal analysis, cable modem and VoIP testing, production test systems and precision microwave related test instruments. These custom subsystems include attenuator and switch matrices and RF distribution systems.

Weinschel's subsystem group has developed a modular approach, trademarked “SmartStep®,” that utilizes a single controller that provides control of digital and programmable attenuators, switches and other devices using various industry standard communications interfaces (GPIB/IEEE-488, RS-232, RS-422, RS-485) to the serial Driver Interface Bus. New designs will include a USB 2.0 Full-Speed configuration, which is 12 Mbps and is compatible with 1.0 (1.5 Mbps) and 1.1 (12.5 Mbps) speeds. The Device Interface Bus (DIB) is a system for connecting a number of relatively low-speed I/O devices to a host, providing a simple, uniform and inexpensive way to control a variety of devices via a single port. The DIB is based on the two-wire serial bus and several software protocol layers that allow the controller to address up to 125 peripheral devices with serial data rates of up to 100 kHz. The DIB is also used to supply DC power to the devices, resulting in a simple, low-cost interconnection system. The future requirements placed on RF and microwave signal control circuitry by the industry will spirit innovation that started with Bruno Weinschel and the company that bears his name. ■



The diagram illustrates the wire bonding process. It shows a wire being fed from a spool, passing through a guide, and being bonded to a substrate. The wire is shown in a curved path, indicating the movement of the bonding head. The substrate is labeled 'WEST BOND INC.' and the word 'BOND' is written above the wire. The text 'WIRE BOND' is prominently displayed in the center. Below the diagram, the website 'www.westbond.com' is listed.

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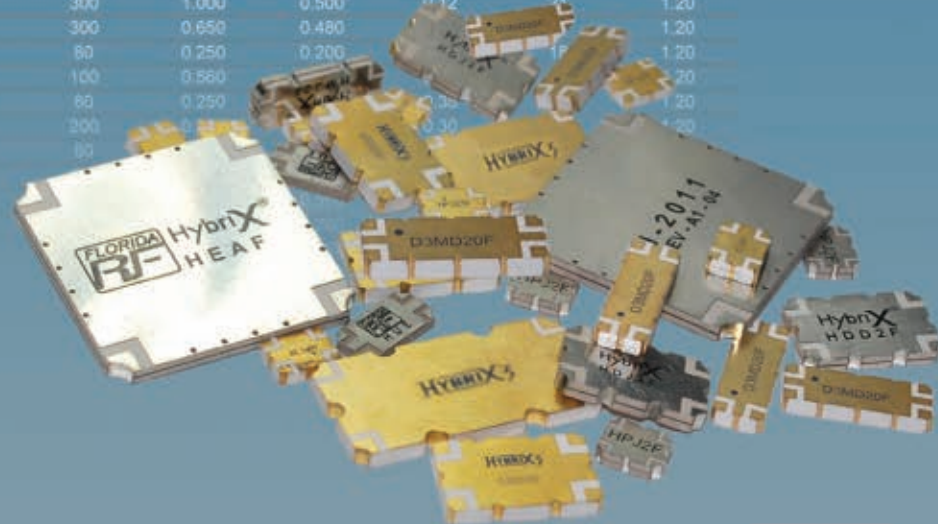
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HN05W03F	15000-18500	50	0.175	0.175	0.70	18	1.50
HUU2F	5000-6000	25	0.400	0.200	0.22	25	1.18
D3PR20F	3400-3600	80	0.250	0.200	0.22	40	1.20
HPR2F	3000-4500	60	0.250	0.200	0.18	24	1.15
HPQ2F	2700-3200	50	0.250	0.200	0.18	23	1.15
HPP2F	2300-2700	35	0.250	0.200	0.21	23	1.23
HMP2F	2300-2700	80	0.560	0.200	0.11	23	1.17
D3DP30F	2300-2700	200	0.560	0.350	0.20	48	1.20

HVR3F	3300-3700	5	0.080	0.050	.30	20	1.20
HVP3F	2300-2700	5	0.080	0.050	.35	24	1.20
HVL3F	2000-2300	5	0.080	0.050	.35	24	1.20
HVJ3F	1700-2000	5	0.080	0.050	.35	24	1.20
HVV3F	700-1000	5	0.080	0.050	.60	17	1.26

HDDF	811-1000	200	0.560	0.350	0.15	26	1.15
HDD2F	811-1000	200	0.560	0.350	0.15	26	1.15
WH0625F	800-2800	150	2.200	0.500	0.48	16	1.38
HDV2F	700-1000	200	0.560	0.350	0.24	24	1.21
D3PV30F	700-1000	200	0.250	0.200	0.10	50	1.15
HDT2F	690-910	200	0.560	0.350	0.25	23	1.17
HLB2F	470-870	500	1.340	0.670	0.12	20	1.20
HSBF	470-860	200	0.650	0.480	0.25	19	1.30
HEAF	150-175	200	1.000	1.000	0.20	20	1.17
HE128MF	123-133	300	1.000	1.000	0.23	28	1.10
HG064M2F	048-084	300	2.000	1.500	0.20	20	1.20
HD128M3F	123-133	10	0.560	0.350	0.80	20	1.35
HAA3F	180-210	200	1.000	0.500	0.30	20	1.20
HLA3F	180-210	300	1.034	0.670	0.30	20	1.20
D3AA30F	180-210	200	1.000	0.500	0.30	48	1.20
HDC3F	380-520	200	0.560	0.350	0.30	20	1.20
HSC3F	400-500	200	0.650	0.480	0.25	20	1.20
HDB3F	470-860	200	0.560	0.350	0.30	20	1.20
HLB3F	470-860	500	1.340	0.670	0.30	18	1.30
W3H0526F	500-2600	100	1.772	0.394	0.50	18	1.30
HPT3F	620-900	150	0.250	0.200	0.18	23	1.15
W3H0630F	800-3000	100	1.969	0.394	0.50	18	1.30
HDD3F	815-960	200	0.560	0.350	0.15	23	1.20
HAD3F	815-960	300	1.000	0.500	0.12	23	1.20
HSD3F	815-960	300	0.650	0.480	0.12	23	1.20
HPD3F	815-960	80	0.250	0.200	0.12	18	1.20
HMD3F	815-960	100	0.560	0.350	0.12	23	1.20
HPF3F	960-1100	80	0.250	0.200	0.30	23	1.20
HDE3F	1000-2000	200	0.560	0.350	0.30	23	1.20
HPG3F	1200-1700	80	0.250	0.200	0.30	23	1.20
HDJ3F	1700-2000	80	0.250	0.200	0.30	23	1.20
HAG3F	1700-2000	80	0.250	0.200	0.30	23	1.20
HPJ3F	1700-2000	80	0.250	0.200	0.30	23	1.20
HQJ3F	1700-2000	80	0.250	0.200	0.30	23	1.20



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MINIATURE FOOTPRINT

ULTRA WIDE BANDWIDTH VCO

0.3" x 0.3" x 0.08"

