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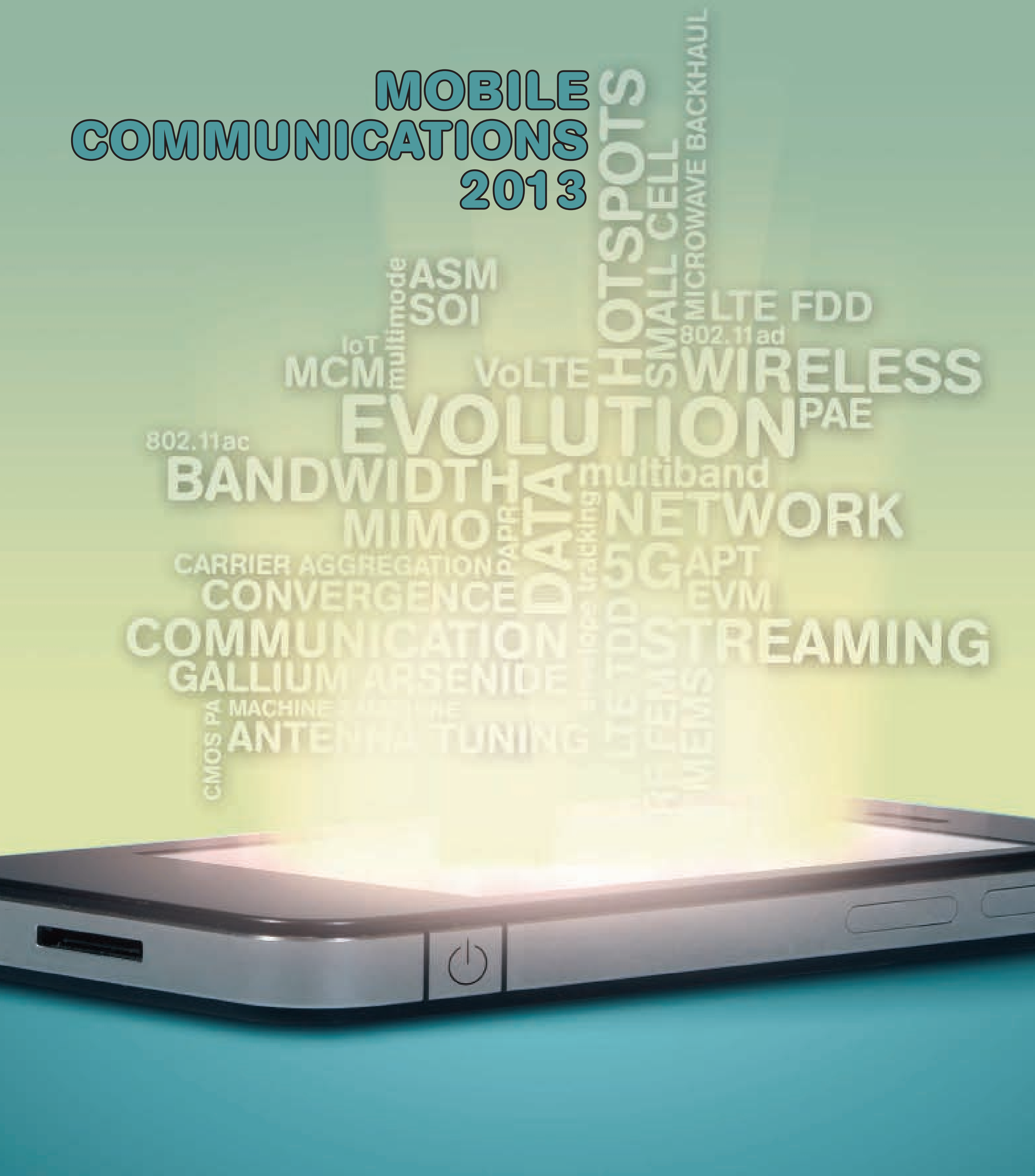

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The Economics of GaAs and CMOS PAs: Crunch Time

The Qualcomm RF360 envelope tracking power supply hit production during the past couple of months, in the Samsung Galaxy Note 3. The funny part was that it is not attached to the Qualcomm CMOS power amplifier. Instead, the Qualcomm Power Management IC drives a GaAs PA supplied by Avago.

To old radio guys like me, the rise of CMOS power amplifiers brings back memories of the first integrated CMOS transceivers for mobile handsets. Back in the 1980s, with AMPS cellular systems, the handset used discrete components in the transceiver. By the 1990s, when 2G systems were starting to ramp up, baseband modem suppliers suggested a migration to CMOS transceivers.

In 1993, many RF engineers laughed at the idea of an integrated CMOS transceiver. Comments like "You're going to sacrifice sensitivity" or "You won't get enough linearity in your front end" were common. But here we are. Twenty years later, it is impossible to find a discrete handset transceiver anywhere in the world.

It is true that the systems engineers sacrificed noise figure and linearity and a few other metrics to achieve the flexibility and low cost of CMOS transceivers. But the benefits of 2G standards (coding gain for CDMA, or wider FM bandwidth for GSM) made up for these sacrifices and it worked out okay.

We will see the sequel to this movie with CMOS power amplifiers. We have seen CMOS PAs take over the constant-envelope GSM market, at price levels that GaAs products will not match. A few 3G handsets now include CMOS PAs, and the battle has begun.

TECHNICAL COMPARISON

There's no doubt that GaAs performs better. As Peter Gammel illustrated in the August issue of *Microwave Journal*, GaAs has a performance advantage in both efficiency and linearity, resulting in roughly 10 percentage points better efficiency with other factors held constant. Especially for waveforms with a high peak-to-average ratio, the combination of power, linearity and efficiency is inherently better due to physical attributes of the semiconductor material.

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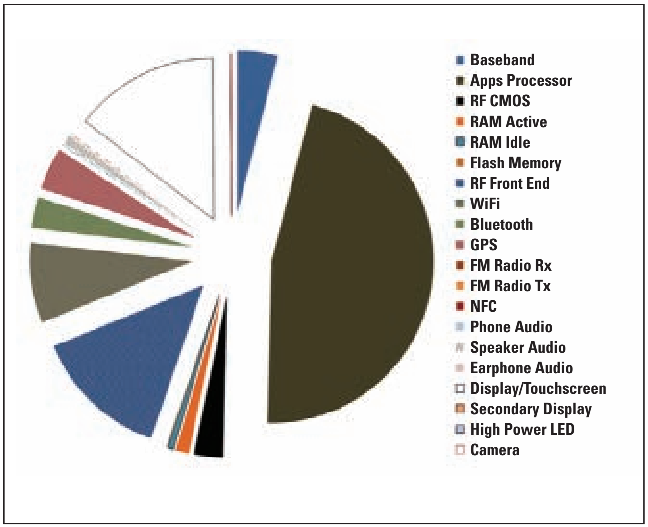


Fig. 1 Breakdown of power consumption in a typical LTE smartphone, urban case, business user.