Model	Frequency Range (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (Inch)
DCO Series					
DCO50100-5	500 - 1000	0.5 - 15	+5 @ 34 mA	-100	0.3 x 0.3 x 0.08
DCO6080-3	600 - 800	0 - 3	+3 @ 15 mA	-105	0.3 x 0.3 x 0.08
DCO7075-3	700 - 750	0.5 - 3	+3 @ 12 mA	-108	0.3 x 0.3 x 0.08
DCO80100-5	800 - 1000	0.5 - 8	+5 @ 26 mA	-111	0.3 x 0.3 x 0.08
DCO8190-5	810 - 900	0.5 - 16	+5 @ 34 mA	-118	0.3 x 0.3 x 0.08
DCO100200-5	1000 - 2000	0.5 - 24	+5 @ 36 mA	-95	0.3 x 0.3 x 0.08
DCO1198-8	1195 - 1205	0.5 - 8	+8 @ 30 mA	-115	0.3 x 0.3 x 0.08
DCO170340-5	1700 - 3400	0.5 - 24	+5 @ 29 mA	-90	0.3 x 0.3 x 0.08
DCO200400-5	2000 - 4000	0.5 - 18	+5 @ 46 mA	-90	0.3 x 0.3 x 0.08
DCO200400-3			+3 @ 46 mA	-89	
DCO300600-5	3000 - 6000	0.5 - 18	+5 @ 35 mA	-80	0.3 x 0.3 x 0.08
DCO300600-3			+3 @ 35 mA	-78	
DCO400800-5	4000 - 8000	0.5 - 18	+5 @ 20 mA	-78	0.3 x 0.3 x 0.08
DCO400800-3			+3 @ 20 mA	-76	
DCO432493-5	4325 - 4950	0.5 - 11	+5 @ 22 mA	-88	0.3 x 0.3 x 0.08
DCO432493-3			+3 @ 22 mA	-86	
DCO450900-5	4500 - 9000	0.5 - 18	+5 @ 20 mA	-76	0.3 x 0.3 x 0.08
DCO450900-3			+3 @ 20 mA	-74	
DCO473542-5	4730 - 5420	0.5 - 22	+5 @ 20 mA	-88	0.3 x 0.3 x 0.08
DCO473542-3			+3 @ 20 mA	-86	
DCO490517-5	4900 - 5175	0.5 - 5	+5 @ 22 mA	-88	0.3 x 0.3 x 0.08
DCO490517-3			+3 @ 22 mA	-86	
DCO495550-5	4950 - 5500	0.5 - 12	+5 @ 22 mA	-83	0.3 x 0.3 x 0.08
DCO495550-3			+3 @ 22 mA	-85	
DCO5001000-5	5000 - 10000	0.5 - 18	+5 @ 20 mA	-75	0.3 x 0.3 x 0.08
DCO5001000-3			+3 @ 20 mA	-73	
DCO579582-5	5780 - 5880	0.5 - 10	+5 @ 20 mA	-90	0.3 x 0.3 x 0.08
DCO608634-5	6080 - 6340	0.5 - 5	+5 @ 20 mA	-85	0.3 x 0.3 x 0.08
DCO608634-3			+3 @ 26 mA	-86	
DCO615712-5	6150 - 7120	0.5 - 18	+5 @ 22 mA	-85	0.3 x 0.3 x 0.08
DCO615712-3			+3 @ 22 mA	-83	

Model	Frequency Range (GHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Typ.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]	Size (Inch)
DXO Series					
DXO810900-5	8.1 - 8.925	0.5 - 15	+5 @ 32 mA	-82	0.3 x 0.3 x 0.08
DXO810900-3			+3 @ 32 mA	-80	
DXO900965-5	9.0 - 9.65	0.5 - 12	+5 @ 27 mA	-80	0.3 x 0.3 x 0.08
DXO900965-3			+3 @ 27 mA	-78	
DXO10701095-5	10.70 - 10.95	0.5 - 15	+5 @ 25 mA	-82	0.3 x 0.3 x 0.08
DXO11441200-5	11.44 - 12.0	0.5 - 15	+5 @ 30 mA	-82	0.3 x 0.3 x 0.08
DXO11751220-5	11.75 - 12.2	0.5 - 15	+5 @ 30 mA	-80	0.3 x 0.3 x 0.08
DXO14851515-5	14.85 - 15.15	0.5 - 15	+5 @ 30 mA	-74	0.3 x 0.3 x 0.08

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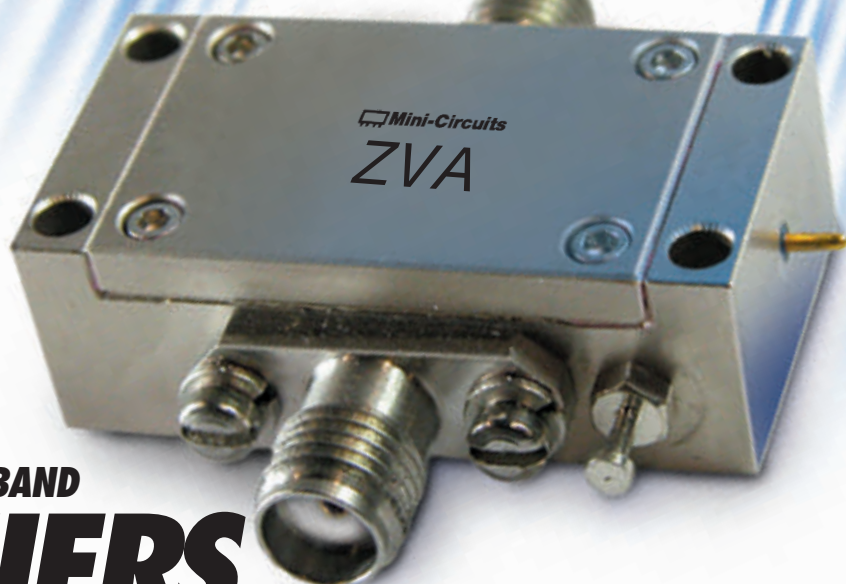
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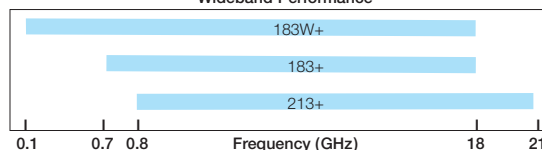


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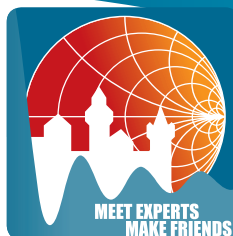


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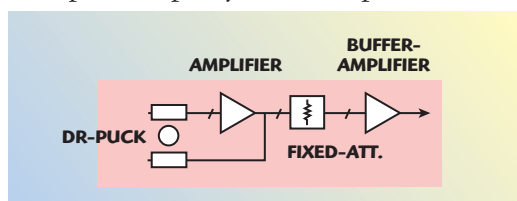
When high data-rates have to be transferred, as with M-QAM modulation in LTE, LMDS, fixed frequency point-to-point digital radio and satellite-links, these systems need low phase noise signal sources either free running or phase-locked. RADAR systems and Research Laboratories also require ultra-low noise sources to generate ultra-low noise carrier signals.

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The circuit in **Figure 1** shows a typical block diagram of the DRO. The design challenge was to develop the lowest phase noise DRO, while minimizing costs through highly repeatable production builds. Such consistency in design and manufacturing could only be achieved through solid circuit simulation, by employing the latest state-of-the-art CAE tools such as ANSYS HFSS and Agilent-EEsof ADS/Momentum. The complete DRO design has been exercised and optimized using circuit and EM co-simulation (see **Figure 2**). This approach enabled us to achieve a high loaded figure of merit (Q_L) for the dielectric resonator arrange-



▲ Fig. 1 DRO block diagram.

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RWW 2013 Highlights

35 Technical Oral Sessions - Mon-Wed, 21-23, Jan., 2013

Interactive Poster Sessions - Mon/Wed, 21,23, Jan., 2013

Student Paper Competition Finals - Mon, 21 Jan., 2013

Demo Sessions - Tue, 22 Jan., 2013

Workshops - Sunday afternoon, 20 Jan., 2013

"Machine-To-Machine (M2M) Communication: A Path Towards the Internet of Things (IOT)"

"Metamaterials in communications and sensing: reality or fiction?"

"Towards THz Communications Systems and Applications"

"Software Defined Radio: Recent Advancements in Hardware and Software"

Panel Sessions, Sun-Mon, 20-21 Jan., 2013

"Tunable and Reconfigurable Radio Frontends"

"Wireless Personal Area Networks"

"Should Design Engineers Really Care About Software Piracy?"

"Base Station Design Breakthrough Opportunities"

Two RWS/SiRF Joint Sessions

"THz Communications: Circuits to Networks"

"Power Amplifiers and Transmitter Modules"

Three Focus Sessions

"Wireless Power"

"Wireless Enabled Automotive and Vehicular Applications"

"Advances in Micro & Millimeter-Wave Biosensing & Interaction"

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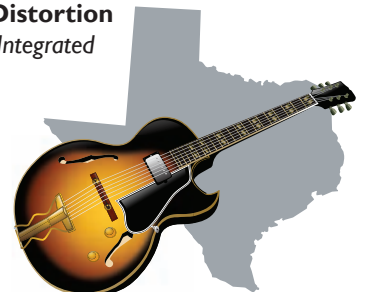
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Wideband and Low-Loss Metamaterial Antennas and Arrays with Tunable Radiation Patterns and Directions for Wireless and Radio Applications

Dr. J. Le-Wei Li (APS), University of Chengdu, China

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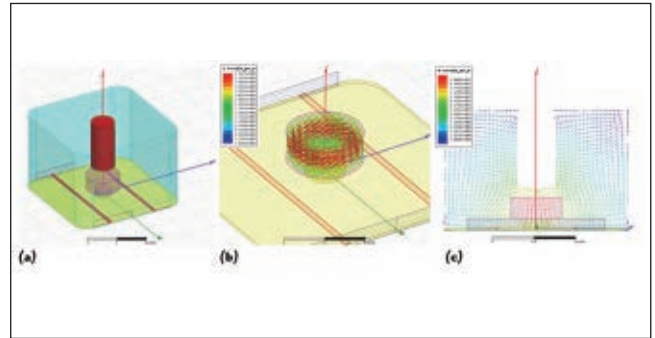


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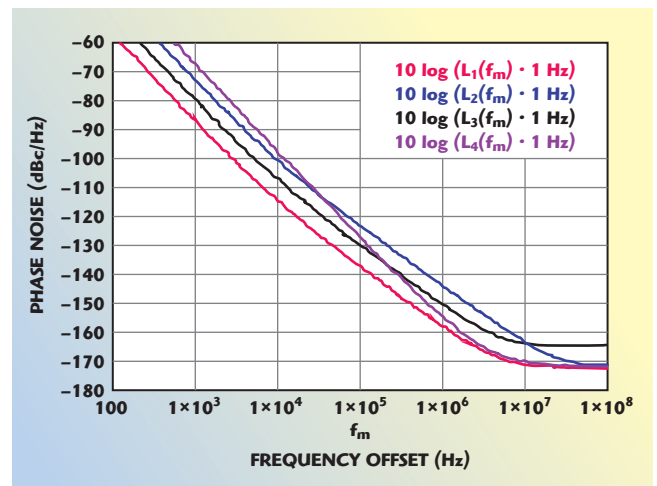
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Product Feature



▲ Fig. 2 Four-port dielectrical resonator model (a), E-Field vector plot within the DR at resonance (b) and H-Field vector plot in YZ-plane (c).



▲ Fig. 3 The impact of possible impairments on the phase noise performance.

ment in conjunction with the oscillator core which is one of the preconditions for achieving lowest phase noise. The oscillator's main active device has been selected carefully with respect to noise figure and flicker noise, with optimum bias level conditions.

Figure 3 illustrates the impact of possible impairments on the phase noise performance. The red trace identifies the measured phase noise performance of Synergy's new 10 GHz model number CDRO1000-8. The blue trace corresponds to a lower Q_L with identical oscillator core noise properties. The black and magenta traces correspond to identical Q_L but significantly higher effective noise figure or flicker corner frequency when the active device is not selected or biased optimally. A combination of these impairments together with nonlinear noise effects account for the much higher phase noise performance found in many competing DRO designs.

The CDRO1000-8 has a typical noise floor of -166 dBc/Hz which approaches state of the art performance. The measured phase noise reaches -111 dBc/Hz at 10 kHz offset as indicated in **Figure 4**. Mechanical and electrical tuning are available for frequency adjustment and phase locking. The frequency is factory set to 10 GHz and can be mechanically varied by approximately ± 50 MHz. The electrical tuning port varies the center frequency by ± 1 MHz with a tuning voltage of 1 to 15 V DC to compensate for frequency drift in phase locked

systems. The temperature stability is typically specified at 80 ppm.

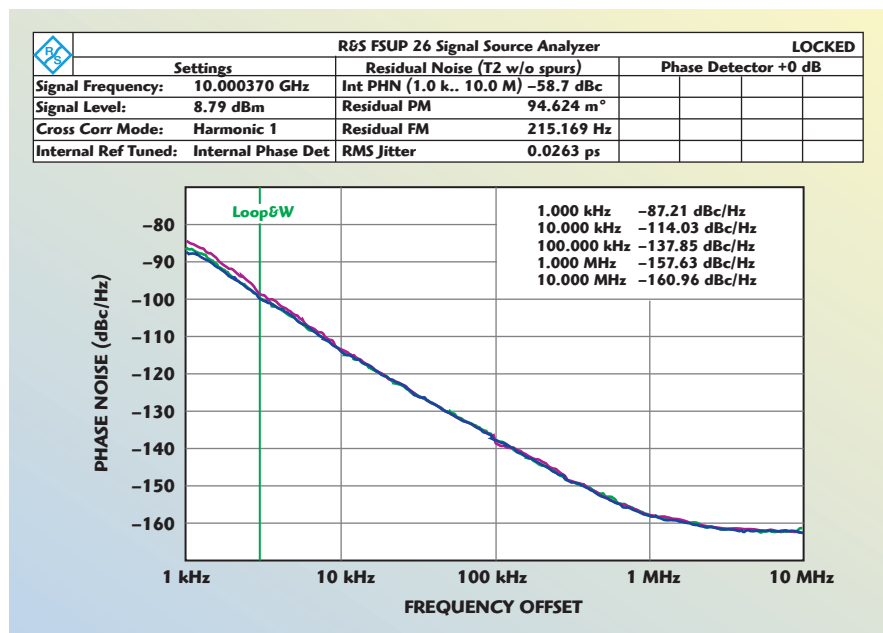
The oscillator supply voltage can vary between +7 to +10 V and the internal voltage regulation gives high immunity to power supply noise. The

supply-current is typically 50 mA and the temperature range is specified from -25° to +70°C. The output-power exceeds +8 dBm. The actual package size is approximately 3.1" × 1.34" × 0.788", including mounting flaps.

Similar to crystal oscillators, DROs tend to be prone to vibrational noise since the dielectric resonator itself cannot be secured mechanically. Therefore vibrations must effectively be damped by other means before they reach the dielectric resonator. The CDRO1000-8 is designed with rugged construction to minimize vibration noise and microphonic effects to prevent unwanted modulation.

Its excellent phase noise performance makes this DRO well suited for low-jitter communication systems, reference oscillators for phase noise measurement, RADAR systems, SDH/SONET, cable TV, SATCOM systems, aeronautical equipment, digital radios (QAM) and laboratory frequency references. Custom frequencies and packages (hermetic) can be developed on request.

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▲ Fig. 4 Measured phase noise of CDRO1000-8.

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Low Loss Cable Family is Extended

The SUCOFLEX 404 and 404D cable assemblies were launched in summer 2011 and the next step in the roadmap of the SUCOFLEX 400 cable family comes with the introduction of the new 18 GHz cable assembly versions of the SUCOFLEX 406 and 406D, which cover the upper limit of the diameters for very low loss cables in this class. Following the tradition of the new SUCOFLEX 400 cable family strategy, the company aims to continue to set new standards for microwave cable assemblies, particularly in markets like test and measurement, space and defence and instrumentation.

In all these applications, minimal electrical losses, as well as a high level of phase stability in a broad temperature range, are vital. Following a period of intensive development, the SUCOFLEX 406 and 406D meet these extremely high requirements. A new dielectric process technology, similar to the SUCOFLEX

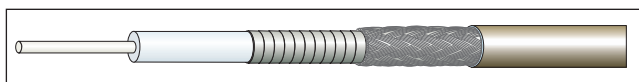
404, significantly improves the electrical properties of the product. Further highlights are its excellent return loss properties and the good phase stability versus bending.

LOW INSERTION LOSS

The construction of the SUCOFLEX 406 and 406D (shown in **Figures 1** and **2**, respectively) is a solid silver-plated copper wire center conductor, encased by an extruded and expanded ultra low density PTFE dielectric. Responsible for the shielding is a wrapped silver-plated copper tape, covered by a silver-plated copper braid. The cable is jacketed with Fluorinated Ethylene Propylene (FEP). For the 406D, an impregnated aramid yarn is used as a ruggedization for higher mechanical strength.

In particular, the extruded and extended ultra low density PTFE dielectric is responsible for the loss performance of SUCOFLEX 400 products. With a dielectric constant of $\epsilon_r = 1.26$, the SUCOFLEX 406 is claimed to deliver the lowest insertion loss currently available in its class.

Another highlight is the CW power capability that has been increased together with a



▲ Fig. 1 The SUCOFLEX 406 is 8.35 mm in diameter.



▲ Fig. 2 The SUCOFLEX 406D is 8.70 mm in diameter.

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Product Feature

very significant improvement in phase stability versus temperature (shown in **Table 1**). This is a great advantage in applications such as phased array antenna systems and also helps to simplify the adjustment of radars.