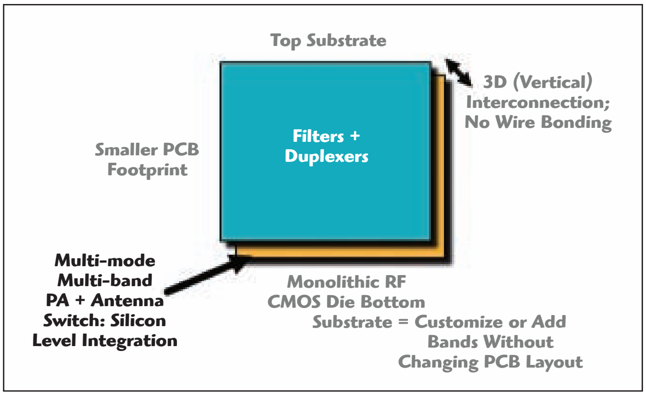


Fig. 2 Qualcomm RF360 CMOS RF front end module.

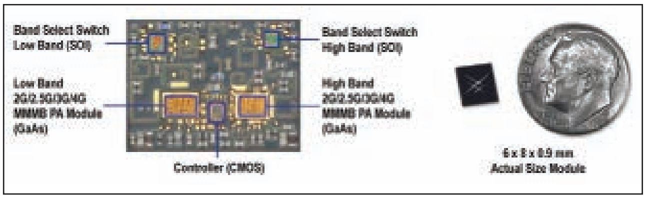


Fig. 3 Skyworks SkyOne™ system in package.

Recently, mobile terminals have started to use multi-mode, multi-band power amplifiers (MMPA) which cover a much wider operating bandwidth than single-band PAs. This is just one more design constraint that limits efficiency/linearity improvement for both CMOS and GaAs.

To continue the improvement, almost all PA suppliers and handset OEMs are investigating envelope tracking (ET). Put simply, ET involves a fast power supply that ramps the voltage rail for the amplifier along with the modulated waveform. As peak power requirements spike up, the supply voltage ramps up. The idea here is to only provide the power that is necessary at any instant in time. CMOS amplifiers are now emerging that use ET to achieve performance roughly on par with non-ET GaAs amplifiers. At the same time, GaAs amplifiers with ET provide excellent efficiency performance. The Samsung Galaxy Note 3, launched during September, uses a Qualcomm ET power supply, with a GaAs PA from Avago in order to achieve a longer battery life.

PERFORMANCE THAT IS "GOOD ENOUGH"

Better performance is always desirable. But at some point, performance for a PA can be "good enough" for a segment of the market. We have seen that already for the GSM market, where CMOS has taken over despite performance tradeoffs. With the arrival of ET, several modem suppliers are betting that CMOS is now "good enough" for some 3G and LTE applications.

From a cost point of view, CMOS PAs are generally perceived as lower cost. Are they? This question has been largely theoretical for several years, but during the past six months, the idea has been subjected to a real-world test. RFMD acquired Amalfi Semiconductor in November 2012 and found that initially the manufacturing cost was too high. However, with a redesign of the CMOS PA to utilize RFMD's streamlined assembly and test facilities, the RFMD CMOS PA will achieve a cost far lower than previous GaAs products. Extending this to 3G and 4G products will take more work, but one initial proof-of-concept is now established.

HOW IMPORTANT IS A 10 PERCENT ADVANTAGE IN PA EFFICIENCY?

Battery life is important to mobile operators, but as multi-core apps processors and large displays have taken over the smartphone market, the RF section of the handset consumes less of the total power. In the Mobile Experts Battery Life Model, the RF front end represents between 14 and 20 percent of the power consumed in a smartphone, accounting for the typical distribution of LTE transmit power levels in an urban network and the losses of a complex multi-band RF front end (see ***Figure 1***). That means that 10 percentage points in PA efficiency results in about four percent longer battery lifetime for a heavy smartphone user, or about half an hour.

In the high-end smartphone market, half an hour is still a worthwhile level of differentiation, so Mobile Experts forecasts that these markets will use GaAs for quite some time. With simpler 3G handsets in cost-sensitive markets, the cost/benefit decision is not yet clear.

RF INTEGRATION

A Complete Front End (CFE) – like Qualcomm's RF360 (see ***Figure 2***) or the Skyworks SkyOne product line (see ***Figure 3***) – represents a single module which addresses all of the RF devices between the transceiver and the antenna. The power amplifiers, filters and duplexers, switches, and antenna mismatch tuning can all be included in the module. This makes life easy for the customer, and in some cases the CFE can save space in the handset. As a result, the CFE is likely to capture a significant portion of the handset market.

On the other hand, the high end of the market is unlikely to benefit much from the CFE. The latest iPhone 5s and the Galaxy S4 are very complex, customized products. Integrating everything into a single module (and concentrating production with a single vendor) increases risk and time to market for the major smartphone vendors.

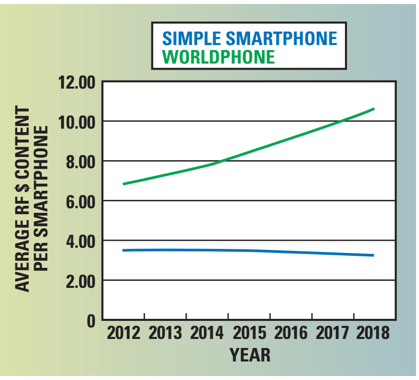


Fig. 4 *Average dollar content for RF per smartphone.*

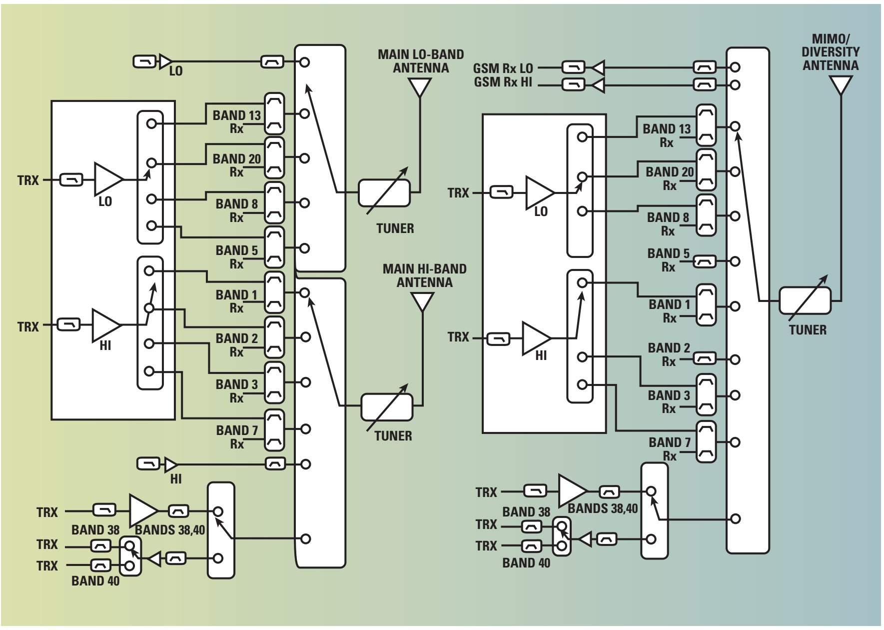


Fig. 5 *An example of the level of customization in a multi-band "worldphone."*

From an RF vendor's point of view, the investment of R&D resources into any RF project is a bet that the resulting product will be useful. A multidisciplinary CFE project can cost $10M or more in R&D expense. No single handset product achieves enough volume to make the R&D cost worthwhile. Because of the straightforward economics of return on investment, any semiconductor vendor will focus CFE development on the most common mainstream applications. The ROI decision can be illustrated with two case studies:

Economics of an Entry Level 3G Smartphone

A CMOS-based CFE with integrated duplexers and filters, covering quad-band GSM and a single 3G band would be useful in at least 40 different handset models. This kind of simple CFE could reach a volume of 100 million units per year, with a long product life cycle. The R&D investment of about $10M would be amortized over 300 million units, reducing the cost burden to three cents per unit.