The new SUCOFLEX 406 cable assemblies have been specifically developed for defence ground systems, as well as for space measurement and instrumentation applications. In this market, low loss, high phase stability

versus temperature/bending and mechanical stability is the key to success.

APPLICATIONS

The SUCOFLEX 406/406D cable assembly is suitable for different applications. In defense technology, its main use is in tactical and strategic communications, electronic warfare and radar systems. Phase-matched cable assemblies are often required for radar applications. Complete sets of phase-matched, time-delay-matched or amplitude-matched SUCOFLEX 406 cable assemblies are available. Also, the special characteristics of the new cable assembly family are likely to make it the preferred solution for all industrial applications where lowest loss is crucial for customer specific installations.

ROLL-OUT

The roll-out of SUCOFLEX 406 and 406D products for selected markets will start with straight male N and TNCA connectors, which will be available by the beginning of 2013. The SUCOFLEX 406/406D including TNCA straight male connector is suitable for 18 GHz and covers MIL-STD-348/313-3. During the course of 2013, the SUCOFLEX 400 product portfolio connector range will be extended and followed by additional thinner cable versions with the lowest losses for frequencies up to 40 GHz, as well as additional connectors, jackets and armor versions for all kinds of applications.

The continuously growing SUCOFLEX 400 family builds on a similar design as the familiar SUCOFLEX 100 products, which have proved their reliability and stability for a wide range of applications for more than 25 years. The connectors have been tuned to the cable in order to preserve the excellent return loss (VSWR) characteristics for the assembly. Current and future RF-systems for defense, space and other industrial applications must comply with the highest requirements; consequently it is essential for the connector components to meet the highest standards.

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TABLE 1

CABLE CHARACTERISTICS FOR SUCOFLEX 406

Impedance	50 \pm 1 Ω
Operating Frequency	18 GHz
Capacitance	72.4 \pm 1.9 pF/m
Velocity of Propagation	89%
Signal Delay	3.74 ns/m (1.14 ns/ft)
Phase Stability vs. Temperature	< 1000 ppm
Phase Stability vs. Bending, 360°, Radius 50 mm	max. 1.5 °/GHz
Insertion Loss Stability vs. Bending	< 0.1 dB
Screening Effectiveness up to 18 GHz	> 90 dB
Attenuation* Coefficients: a: 0.1200 b: 0.0080	max. 0.66 dB/m @ 18 GHz
Weight (406/406D)	145 gr/m/155 gr/m
Minimum Bending Radius (406)	> 30 mm
Minimum Bending Radius (406D)	> 80 mm
Operating Temperature	-55° to +125°C
RoHS (2002/95/EC)	compliant

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Improving Ultra-Low Cryogenic Temperature Measurements

Noise and uncertainty are the enemies of temperature measurement accuracy, resolution and speed. In the science of cryogenic temperature measurement and control, there are unique challenges in addressing the many sources of potential error. Because the allowable excitation power for the sensors becomes diminishingly small as the temperatures being measured approach absolute zero, the signal levels being measured from those sensors are extremely low. Thus, elimination of noise becomes a critical factor in overall measurement quality.

Recent noise-reducing circuit improvements to cryogenic temperature controllers are improving their overall measurement capability. Among these improvements are improved heater output circuits that generate lower noise and better layout and isolation of the critical input circuits so they pick up less noise.

The newest cryogenic temperature controllers, such as the Model 350 developed by Westerville, OH-based Lake Shore Cryotronics, actually enable ultra-low temperature platform users and OEMs to achieve a new level of quality in measurement and control without requiring the use of more sophisticated AC resistance bridge instruments. This is achieved by reducing input noise by almost a factor of

two over previous controllers and limiting the impact of environmental noise. The result is the ability to operate at excitation powers that are nine times lower than before, with a comparable reduction in measurement self-heating errors and an improvement in resolution, speed and overall control stability.

Another significant innovation is the adaptation of specialized noise reduction input circuitry from AC resistance bridges. This technology has enabled these premium instruments to provide accurate measurement and control down to 20 mK and below by preventing external noise power from creating self-heating in the sensor. In real-world ultra-low temperature (ULT) installations, it is impossible to eliminate all of the noise induced in the sensor's input wiring from external sources. Rather than asking researchers to continually fight these effects with grounding and shielding schemes that will always be somewhat imperfect, the instrument's noise reduction circuitry cancels this noise internally. **Figure 1** shows the general design of differential current source circuitry (US Patent 6,501,225) developed specifically for noise reduction in an AC resistance bridge.

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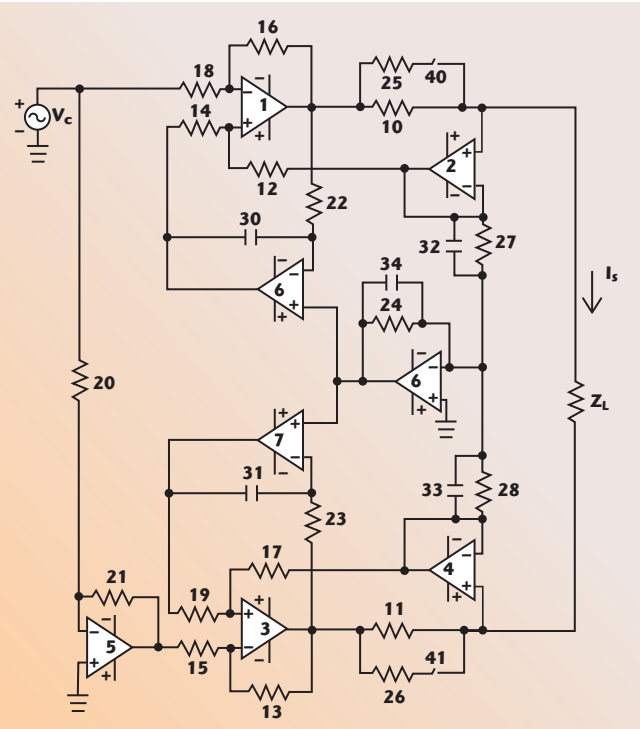
Product Feature

Integration of this and other circuit improvements into modestly-priced next generation controllers enables them to measure and control temperatures down to 100 mK using sensor excitation current levels of as little as 10 nA, with resolution on the order of a few μ K. This is quite suitable for pumped Helium-3 (He-3) refrigerators and similar ULT platforms. Reduced excitation current increases measurement accuracy by reducing errors due to self-heating. Better resolution means faster measurements, because a dependable result can be achieved with less averaging – and faster measurements enable faster response and better overall control stability for more consistent temperature management at the extremes.

Lake Shore Cryotronics incorporated a variety of such electronic enhancements into its new Model 350 cryogenic

temperature controller. Extensive real-world validation testing was conducted at the company’s in-house cryogenic sensor calibration facility that operates dilution refrigerators (DR) as part of an ultra-low temperature test-bed. **Figure 2** shows the calibration facility with DRs.

Comparisons were made between the new Model 350 controller and a previous design, the Model 340. Since the new controller is capable of lower excitation current settings than the earlier model, the older model’s minimum current setting (30 nA) was used for the comparison. A Cernox™ CX-1010 sensor was selected with a 30 k Ω value

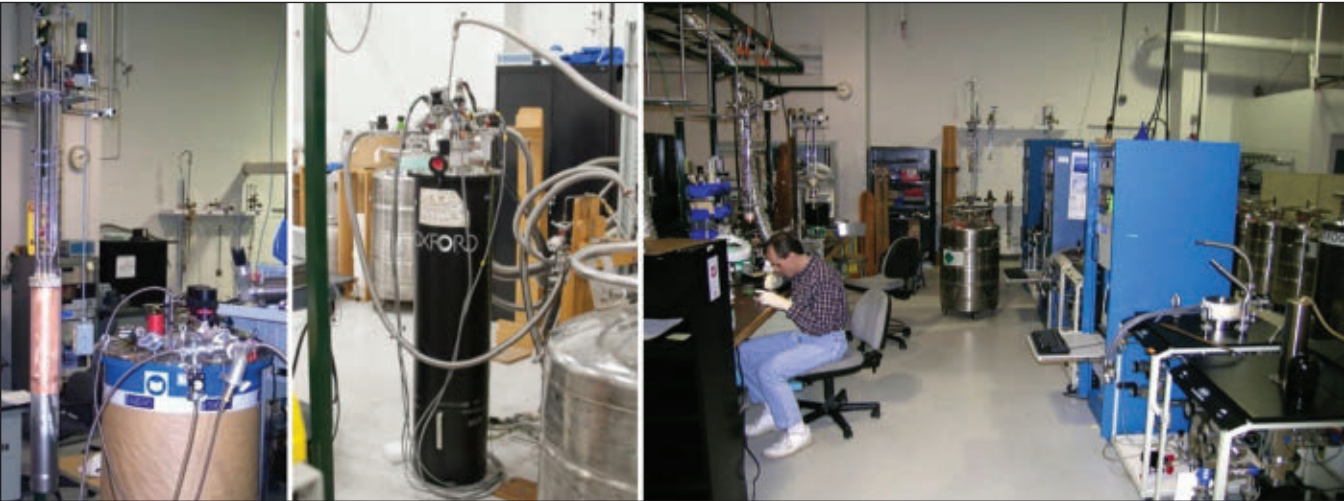


▲ Fig. 1 Noise reduction circuitry design used in AC resistance bridges (US Patent 6,501,225).

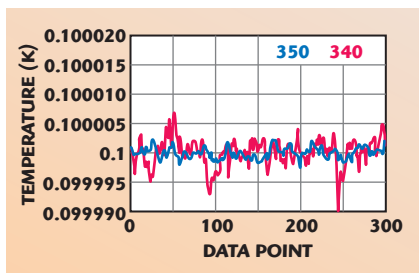
TABLE I SENSOR EXCITATION POWER VS. SELF-HEATING TEMPERATURE OFFSET FOR CERNOX™ CX-1010 SENSOR			
Excitation Current/Voltage	Sensor Resistance	Sensor Power	Self-heating Offset
10 nA	30 k Ω	3 pW	6 mK at 100 mK
30 nA	30 k Ω	27 pW	54 mK at 100 mK

TABLE II MEASURED NOISE				
Baseline (at 100 mK)	Sensor Power	Noise Measured/ Specification ¹	Noise ²	
Model 350 (10 nA)	3 pW	2.2 Ω /4.5 Ω	3.9 μ K	
Comparison (at 100 mK)	Sensor Power	Noise Measured/ Specification ¹	Noise ²	Adjusted Noise ³
Model 350 (30 nA)	27 pW	0.7 Ω /1.3 Ω	1.3 μ K	3.9 μ K
Older Model 340 (30 nA)	27 pW	1.3 Ω /1.3 Ω	2.4 μ K	7.2 μ K

¹RMS noise specification with 0.5 s filtering
²Temperature equivalence calculated from the typical sensitivity of a Cernox sensor at 100 mK (-558,110 Ω /k)
³Adjusted temperature converts measured noise to a 10 nA equivalent (noise \times 3). Shows how the Model 340 would compare if it could operate at 10 nA. Note that although noise levels would be higher, self-heating errors would be reduced.



▲ Fig. 2 Cryogenic sensor calibration facility.



▲ Fig. 3 Sensor readings in test comparing Model 350 with older Model 340 (30 kΩ, 30 nA).

at 100 mK, which was the target temperature for this test.

Table 1 shows the power and resulting self-heating offsets at excitation currents of 10 and 30 nA when using this sensor, illustrating the importance of excitation power and sensor selection. A typical Cernox CX-1010 sensor has a thermal resistance R_{TH} at 100 mK of about 2×10^9 K/W, and can have an electrical resistance R_e from 5 to 100 kΩ. Self-heating offset (ΔT_{SH}) depends on the excitation power P_s according to the equation $\Delta T_{SH} = P_s R_{TH} = I^2 R_e R_{TH}$.

The new Model 350 is designed to work well with Cernox sensor resistances at 10 nA, with minimal self-heating. Under normal circumstances, this 10 nA current range would be used for measurement at 100 mK, and the resulting 6 mK offset is comparable to the total 5 mK uncertainty of a Cernox sensor. At the higher 30 nA excitation current, as was required in the comparison test, higher self-heating would be expected, but those effects would be consistent between the controllers. Lower sensor resistances could have been selected, but would have resulted in reduced sensitivity at the target temperature.

For this comparison, 300 data points were taken and the standard deviation was calculated to give an estimate of the typical RMS noise. The instruments were set to a 0.5 s filter with a sample rate of 10 Hz. This filter reduced the noise by about 2.24 (i.e., $\sqrt{5}$) for both the new Model 350 and the older model alike. **Figure 3** shows the measurements from the comparison test, and clearly shows the improved noise performance of the Model 350 over the previous Model 340 controller.

Table 2 summarizes the measured results and shows the actual noise measured versus each instrument's documented specifications. Noise

measured (Ω) reflects the uncertainty in sensor resistance as measured by the instrument. The older Model 340 met its specification, while the Model 350 thoroughly beat its published specification – additional confirmation of the ability to successfully apply the new controller in extreme conditions.

Overall, the Model 350 demonstrated about half the input noise of its predecessor as a result of the updated

circuitry. With this ability to use significantly lower excitation power, self-heating errors are reduced enabling higher measurement resolution speed and control stability.

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Broadband Limiter

Mini-Circuits has developed an ultra-wide frequency power limiter. The CLM-83-2W+ is an RoHS-compliant limiter, which protects against ESD and input RF power surges, up to 1.6 W, across a very wide frequency range. Its internal diodes are bonded to a multilayer integrated LTCC substrate and then hermetically sealed under a controlled nitrogen atmosphere with gold plated covers and eutectic AuSn solder. The terminal finish on the tiny, low-profile case is Ni-Pd-Au.

These rugged, tiny limiters, only 0.12" × 0.12" × 0.045", provide excellent protection for low noise amplifiers and other sensitive equipment, especially in hostile environments where unwanted signals prevail, such

as manufacturing sites, train tunnels and ECM and ECCM.

The CLM-83-2W+ key features include:

- Limiting abilities from +12 to +32 dBm to protect against very strong undesired signals to help prevent burn out of amplifiers and other highly sensitive components.
- Ultra wideband, from 30 to 8200 MHz, to protect against many different types of unwanted signals.
- Tiny surface mount, useful in crowded PCB boards where space is at a premium.
- Ceramic, hermetic, nitrogen filled construction, to protect against moisture, for long term reliability.
- A response time of 2 ns to react instantaneously to limit unwanted

high level signals.

- A recovery time of 8 ns as a minimal downtime, after unwanted signals are removed, with quick restoration of standard operating levels.
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Centellax announced that its line of microwave products, including ultra-broadband amplifier MMICs die, test equipment and military systems, frequency dividers and prescalers, and broadband amplifier modules, can now be ordered online from www.centellax.com. Customers can place orders at any time, through a secure online ordering gateway (128 bit SSL). Payment is made using American Express, MasterCard or Visa. Order minimum is \$250.00 for online purchases. A Centellax customer service team member will contact you within one business day regarding your order status.

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Chinese Language Website

Emerson Network Power Connectivity Solutions launched its new Chinese language website on emersonconnectivity.com. The site went live in September and provides product and brand awareness throughout China, a target and rapidly developing market for the company. The new site provides users with a comprehensive overview of Emerson Connectivity Solutions, including product features, news and events, product search functionality, press releases, datasheets and installation instructions. Visitors to the site will also have immediate access to regional sales contacts and distributor firms within the region.

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New Website

Interference Technology launched its new website, which features a comprehensive EMC Buyers' Guide and a channel focused entirely on European content. In addition to the enhanced search functions for archived technical articles, the new website organizes news, articles, standards, and product information according to a dozen EMC technologies, from filters and ferrites to antennas and amplifiers, as well as related to specific EMC markets, such as automotive, military or telecom. This new layout according to product and market channels simplifies the search experience.

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www.interferencetechnology.com



RF Coaxial Connector Website



San-tron announced major improvements to its website, including a faceted search empowered product finder which pulls from San-tron's extensive library of RF and microwave coaxial connectors and adapters and cable assemblies. The site also offers an expanded Knowledge Center and details on San-tron's latest SRX™ low PIM cable assemblies and adapters. The Knowledge Center offers a variety of videos, engineering tools and detailed documents to help visitors learn more about San-tron's products and how to incorporate them into their designs with optimum results.