Of the 2.2 billion handsets produced this year, 1.7 billion are feature phones, simple smartphones with three data bands or fewer, PC dongles, tablets or M2M modems. Most of the industry focus falls on the high-end smartphones, because smartphones with four or more data bands (worldphones) are the most complex and challenging applications. Today, 84 percent of handsets have three or fewer data bands. CMOS-based CFEs are targeted at this market (don't listen to all the hype to the contrary). Mobile Experts predicts that the RF dollar content in an entry-level smartphone will decline over the next few years (see ***Figure 4***).

Economics of a Single-SKU "Worldphone"

A CFE covering 12 different data bands (plus quad-band GSM) represents a much higher level of R&D investment, with a complex filter bank and a multi-mode multi-band amplifier in addition to switching and possible antenna tuning (see ***Figure 5***). Creating this kind of CFE module could cost $40M or more in R&D expense. Then, the production run would last for about 12 to 18 months before the product would be replaced by something else. Even with a successful run of 100 million units, the R&D cost represents 40 cents per unit, not three cents.

Another issue comes from time-to-market. Our hypothetical single-SKU super-module would be difficult to develop in the right bands, power levels and form factor within the R&D cycle. Samsung and Apple do not know exactly what they need two years from now.

In general, handset OEMs do not pay premium prices for integration. A PA/duplexer module does not sell for a higher price than the discrete PA and duplexer separately. While the CFE saves R&D cost for the OEM, our estimated 40 cents in R&D cost cannot be passed along to the OEM as a higher price.

Looking at the worldphone market, the growth is clear. The iPhone's entry into China will result in big growth for worldphones. By 2018, 42 percent of the handsets produced worldwide will include four or more data bands. With far higher dollar content than entry-level smartphones for RF devices, there is still major growth in the high end of the RF front end market.

MARKET SEGMENTATION

When Henry Ford built cars and trucks in the 1910s, he put the same transmission into both vehicles. The early automotive market fit this model of commonality, and mass-producing a single transmission drove improvements in quality and cost that made vehicles affordable for everyone. Eventually, the market grew large enough that investment in different transmissions for lighter cars and heavy trucks made economic sense.

The mobile terminal market has finished that early phase of market development, where the same modular strategy was used for every application. At $5B in market size, the mobile RF front end ecosystem can support different product strategies for different tiers of the market. The CFE approach is most viable for the RF suppliers at the low end of the market, where R&D investment is lower and volumes are higher. A modem supplier like Intel or Qualcomm can offer a CFE for low end smartphones and capture a sizable chunk of market revenue. At the high end of the market, separate modules used in more flexible combinations are a better solution.

IT'S ABOUT THE PROCESSORS

While the PA engineers arm wrestle over which wafer to use, another fight is taking place in the modem. Qualcomm has lost significant market share to MediaTek and Spreadtrum in China, and it wants it back. One way to do that is to offer a simpler product line, with a chipset that takes care of everything: applications processor, modem, transceiver and RF all the way to the antenna. A handset OEM does not need deep RF expertise with this approach. Enter Qualcomm's RF360 product, which includes the ET power supply, PA, filters and antenna tuning. For entry-level smartphones, this addition to the Qualcomm product line could make it easier to sell modems.

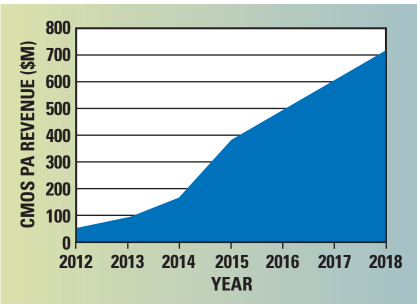
Intel, MediaTek, Broadcom, Nvidia, Spreadtrum and Marvell are all working on ET programs, indicating that there is some merit to this strategy for processors. At this moment, there is only one modem supplier with an ET/PA product – but as time passes, multiple competitors will take part and the modem/transceiver/ET/PA relationships will become very important in the market. Some of these vendors plan to use CMOS PAs, and others have GaAs partners.

By themselves, Qualcomm will not compete aggressively for PA business. (A great example is the Galaxy Note 3, where Qualcomm is happy to support a GaAs PA). Things will change when Qualcomm, Intel and MediaTek begin to compete head-to-head with solutions that include RF. Fighting for the bigger modem business, the price erosion in PAs may be severe. These companies may need to defend their modem business with low prices for PAs. It is never healthy to add a few new competitors into a market which is below about 10 percent growth.

MARKET IMPACT

For GaAs vendors, the main question comes down to this: How much market share will CMOS take? Will the GaAs fabs be fully utilized? Will price erosion become a problem?

The market for GaAs power amplifiers was already slowing, as multi-mode, multi-band PAs take hold and limit market growth by reducing the need for additional PAs in new bands. In the Mobile Experts forecast "RF Front Ends for Mobile Terminals 2013," overall RF front end market revenue will grow by 15 percent annually for the next five years, but the PA segment growth will be much weaker, at six percent or possibly lower due to a combination of MMPA adoption and price erosion.

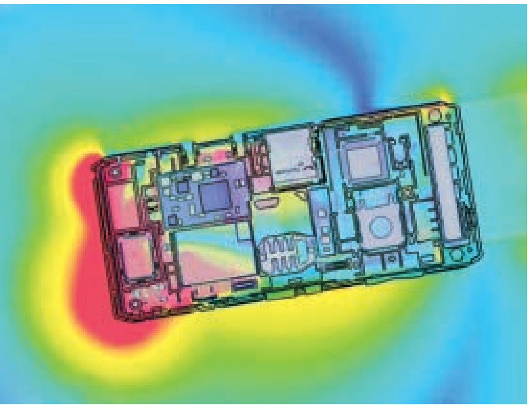


▲ *Fig. 6 CMOS PA revenue projection.*

In the 1990s, the battle between discretes and CMOS transceivers was short and decisive. The sequel will not end the same way. In the PA world, changing peak-to-average requirements play directly into the strengths of GaAs. Fragmented frequency bands mean that most worldphones will need to be highly customized for years to come. There is no clear path for CMOS to enter the high end of the market, where performance matters.

Emerging CMOS products will gobble up the low end of the market, growing to more than $700M by 2018, or roughly 25 percent of the total PA market value (see ***Figure 6***). GaAs PAs will continue to dominate the high end. In the end, the CMOS PA growth will rob the GaAs PA suppliers of the opportunity for market growth, and the "cash cow" business at companies such as RFMD and Skyworks will be impaired. A few GaAs suppliers will continue to succeed, but they will compete for a flat GaAs market in a highly fragmented LTE landscape. Nobody ever promised that life would be easy. ■

Joe Madden *founded Mobile Experts in 2002, and serves as the company's primary expert in semiconductors for handsets and infrastructure. A Silicon Valley veteran, Madden has 24 years of experience in wireless hardware, supplying amplifiers and filters into both base station and handset applications. He survived two startups, including successful IPOs and LBOs along the way. He holds a degree, cum laude, in Physics from UCLA.*



Design and Test Challenges for Next-Generation 802.11ac, ad WLAN Standards

Equipment based on the 802.11 wireless LAN standards (first IEEE 802.11a and b, 802.11g in 2003 and 802.11n in 2009) has moved firmly into the home and home office environment. Now, whether at work or play, we have multiple devices that need to be connected together: computers, smartphones, tablets, printers, game consoles, media servers, scanners and more. Beyond what we do now, proposed usage models requiring even higher data throughput to support tomorrow's home and office applications are driving the most recent versions of wireless LAN standards.

In addition to the 2.4 and 5 GHz wireless LAN standards currently used, there are active proposals within the standards organization for vehicular applications (802.11p), TV white space frequencies (802.11af) and sub-1 GHz to support extended range applications (802.11ah), though there is no commercial activity yet in these areas.

802.11ac

IEEE Working Group TGac has specified 802.11ac as an extension of 802.11n, providing a minimum of 500 Mbit/s single link and 1 Gbps overall throughput, running in the 5 GHz band. The physical layer is an extension of the existing 802.11n standard, and bearing in mind the huge number of existing client devices, backward compatibility with existing standards using the same frequency range is a must. ***Table 1*** shows the physical layer features of 802.11ac and highlights the mandatory extensions from 802.11n. Companies are already shipping commercial products based on the current draft of the standard.

The new wider channel bandwidths are shown in ***Figure 1***. While 160 MHz and 80+80 MHz modes are both included as optional features in the 802.11ac standard, it is likely that first devices will have a maximum of 80 MHz bandwidth, and no more than the maximum four spatial streams specified in 802.11n.

Even though the first 802.11ac consumer devices might be limited to an 80 MHz channel with four spatial streams, 160 MHz and 80+80 MHz modes are both included as optional features and will be a focus for chip and device development. New simulation, signal generation and analysis tools must include scenarios of non-contiguous frequency blocks, as well as being able to cope with the need for 160 MHz modulation bandwidth at 5 GHz. Previous RF wireless communications standards have required much narrower channel bandwidths, and test equipment development has followed those needs. For transmitter design and development, today's vector signal analyzer (VSA)

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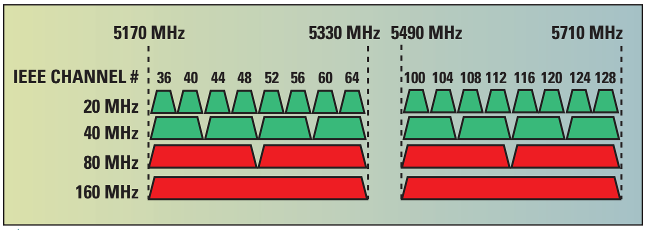
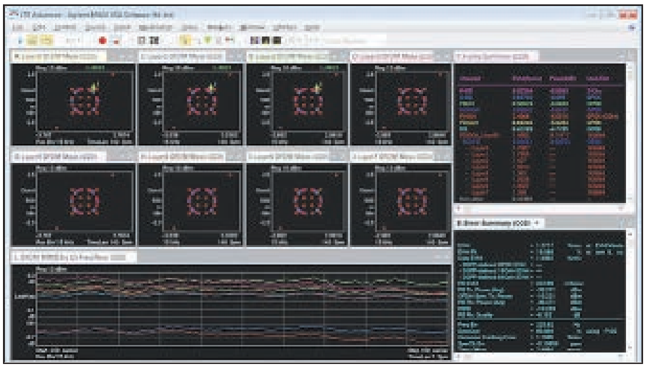
TABLE I IEEE 802.11ac KEY SPECIFICATIONS		
Feature	**Mandatory**	**Optional**
Channel bandwidth	20, 40 and 80 MHz	160 MHz, 80+80 MHz
FFT size	64, 128, 256	512
Data subcarriers/ pilots	52/4, 108/6, 234/8	468/16
Modulation types	BPSK, QPSK, 16QAM, 64QAM	256QAM
MCS supported	0 to 7	8 and 9
Spatial streams and MIMO	1	2 to 8 Tx beamforming, STBC Multi-user MIMO (MU-MIMO)
Operating mode/ PPDU format	Very high throughput/VHT	



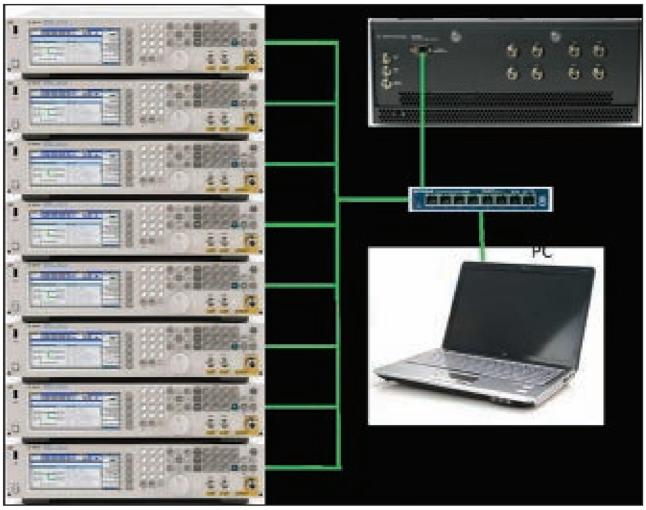
▲ *Fig. 1 IEEE 802.11ac frequency allocation for Europe/Japan/ global regions.*



▲ *Fig. 2 Example of 8x8 MIMO demodulation with Agilent VSA.*

must be able to cope with the correct demodulation, analysis and display of a wireless signal that uses two frequency blocks, OFDM modulation and may comprise up to the eight MIMO data streams allowed in the standard. ***Figure 2*** is an example display, showing each of the eight MIMO transmit streams and a summary table of the results.

The receiver must recover multiple simultaneous signals and adequately demodulate and decode them. The signal generation equipment needed for receiver design and development has the same overall frequency, bandwidth and multiple data stream requirements as the transmitter. In addition, it must provide a wide range of stress-test conditions – including repeatable and deterministic dynamic fading of each MIMO path as well as interference scenarios to ensure the receiver is designed to cope with the worst real world conditions. Up to eight separate signal generators may be needed to produce the required MIMO channel, along with additional generators to provide interference. Both modular and desktop product configurations are available, each having its own benefits and providing choices depending on specific test requirements. ***Figure 3*** shows one example.



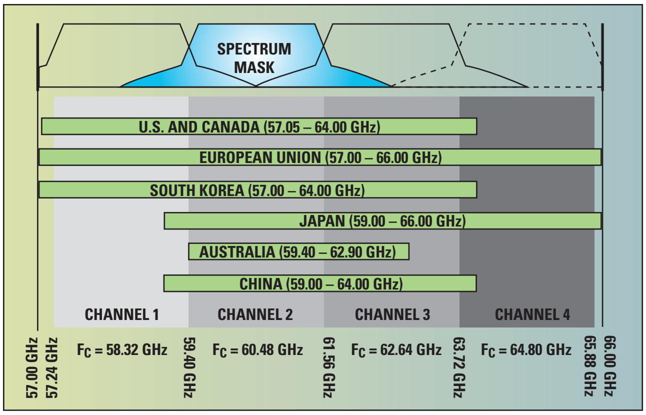
▲ *Fig. 3 Signal generator configuration for MIMO receiver test.*

802.11ad

While 802.11ac is an extension of the existing 802.11n specification, 802.11ad represents a completely new paradigm. Extreme data capacity requires a large spectrum allocation. Data capacity is ultimately tied to modulation order and bandwidth. Simplicity of design demands such bandwidth be a smaller percentage of the transmission frequency (Q) and the practical reality is such bandwidth is only available at higher frequencies. 802.11ad has been specified by Working Group TGad, in partnership with the Wireless Gigabit Alliance, and operates over a short range in an established global unlicensed 60 GHz band. It is designed to provide the multi-gigabit data rates required for uncompressed high-definition multimedia transmissions, including known futures such as 2048×1080 and 4096×2160 digital cinema and 3D video streaming.