San-tron Inc.

www.santron.com



Richardson RFPD Homepage



Richardson RFPD launched its redesigned website homepage. The new design offers more direct, one-click access to Richardson RFPD's portfolio of products and industry-leading suppliers, best-in-class design support, and purchase options. The new homepage includes a scrollable, linked list of suppliers; design support quick-links to block diagrams, application notes, white papers and more; new product and featured supplier highlights; and a Quick Buy form where customers can easily enter a part number to obtain a quote or buy a part.

Richardson RFPD Inc.

www.richardsonrfpd.com



New Products

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE

FEATURING **VENDORVIEW** STOREFRONTS

Components

Fixed Attenuators



Aeroflex/Inmet's improved 100 W fixed attenuators are ideal solutions for high power PA testing, load simulation and many other test environments.

Inmet's 6N100W-XX operates from DC to 6 GHz, has excellent attenuation accuracy (30 dB \pm 1.5 dB) and a VSWR of less than 1.45:1. They are available in standard values of 3, 6, 10, 20, 30 and 40 dB and with Type N, SMA, 7/16 DIN or TNC connectors. Other dB values and custom connector configurations are available as options.

Aeroflex/Inmet,
www.aeroflex.com.

Phase Adjusters

The Coaxicom 3993 series of phase adjusters from Coaxial Components Corp. are designed to deliver a means of phase adjustment over frequency ranges up to 18 GHz. The 3993-1 SMA RF phase adjustable adapter has an adjustment range of 180° minimum and a maximum VSWR, with insertion loss of 1.30:1 and 0.42 dB, respectively. The 3993-2 and the 3993-3 are phase adjustable connectors with SMA plugs for direct solder to 0.141" and 0.086" semi-rigid cable or COAXICOM ULTRA-FLEX, respectively.

Coaxial Components Corp.,
www.coaxicom.com.

Hopping Filters



Lark Engineering offers a full line of low cost frequency agile filters (hopping filters) from 1.5

MHz to 1 GHz available in three surface mount housings (leadless). Tuning is voltage controlled or using an 8 bit parallel interface, allowing 254 tune words for frequency control. Lark's hopping filters are available with bandwidths from 4 to 20 percent with a 3 to 30 dB shape factor of 7:1. Applications include ground, shipboard and airborne environments.

Lark Engineering,
www.larkengineering.com.

Temperature Sensor



Linear Technology introduced the LTC2996 high accuracy temperature sensor for 2.25 to 5.5 V systems. The LTC2996

measures a remote diode's temperature with $\pm 1^\circ\text{C}$ accuracy and its own die temperature

with $\pm 2^\circ\text{C}$ accuracy while rejecting errors due to noise and series resistance. The device provides a voltage-proportional-to-absolute-temperature (VPTAT) output, as well as individual under temperature and over temperature alert outputs, defined by user-adjustable thresholds. No code is required to configure the device. With a 200 μA quiescent current, the LTC2996 provides a precise, space-saving, micropower temperature monitoring solution.

Linear Technology Corp.,
www.linear.com.

Unequal Power Splitters



MECA launched a line of unequal power splitters or tappers, developed to unevenly split high power signals for in-building DAS applications and designs. The line consists of six models offering a 2, 3, 4, 6, 8, or 10:1 signal-split ratio, over 698 to 2700

MHz (cellular, PCS, AWS, and BRS/EBS frequencies) and feature low PIM ratings (better than -150 dBc), with ultra-low VSWR and minimal coupling variation over the entire frequency band. They handle high power levels of 300 W (CW) and have an operational temperature range of -55° to $+85^\circ\text{C}$.

Microwave Electronic Components of America (MECA),
www.e-meca.com.

Conductor Cables



Florida RF Labs has expanded its line of stranded center conductor cables Lab-Flex® S, a modified version of the Lab-Flex® high performance

flexible cable assemblies. Lab-Flex S cables offer higher flexure rates and durability than solid center conductor designs. They have stainless steel connectors and employ a unique solder sleeve which provides the strongest cable to connector termination in the industry. With cable designs up to 65 GHz, there is a large selection of connector interfaces and configurations including: 1.85mm, 2.4mm, 2.92mm, SMA, TNC and Type N.

Florida RF Labs,
www.emc-rflabs.com.

Frequency Mixer



er. The LVI-452VH+ features very high IP3 (33 dBm typical), excellent L-R isolation (45 dB typical) and L-I isolation (40 dB typical), and high 1 dB compression (20 dBm typical). It has

Mini-Circuits introduced its high IP3 Level 23 (LO power +23 dBm) 3220 to 4500 MHz frequency mixer.

a shielded metal cover, is aqueous washable and is protected by U.S. Patent 6,807,407. It has an operating temperature of -45° to 85°C and a storage temperature of -55° to 100°C .

Mini-Circuits,
www.minicircuits.com.

Power Divider



Narda Microwave-East introduced a high-power, two-way power divider that operates from 500 MHz to 2.5 GHz and

handles up to 250 W CW input power (2 kW peak power). Model 2372A-2 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 and 18 dB from 700 MHz to 2.5 GHz, and VSWR of less than 1.5:1. It measures $3.5" \times 2.5" \times 1"$.

Narda Microwave-East,
www.nardamicrowave.com/east.

Solid-State Switch



PMI model P2T-14D415D4-15-SMT-20W is a driverless, 20 W, SP2T solid-state switch that is supplied in a compact package designed



for surface mount applications. This switch operates from 14.4 to 15.4 GHz and has an insertion loss of 1.2 dB maximum at $+25^\circ\text{C}$. The Tx/Rx isolation

is better than 10 dB and this switch can handle input power levels up to 20 W. The switch measures only $0.35" \times 0.5" \times 0.21"$. Other frequency ranges are available.

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

Hybrid Couplers



RFMW announced design and sales support for Florida RF 0805 hybrid

couplers. These miniature couplers handle RF power up to 5 W CW and have greater thermal conductivity than comparably sized options. Standard applications include LNA circuits where a balanced topology using a hybrid coupler provides a higher intercept point than a single stage, offering increased sensitivity and therefore range. The hybrids can also be used in final stage amplifier circuits for pico cells and indoor repeaters. Five models cover the major commercial spectrum from 700 to 3700 MHz.

RFMW Ltd.,
www.rfmw.com.

New Products

Hybrid Coupler VENDORVIEW

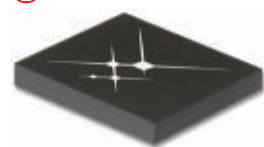


Richardson RFPD announced immediate availability and full design support capabilities of a new 400 W SMT hybrid coupler and matching termination from Anaren. Part of the

Xinger®-III line, the X3C06A4-03S is a low profile, high performance 400 W, 3 dB hybrid coupler for two-way power combining/dividing in a small, easy to use surface mount package that can easily replace bulky, drop-in couplers. The X3C06A4-03S covers 410 to 860 MHz and is well-suited for UHF broadcast and RF plasma lighting applications.

Richardson RFPD Inc.,
www.richardsonrfpd.com.

Single-Pole Double-Throw Switch VENDORVIEW



Skyworks introduced a very high isolation (>60 dB) yet low loss (0.8 dB) single-pole double-throw switch

with integrated 50 Ω terminations and broadband operation to 6 GHz. The cost-effective SKY13372-467LF targets cellular infrastructure applications requiring feedback and filter-bank switching where low loss and high channel to channel isolation performance is required. The new switch is also ideal for military communication and various RF test and measurement applications. It is pin-to-pin compatible with Skyworks' existing high isolation SPDT switch: SKY13286-359LF.

Skyworks Solutions Inc.,
www.skyworksinc.com.

Power Doublers



TriQuint introduced two new high performance 12 V infrastructure power doublers: the TAT2801 and TAT8801A1H. Both are ideally suited for line extender output amplifier and distribution node amplifier designs.

The TAT2801 provides exceptionally high output and linearity for DOCSIS 3.0 Edge QAM and cable modem termination system (CMTS) applications. It has the highest linearity of the two new doublers. The cost-effective TAT8801A1H is designed to meet most line extender output level requirements through its optimal performance and low power consumption.

TriQuint Semiconductor Inc.,
www.triquint.com.