The unlicensed frequency allocations at around 60 GHz in each region do not match exactly, but there is substantial overlap; at least 3.5 GHz of contiguous spectrum is available in all regions that have allocated spectrum. The ITU-R recommended channelization comprises four channels, each 2.16 GHz wide, centered on 58.32, 60.48, 62.64 and 64.80 GHz respectively. As ***Figure 4*** illustrates, not all channels are available in all countries. Channel 2, which is globally available, is therefore the default channel for equipment operating in this frequency band. In November 2011, this channelization and the corresponding spectrum mask for the occupying signal were approved by ITU-R WP 5A for global standardization.

The 802.11ad specification defines a backward-compatible extension to the IEEE 802.11-2007 specification that extends the MAC and physical layer (PHY) definitions as necessary to support short-range (1 to 10m) wireless interchange of data between devices over an ad-hoc network at data rates up to approximately 6.75 Gbps in the 60 GHz unlicensed band. It also supports session switching between the 2.4, 5 and 60 GHz bands.



▲ *Fig. 4 60 GHz band channel plan and frequency allocations by region.*

802.11ad uses RF burst transmissions that start with a synchronization preamble (common to all modes) followed by header and payload data. The preamble is always single-carrier modulation, the header and data may use single-carrier (SC) or OFDM modulation depending on the target bit rate.

The 802.11ad PHY supports three distinct modulation methods:

- Control Modulation; the Control PHY.
- Single Carrier (SC) Modulation; the Single Carrier PHY and the Low Power Single Carrier PHY.
- Orthogonal Frequency Division Multiplex (OFDM) Modulation; the OFDM PHY.

Each PHY type has a distinct purpose and packet structure, but care has been taken to align the packet structures, and in particular the preambles, to simplify signal acquisition, processing and PHY type identification in the receiver. The three packet types share an essentially common preamble structure comprising a Short Training Field (STF) followed by a Channel Estimation Field (CEF). These fields are constructed from π/2-BPSK modulated repeating Golay sequences.

Golay complementary sequences are sequences of bipolar symbols (±1) that have been mathematically constructed to have very specific autocorrelation properties. The 'a' and 'b' indicate that the "G_a128" and "G_b128" sequences form a complementary pair and the suffix indicates the sequence length.

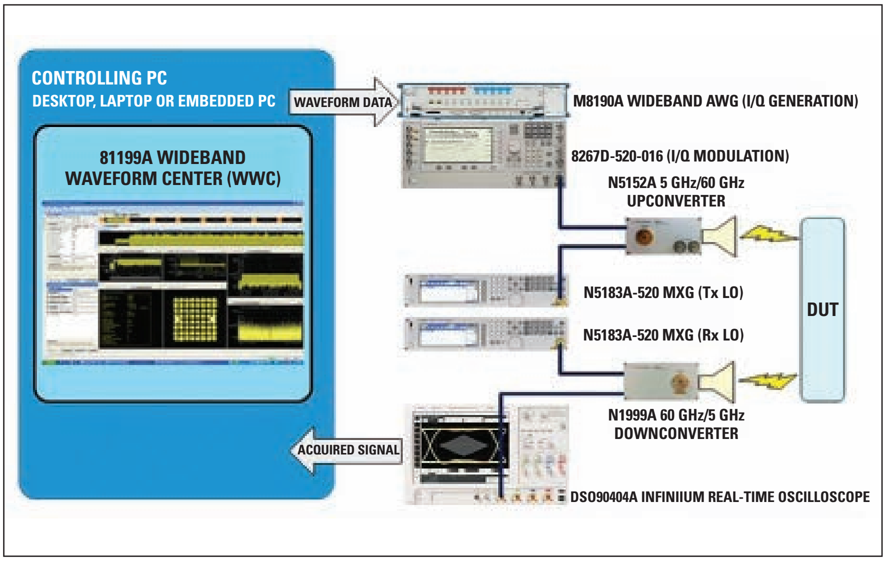
The mathematics behind the sequence constructions is beyond the scope of this article, but important attributes of these sequences are:

1. The autocorrelation of each sequence has low side lobes and low DC content under π/2 rotation.
2. The sum of the very good but imperfect autocorrelation functions of the G_a and G_b sequences is perfect (the side lobes cancel exactly).

Multiple-antenna configurations using beam steering are an optional feature of the specifications. Beam steering can be employed to circumnavigate minor obstacles, such as people moving around a room or a piece of furniture blocking line-of-sight transmission.

Component and system design and test at 60 GHz is a well-understood and established science, but its application to high-volume, low-cost devices for the consumer market is new. Two major differences are the much wider modulation bandwidth than other wireless communications systems, and the physical construction of the devices which may not allow direct connection.

The system shown in ***Figure 5*** combines all the equipment needed for transmitter and receiver design and development in one software-controlled package, providing signal generation and analysis capability tailored to high-bandwidth applications running in the 60 GHz band. It allows the use of calibrated horn antennae, since in many complete devices, the antenna is bonded directly to the RF components and a direct metallic connection is not possible. The system can also be used in conjunction with software (Agilent's SystemVue design libraries) to analyze and compare real-world measurements with those predicted by design simulations.



▲ *Fig. 5 802.11ad physical layer signal generation and analysis solution.*

CONCLUSION

802.11ac and 802.11ad both aim to provide significantly higher data throughput than previous wireless LAN systems and are complementary. 802.11ac is an evolution of the 802.11 WLAN capability. It gives the "unwired office" the ability to compete directly with gigabit wired systems, while offering much better office layout and connection flexibility. 802.11ad is an extension of the 802.11 family providing ad-hoc connectivity to deliver extreme data rates between devices over short distances. Both standards pose new challenges in design, development and test: 802.11ac due to the somewhat wider bandwidths used and 802.11ad due to the even wider bandwidth and to the new application of 60 GHz technology to consumer devices. In each case, proving design integrity during product development is critical. Manufacturing test must be minimal enough to preserve cost, while being sufficient enough to ensure product and process control. ■

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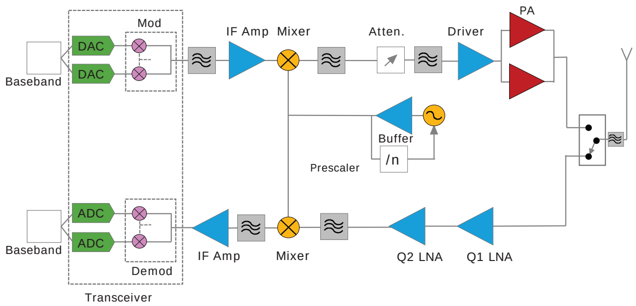

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CoMP: The Most Challenging Technology Component in LTE-Advanced 3GPP Release 11

LTE has become a global phenomenon: By August 2013, a total of 204 LTE networks in 77 countries were commercially operated. With only four years of real-life deployment, however, the technology is still in its infancy compared with 2G/3G technologies. But time in mobile communications moves quickly, and significant improvements were added to the initial LTE technology as specified in 3GPP Release 8.

In LTE 3GPP Release 9, the main improvements are support for multimedia broadcast multicast services (eMBMS), positioning and, last but certainly not least, optimizations such as semi-persistent scheduling (SPS) and transmission time interval (TTI) bundling in order to more efficiently support voice services. 3GPP Release 10 – the start of LTE-Advanced – added technology components that are even more significant. The one that is most in demand is carrier aggregation, which is already in commercial use and allows more efficient utilization of the fragmented spectrum available to an individual operator.

The next set of improvements was added in 3GPP Release 11. For this release, the core network and radio access protocols were finalized in December 2012 and June 2013, respectively. Defining test specifications, of course, takes additional time. This article introduces coordinated multipoint operation (CoMP), an enhancement that was initially discussed in the 3GPP Release 10 time frame. CoMP is widely talked about and applicable to the cellular industry. This article also examines the impact on testing both base station and end-user devices that support CoMP.

CoMP AND LTE-ADVANCED

CoMP for LTE is one of the most important technical improvements with respect to heterogeneous network (HetNet) deployment strategies, but also for the traditional homogeneous network topology. In brief, HetNets aim

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to improve spectral efficiency per unit area using a mixture of macrocell, picocell and femtocell base stations and/or remote radio heads (RRH).

In contrast, homogeneous network topologies comprise cells of about equal size, usually the macro layer. Nevertheless, with both network deployment strategies, cell edge users can experience intercell interference. This type of interference is caused by the downlink transmissions from two (or more) different base stations (cells). In a frequency reuse 1 system like LTE, when the same frequency is used in all cells, this affects in particular user devices at the cell edge. The goal of CoMP is to further minimize intercell interference for cells that are operating on the same frequency. With HetNets, this intercell interference becomes even more significant due to unbalanced output powers used in the macrocell and picocell/femtocell layer.

As the name implies, CoMP will make it possible to coordinate the optimization of transmission and reception from multiple distribution points, which could be either multiple cells or RRHs. CoMP will enable joint transmission and/or reception to mobile devices. It will also have a positive effect on power consumption as well as overall throughput and thus system capacity. Plus, it will allow load balancing between cells that are coordinated.

3GPP standardization is based on four different CoMP scenarios (see ***Figure 1***). The first two scenarios focus on homogeneous network deployments, one with a single eNodeB serving multiple sectors (scenario 1) and the other with multiple high-transmit-power RRHs (scenario 2). The remaining two scenarios target HetNets, where macrocells and small(er) cells are jointly deployed using different cell identities (ID), as shown in scenario 3, or the same cell ID, as shown in scenario 4.

Due to its complexity, CoMP has been separated during the standardization process into two independent work items for downlink and uplink. Both link directions benefit from the two major schemes being used in CoMP: joint processing (JP), which includes joint transmission (JT, downlink) and joint reception (JR, uplink) as well as coordinated scheduling/beamforming.

WHAT'S IMPORTANT TO KNOW ABOUT CoMP?

Performance gains from CoMP result from managing the interference at cell boundaries, specifically in the HetNet scenario. To understand the details behind downlink and uplink CoMP, it is essential to know the terminology used: CoMP cooperating set, CoMP measurement set and CoMP resource management.

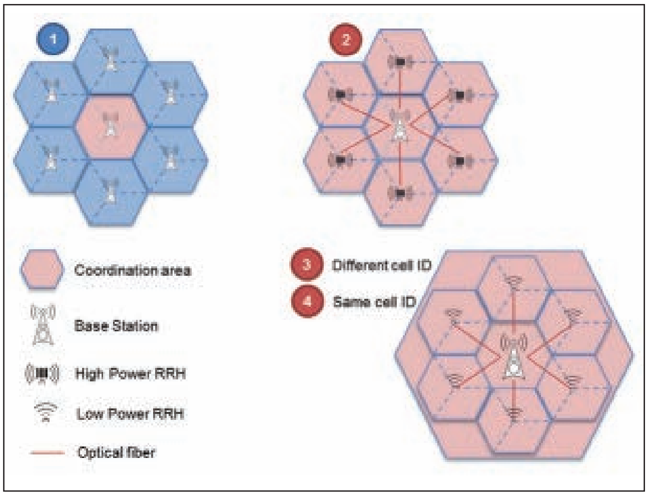


Fig. 1 Coordinated multipoint operation (CoMP) scenarios.

CoMP cooperating set: The CoMP cooperating set is determined by higher layers. It is a set of geographically separated distribution points that are directly or indirectly involved in data transmission to a device in a time-frequency resource. Within a cooperating set, there are CoMP points. With regard to the CoMP schemes, the set could contain multiple points at each subframe (e.g., joint transmission) or a single point at each subframe (e.g., coordinated scheduling/beamforming).

CoMP measurement set: The CoMP measurement set is a set of points about which channel state information (CSI) or statistical data related to their link to the mobile device is measured and/or reported. This set is determined by higher layers. A mobile device is enabled to down-select the points for which the actual feedback is reported.

CoMP resource management: The CoMP resource management is a set of CSI reference signal (CSI-RS) resources for which CSI-RS-based reference signal received power (RSRP) measurements can be made and reported.

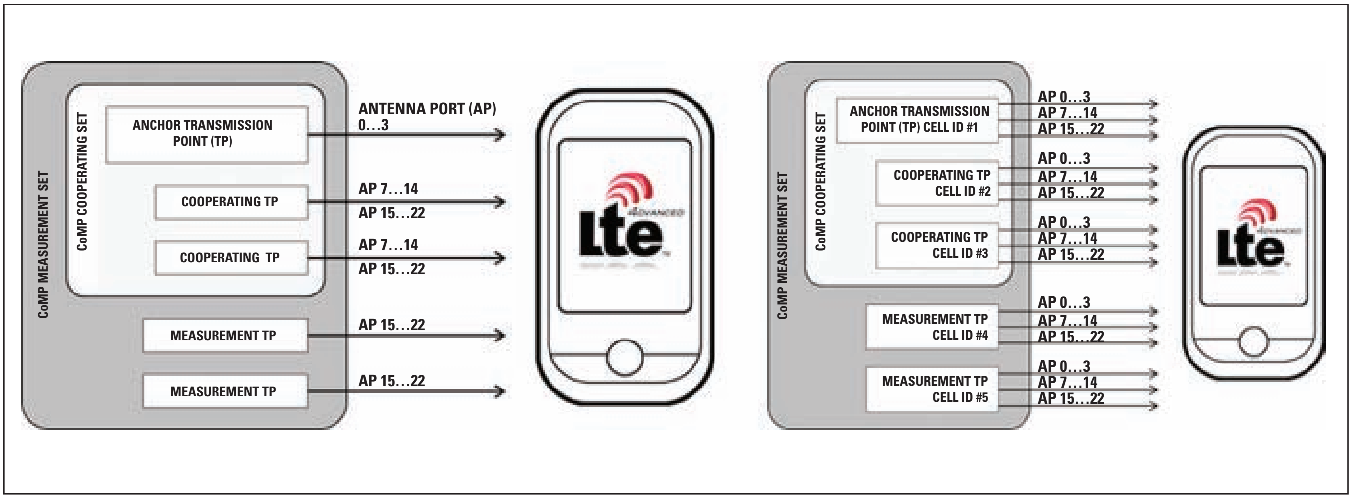
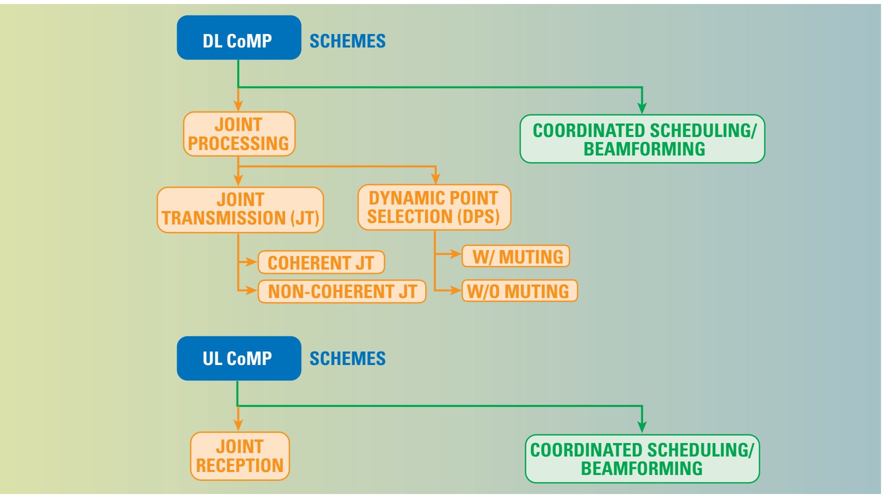