Waveguide Modules



Vubiq announced new 60 GHz transmitter and receiver integrated waveguide modules. Features include small size, complete transmitter and receiver

functions with connectorized interface for I/Q signal inputs and outputs, power and reference clock. RF connection is via WR15 waveguide flange. 57 to 64 GHz frequency coverage; Tx output of 10 dBm; and Rx noise figure of 6 dB. Fully integrated SiGe BiCMOS Tx and Rx in an easy to use waveguide module package. Also available: complete development system with GUI software.

Vubiq Inc.,
www.vubiq.com.

Multipliers



Wright Technology introduced broadband frequency operation multipliers with improved harmonics and

low input drive, with increased output power available. Model ASX20-220 has an input frequency of 8.75 to 9.75, output frequency of 17.5 of 19.5, 10 dBm minimum Pin, 20 dBm minimum Psat out, -20 dBc maximum harmonics, -60 dBc typical spurious, and 400 DC mA typical at +12 VDC.

Wright Technologies Inc.,
www.wrighttec.com.

Amplifiers

GaN Amplifier

Model SSPA 2.9-3.1-300 is a high power, pulsed or CW GaN RF amplifier that can be employed throughout the S-Band frequency range. It is



optimized for operation from 2.9 to 3.1 GHz. The devices in the amplifier are not matched, therefore it can operate from

2.7 to 2.9 GHz or 2.7 to 3.5 GHz with similar performance. This amplifier operates with a base plate temperature of -40° to +85°C. It is packaged in a modular housing that is approximately 5" (width) \times 8" (long) \times 1.94" (height).

Aethercomm Inc.,
www.aethercomm.com.

Single Band Amplifiers



Model 15S1G6 and 50S1G6 are single band 15 and 50 W amplifiers that cover the 1 to 6 GHz frequency band.

The ability to use one band instead of two means you use less power, and don't require the amplifiers to be switched from one band to the other to perform the required tests. Along with excellent performance, it has a remote interface standard (a feature that is an extra with competitive amplifiers), a lower noise figure, and an exceptional output VSWR of 1.5:1.

AR RF/Microwave Instrumentation,
www.arworld.us.

Transimpedance Amplifier

The MATA-038032A is a dual channel differential linear TIA with AGC for 100G DP-QPSK (32 Gbps \times 4) receivers. Each channel has dif-

ferential input and output. It offers both manual and automatic gain control modes. In manual mode the gain can be controlled from 200 Ω to 5 K Ω differential via an external pin. In automatic mode, the gain is automatically adjusted to provide a constant output voltage. The TIA provides a linear amplification for current levels from 0.1 to 2 mA differential and has adjustable bandwidth between 17 and 25 GHz.

M/A-COM Technology Solutions Inc.,
www.macomtech.com.

Low Noise Amplifier



The AMFW-4F-12401800-25-18P-WR62F is a very low noise, high dynamic range weather-proof Ku-Band waveguide front end, operating



12.4 to 18 GHz. It includes a pressure sealed WR62 waveguide input and SMA (F) connector output.

The LNA is lightweight with a small profile and footprint, the aluminum alloy housing is sealed against most severe environmental conditions. It includes reverse voltage, over current and over temperature protection in addition to full internal regulation. Total weight is approximately 270 g, and dimensions are 2.1" \times 1.31" \times 1.31".

MITEQ Inc.,
www.miteq.com.

Power Amplifier



RFMD's new RFPA2089 is a single-stage In-GaP HBT power amplifier specifically designed for wireless infrastructure applications. It offers



high-gain linear operation at a comparably low DC power making it ideal for next generation radios requiring high efficiency. Its external matching allows

for use across various radio platforms. It features -60 dBc ACPR at 13 dBm WCDMA, 0.25 W OP1dB, 17.6 dB gain at 2.65 GHz, single-supply 5 V operation and class 2 (2000 V) HBM ESD.

RF Micro Devices,
www.rfmd.com.

Sources

Clock Generators



The HMC1033LP6GE and the HMC1035LP6GE offer programmable frequency synthesis from 25 MHz to 2.5 GHz in both integer and fractional relationships to their reference clocks. The HMC1033LP6GE is ideal for clocking



DSP, FPGA and high performance processors as well as physical layer devices, and operates from 25

to 550 MHz. The HMC1035LP6GE is de-

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aluminum cases house our patented mechanical switches, the only ones available anywhere, at any price, that offer up to 10 years/100 million cycles of guaranteed performance.[†] Just go to minicircuits.com for technical specifications, performance data, pricing, and real-time availability—or give us a call to discuss any custom programming needs—and think how much time and money you can save!

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Model	# Switches (SPDT)	IL (dB)	VSWR (:1)	Isolation (dB)	RF P _{MAX} (W)	Price \$ (Qty. 1-9)
USB-1SPDT-A18	1	0.25	1.2	80	10	385.00
USB-2SPDT-A18	2	0.25	1.2	80	10	685.00
USB-3SPDT-A18	3	0.25	1.2	80	10	980.00
USB-4SPDT-A18	4	0.25	1.2	80	10	1180.00
NEW USB-8SPDT-A18	8	0.25	1.2	80	10	2495.00

* See data sheet for an extensive list of compatible software.

[†] The mechanical switches internal to each model are offered with an optional 10 year extended warranty. Agreement required, see data sheets on our website for terms and conditions. Switches protected by patents 5,272,458 6,650,210 6,414,577 7,633,361 7,843,289 and additional patents pending.

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Passive Components and Antennas

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Emerging RF and Microwave Technologies

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Paper Due: January 15, 2013
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New Products

signed to meet the stringent requirements of high speed data converters (ADC/DAC) with excellent phase noise floor performance of -162 dBc/Hz, and operates from 25 MHz to 2.5 GHz.

Hittite Microwave Corp., www.hittite.com.

DFRM



NEL Frequency Controls announced the release of the dual frequency reference module (DFRM). The new module consists of two ultra low phase noise OCOs at 10 and 100 MHz that are phase locked together to provide a fully characterized "plug and play" solution. The DFRM provides customers both low frequency (10 MHz) and intermediary frequency (100 MHz) references in their applications to frequency lock with each other. This solution is integrated in a module with optimized phase noise performance.

NEL Frequency Controls, www.nelfc.com.

Coaxial Noise Source



NoiseWave announced the NW2G-CS coaxial noise source. The unit is available in 6, 15 and 30 dB ENR and features a small profile housing of 0.75" by 0.5" by 1.25" excluding connectors. It has flatness better than ± 1 dB over the

frequency range 10 kHz to 2 GHz and comes with calibrated cardinal ENR frequencies. The NW2G-CS is available with a variety of connectors. Standard operation is from +28 V DC with a 20 mA maximum current draw.

NoiseWave, www.noisewave.com.

Software

Compliance Testing Software



Agilent announced the industry's only test suite for compliance testing of computer and embedded DDR2/3/4 and LPDDR2/3 memory applications. With this software suite and an Agilent logic analyzer, digital designers can monitor DDR2/3/4 or LPDDR2/3 systems in real time to identify elusive, intermittent violations in protocol or bus-level timing. The new software allows users to customize tests, either by adding to existing test groups or by defining unique test groups of valid logic analyzer triggers for protocol or bus-level timing violations.

Agilent Technologies Inc., www.agilent.com.

Test Equipment

Frequency Sources

Berkeley Nucleonics commercially released a full line of high performance, robust, and extremely cost effective RF/microwave signal generators. The line sets a new standard in performance to cost. Capable of



producing in excess of 20 GHz, with very low phase noise, fast switching speeds and extensive modulation capabilities in a variety of packaging options, including bench-top, portable battery operation, 1U 19" rackmount and card-level for OEM integration. These instruments offer a wide array of options to meet almost any application requirement.

Berkeley Nucleonics Corp., www.berkeleynucleonics.com.

Wireless Test Set



Anritsu introduced the MT8870A universal wireless test set with manufacturing test capability for up to eight UE devices in a single mainframe without the need for external switching. The tester's basic module includes an integrated VSA, VSG and

New Products

multi-core processor, and users can configure a mainframe with up to four modules with four VSAs and four VSGs, depending on test requirements. Combining this high-density test capability with the latest parallel TX/RX calibration and verification test modes enables high-speed production test throughput and highly flexible line layouts.

Anritsu Co.,

www.anritsu.com.