Fig. 2 Downlink CoMP cooperating and measurement set for cells using the same (left) or different (right) cell identity/identities.



▲ *Fig. 3 Overview of downlink (DL) and uplink (UL) CoMP schemes.*

Figure 2 shows the CoMP cooperating set and the CoMP measurement set for the two cases defined: Either all cells use different physical cell identities, or multiple cells have the same cell identity. In the latter case, the concept of virtual cell identities (VCID) can be applied. VCIDs are assigned by higher layers.

CoMP SCHEMES

Figure 3 provides an overview of the CoMP schemes used in the downlink and uplink. In the downlink, joint transmission enables simultaneous data transmission from multiple points to a single UE or even multiple UEs. This implies that the UE data is available at multiple points, belonging to the CoMP cooperating set, throughout the network. The goal is to increase signal quality at the receiver and thus the average throughput. The coherency of JT refers to the ability to form precoders that exploit the phase and possibly amplitude relations between channels associated with different transmission points.

In other words, in coherent JT the signal from multiple transmission points is jointly precoded. In noncoherent JT, the UE would receive multiple signals individually precoded by each transmission point. In general, JT requires a low latency between the transmission points, high-bandwidth backhaul and low mobility UEs. Also for dynamic point selection (DPS), the physical downlink shared channel (PDSCH) data has to be available at multiple points. However, in contrast to JT, data is only transmitted from one point at any given time. For coordinated scheduling/beamforming, the data is only present at one transmission point.

Furthermore, with the coordination of frequency allocations and used precoding schemes (beamforming) at the various transmission points, performance can be increased and interference mitigated. The CoMP schemes implemented for the uplink are similar. For joint reception, the physical uplink shared channel (PUSCH) data transmitted by the UE is received jointly at multiple points (part of or entire CoMP cooperating set) simultaneously to improve the received signal quality.

With regard to coordinated scheduling and beamforming in the uplink, the scheduling and precoding selection decisions are made with coordination among points corresponding to the CoMP cooperating set. But the PUSCH data is intended for one point only. A fundamental change due to CoMP in the LTE uplink is the introduction of virtual cell IDs. As of 3GPP Release 8, the generation of the demodulation reference signal (DMRS) embedded in two defined single carrier frequency division multiple access (SC-FDMA) symbols in an uplink subframe is dependent on the physical cell identity (PCI). The PCI is derived from the downlink.

For future HetNet deployment scenarios, where a macro cell provides the coverage and several small cells are used for capacity, there is higher uplink interference at the cell boundaries. This is especially true for when macrocells and small cells are using the same cell identities. The VCID concept makes it possible to signal a dedicated cell ID via radio resource control (RRC) signaling to be used by the UE for uplink transmission, which allows the UE signal to be received by different reception points.

TESTING CoMP

LTE-Advanced CoMP is a complex and powerful technology enhancement. The various downlink and uplink CoMP schemes permitted increase both base station and mobile device complexity. With respect to uplink CoMP, the burden appears on the base station receiver end. More precisely, UE data needs to be transferred between multiple reception points and jointly processed. For intra-eNodeB (intrasector) CoMP, this becomes purely implementation-dependent without impact on testing, since the combining takes place in a single entity.

Simulating multiple UEs for testing the base station receiver is a standard test case used since the beginning of LTE (as well as other cellular technologies). Transferring user data between multiple reception points places latency requirements on the inter-eNodeB interface, which in the best case can be satisfied with fiber connections. Therefore, today's method for testing a single eNodeB will evolve into testing a distributed base station architecture comprising multiple baseband units (BBU), sometimes also called digital units (DU), in combination with high-power or low-power RRHs (as shown in Figure 1, scenarios 2 to 4).

However, this will not change the testing principle, because the input signal from multiple UEs needs to be provided in the same way as it is today. There also remains the need to verify the signaling information exchange between UE(s) and BBUs combined with RRHs. A new test scenario will likely be added in order to verify the VCID concept. In the downlink, i.e., testing the UE implementation, CoMP requires redesign in the receiver chain because multiple signals from multiple transmission points – potentially on multiple frequencies – need to be successfully combined. In order to allow any CoMP algorithm to schedule the best possible resource from the best possible transmission

point, it is essential to have good knowledge of the channel conditions of a particular UE toward the cooperating transmission points.

Consequently, UE measurements on the various reference symbols (cell and channel state information reference symbols [CSI-RS] and interference measurement resources [IMR]) need to be verified. This requires a mobile communications tester to establish multiple scenarios in an easy and efficient way. In contrast to traditional LTE operation, signals from multiple transmission points may expose frequency and time shifts.

Since reporting channel quality information (CQI) is so important, frequency and timing correction measures at the UE end need to be tested extensively as well. The responsible working group (RAN5) in 3GPP has just started drafting the test case details based on initial agreements made in 3GPP RAN4, the group that defines the performance requirements.

Finally, any efficient CoMP algorithm in the network may be applicable to a large number of cells in a certain network area, if not in the complete network. This means that it may be possible to verify whether the implementation-dependent CoMP algorithm is delivering its capacity gain promise by monitoring KPIs in the core network (e.g., overall data throughput per cell). In case of errors, it will be necessary to conduct dedicated drive testing in order to identify the root of a problem.

CoMP is a key technology component in LTE-Advanced 3GPP Release 11 for further increasing system capacity. The advent of continuously increased data consumption specifically on smartphones, along with the anticipated, exponentially growing number of machine-type communications devices such as sensors, makes CoMP the technology of choice for network operators for satisfying capacity needs.

The major design challenge is on the network end, since if coordination is done across multiple cells, high capacity and low latency interfaces between BBUs are required. Additionally, precise knowledge of propagation conditions at the end user position is essential. This requires comprehensive verification of UE reporting behavior under various conditions. ■

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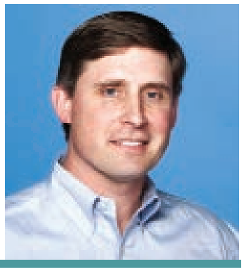
The Road to 5G FAQs



James Kimery, Director of Marketing, National Instruments

WHAT IS 5G AND WHY IS IT NEEDED?