Temperature Measurement

The FOTEMP1-OEM-MNT measures temperature in high electromagnetic interfered environments and other environments where



measurement with common electric temperature sensors is not possible. The sensor is completely non-conductive, with an outer jacket

made from PTFE and a GaAs-crystal sensor tip. It is designed to withstand harsh and corrosive environments. Since the position of the band gap is temperature dependent, it shifts about 0.4 nm/Kelvin. The measurement device contains a light source and a device for the spectral detection of the band gap.

OPTOcon AG,

www.optocon.de.

Vector Signal Generator

VENDORVIEW



Rohde & Schwarz has enhanced its fully integrated R&S SGS100A by adding a model for I/Q modulated signals from 80 MHz to 12.75 GHz. Combined with an I/Q baseband generator, the instrument can be used to generate test signals for all radio standards in this frequency range. The I/Q modulator's wide RF bandwidth of 1 GHz makes it possible to generate pulses with high chirp bandwidths and steep pulse edges.

Rohde & Schwarz GmbH & Co. KG,

www.rohde-schwarz.com.

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- AVOZ-D2-B: for production testing attenuators
- AVR-DV1-B: for phototriac dV/dt tests

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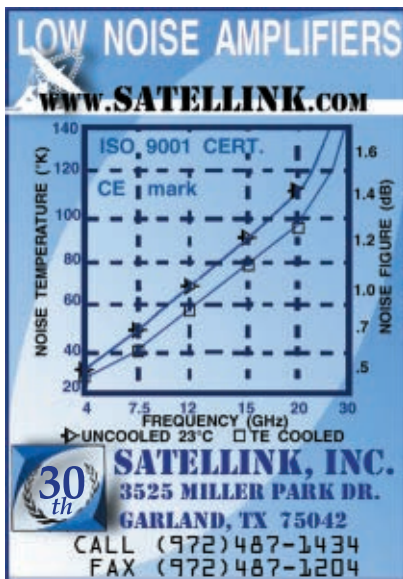
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The Book End



Green Radio Communication Networks

Edited by Ekram Hossain,
Vijay K. Bhargava and
Gerhard P. Fettweis

As Gerhard Fettweis authored our cover story this month on a vision for 5G networks of the future, it is only fitting that we review a book co-authored by him, *Green Radio Communication Networks*. The importance of reducing energy costs, reducing CO₂ emissions and protecting the environment are leading to an increased focus on green, energy-efficient approaches to the design of next-generation wireless networks. At the same time there is great pressure to reduce operational expenses for network operators.

The information and communications technology industry sector accounts for about 2 to 6 percent of the energy consumption worldwide and a significant amount of this is wireless/

mobile communications, according to the book preface. *Green Radio Communication Networks* presents state-of-the-art research on green radio communications and networking technology by leaders in the field. Summarizing existing and ongoing research, the book consists of articles covering different aspects of green cellular radio communications and networking issues that include network architecture; performance models for green radio networks including energy-harvesting wireless networks; physical communication techniques for green radio, including novel modulation and coding techniques and joint physical and medium access control optimized techniques; dynamic power-management/energy-conservation techniques for base stations in cellular wireless networks; relaying and user cooperation techniques and energy-cognizant wireless protocols for green radio communications; and standardization initiatives,

test-beds, prototypes, practical systems and case studies.

Green Radio Communication Networks is written for researchers and professionals working in wireless communication and one of the first books written in this area of study. It is a good reference for key concepts and design techniques for energy-efficient communications and networking and provides information for the design of future-generation cellular wireless systems.

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2013 Microwave Wireless Industry Exhibition in China (MWIE 2013)

2013 National Conference on Microwave and Millimeter Wave

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2013 Microwave Wireless Industry Exhibition (MWIE2013) and 2013 National Conference on Microwave and Millimeter Wave in China (NCMMW2013) will be held in Xuehao Hotel, Chongqing, China, in 21~23 May, 2013.

NCMMW2013 is China's largest conference on microwave and millimeter wave technologies. It is organized by Chinese Institute of Electronics (CIE) and held every two years (every odd year).

MWIE has already been held for over 10 years. It is one of most important events of the National Conference on Microwave and Millimeter Wave in China held every odd year, and the International Conference on Microwave and Millimeter Wave Technology held every even year.

MWIE2013 will be another grand exhibition after "MWIE2012" in Shenzhen, "MWIE2011" in Qingdao, "MWIE2010" in Chengdu, "MWIE2009" in Xi'an, "MWIE2008" in Nanjing China!

Date: May 21~23, 2013

Venue: Xuehao Hotel, Chongqing, China



"9th Committee Enlarged Conference of Microwave Society of Chinese Institute of Electronics" will be held during the period of MWIE2013. Nearly 80 Committee members from institutes, universities and companies of all parts of China will attend the conference and visit the exhibition. This is the best chance to let Chinese people know your company and products; exhibit in MWIE2013 is the best choice for your products to enter Chinese market.

Exhibitors to be attended:

Manufacturers / distributors for RF / microwave / millimeter wave devices / components: solid state device and circuits (including mmic): amplifiers, mixers, oscillators, etc. and passive components: filters, duplexers, couplers, attenuators, and antennas etc

Designer / distributor for RF / microwave / millimeter wave software

Manufacturers / distributors for RF / microwave / millimeter wave equipments

Manufacturers / distributors for RF / microwave PCB and connectors

Manufacturers / distributors for microwave absorber

Manufacturers / distributors for microwave / millimeter inductor, capacitor and high power resistor

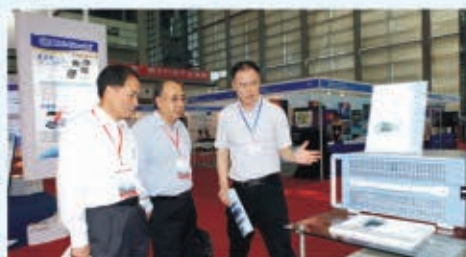


Why you should attend?

MWIE2013 is the largest event of microwave, millimeter wave and RF field in China, which is sponsored by Microwave Society of Chinese Institute of Electronics. MWIE 2013 is where to provide a platform for enterprises engaged in microwave, millimeter wave and RF field to publicize your company/ products in China.

MWIE 2013 will provide a chromatic page of introduction for each exhibitor in List of Exhibitors, which is free.

MWIE 2013 is where to provide a nice opportunity for the scientists and engineers specialized in the field of microwave and millimeter wave to present your new ideas and learn from each other.



MWIE 2012



Please visit :

www.cnmw.org www.cnmw.cn

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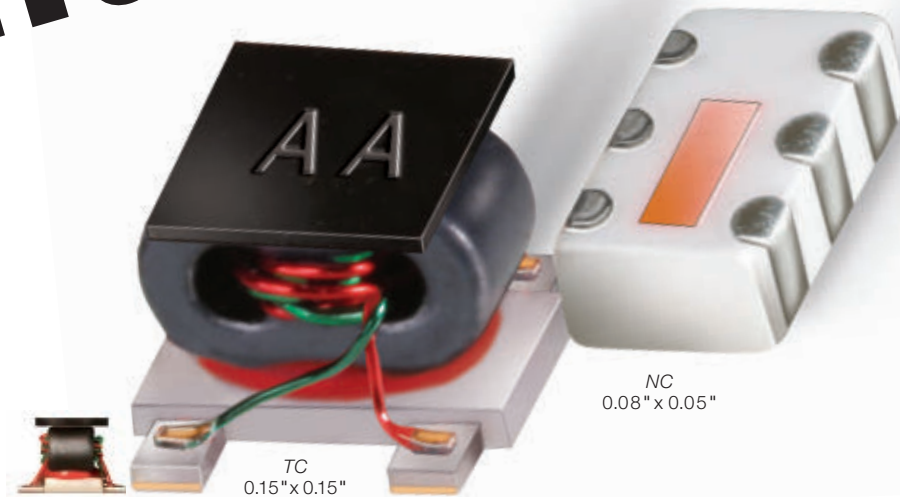
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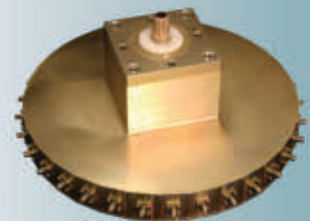
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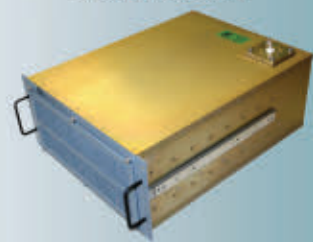
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