Since the cell phone was first introduced many years ago, cellular infrastructure has undergone many transformations. The first generation cellular networks were based on "analog" technology such as Advanced Mobile Phone Service (AMPS). The second generation (2G) systems featured digital technology utilizing standards such as Global System Mobile (GSM). In terms of capability, 2G added basic SMS (texting) to voice with limited wireless data capability. Web browsing on a 2G mobile device was limited. Wireless data was driven by texting, email and static photo transfers.

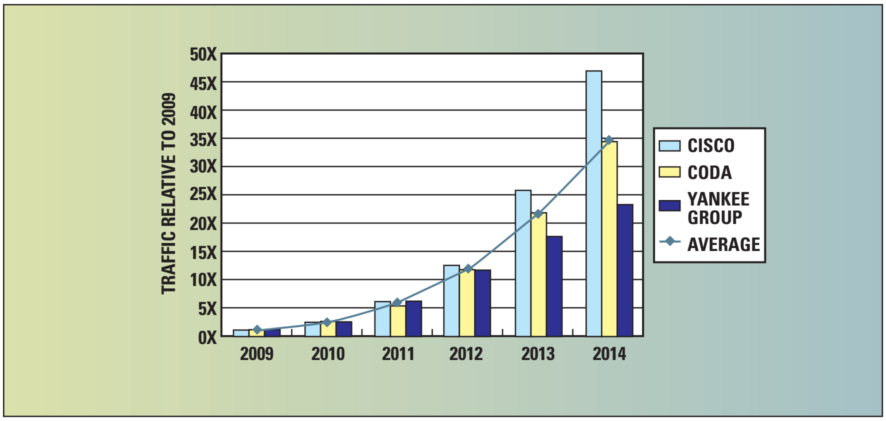
TABLE I

DATA SPEEDS

Network Generation	Down Link (Mbps)	Up Link (Mbps)
4G	300	150
3G	14.4	<<14.4

3G, or third generation networks, added a higher speed data capability where limited video could be transferred using Wideband Code Division Multiple Access (W-CDMA). Later evolutions of 3G included HSPA and HSPA+ (the equivalent of 3.5G) and delivered an enhanced user experience. However, big data applications such as streaming video were slow compared to WiFi or Wireless LAN speeds, which most consumers used as a comparison benchmark.

Today, network service providers are rolling out fourth generation (4G) networks based on Long Term Evolution (LTE). LTE offers significant upgrades over 3G in terms of data throughput with up to five to six times faster peak rates (see ***Table 1***). Most service providers plan to transition to LTE-Advanced, or 4.5G, which is expected to double the available bandwidth from LTE. With LTE and LTE-Advanced, wireless data consumers now have a communication technology that rivals current WiFi in terms of user experience.



▲ *Fig. 1 Industry forecasts of mobile data traffic (From* Mobile Broadband: The Benefits of Additional Spectrum*, FCC Report 10/2010).*

On the surface, future wireless data capabilities along the LTE trajectory appear to approach parity with WiFi from a user experience perspective, ostensibly reducing or mitigating the need for quantum leaps in increased bandwidth. However, with the rapid adoption of smart devices such as smartphones, tablets and even fablets, network capacity and bandwidth are being consumed at accelerated rates. In fact, industry analysts predict that wireless data demand will exceed 2009 levels by over 35× in 2014 (see ***Figure 1***), and this growth rate is not expected to subside any time soon. Capacity is, in effect, a function of bandwidth. More bits transmitted faster free up spectrum for other users and their data demands. Doubling the data rate effectively increases the capacity by 2×. Therefore, the primary motivation for investments in 5G research is to increase network capacity via increased bandwidth and to avoid a capacity shortage.

ARE LTE AND LTE-ADVANCED NOT SUFFICIENT TO ADDRESS CONSUMER DEMAND?

Considering the rate at which wireless users are consuming data, there is genuine concern across the industry that network capacity may become constrained in the not too distant future without significant technology upgrades. Let's take, for example, current LTE quoted rates, 300 Mbps in the downlink and 150 Mbps in the uplink. These rates are about four to five times faster than 3G and 3.5G technologies. LTE-Advanced may essentially further double to quadruple data rates. So, in a span of 10 to 15 years, the world's cellular operators increased capacity by 20×. In that same time frame, "demand" increased by more than 100×. It's clear that LTE-Advanced is necessary and that a new fifth generation network is critical. Wireless infrastructure companies and other members of the 3GPP standardization body, in fact, have set out a challenge to increase capacity by "1000× by 2020" (www.cvt-dallas.org/MBB-Nov11.pdf).

HOW WILL 5G ADDRESS THE "BANDWIDTH/CAPACITY" CRUNCH?

First of all there is much discussion regarding 5G – what it will be or what it will not be. We do know that 5G will have to be much faster than today's 4G networks and the eventual LTE-Advanced (sometimes referred to as 4.5G). The real question is how we achieve faster performance and high capacity with the current infrastructure including existing equipment, available spectrum and so on. The 3GPP standardization body is establishing an investigative group to explore the next generation wireless question, which will hopefully be kicked off early next year. The consensus is that there is no "silver bullet" or one technology that will lead to the necessary bandwidth expansion, but a combination of advancements such as heterogeneous networks encompassing small cells and coordinated multipoint, reallocation of spectrum, and other advanced techniques such as self-organizing networks (SON).

WHAT TECHNOLOGIES ARE BEING INVESTIGATED TO SUPPORT A POTENTIAL 5G STANDARD?

Several technologies are being researched today to increase spectrum efficiency and lower the intercell interference such as heterogeneous networks, small cells, relays and coordinated multi-point. Essentially the motivation behind these research vectors is to lower the load per base station by increasing the density, which in turn increases spectrum efficiency to users in a smaller geographic area. All of these options focus on deploying more infrastructure equipment and further increasing utilization by employing "smart" techniques (i.e., coordinated multi-point, beamforming and so on). Fundamentally, by sharing network information at the base station level, load and coverage per user can be optimized to more effectively use the existing spectrum.

A more difficult challenge is the availability of spectrum. The transition from 3G to 4G introduced new technologies for increased data throughput and reliability, but what is often overlooked is that new spectrum was introduced in conjunction with the LTE rollouts. For example, in the United States, the 700 MHz spectrum was auctioned specifically as a vehicle to deploy LTE.

This scenario also played out similarly with W-CDMA and the 3G rollout as 2G networks were pervasive and successful. 3GPP offered new coding and modulation techniques but these new technologies were largely (if not exclusively) deployed on new spectrum earmarked for those deployments.

With 5G, the answer is not so simple. Unless industry, government and associated spectrum regulating entities can agree on how and when to reallocate spectrum, there is essentially no spectrum available below 6 GHz. Reallocating spectrum is not an easy task since many service operators paid billions of dollars to acquire the spectrum already in use, and transitions are not easy or cheap.

Of particular note is the research that Dr. Ted Rappaport is doing at NYU Wireless. Dr. Rappaport has been characterizing the spectrum at 28, 38 and 60 GHz plus E-Band that covers frequencies from 71 to 76 GHz in New York City – which is a very challenging environment. These measurements show that wireless outdoor communication is possible at those frequencies although significant investment is required to make communication at these frequencies feasible.

IS 28 GHz TO mmWAVE E-BAND A CHALLENGING DESIGN TASK?

None of the options proposed to address the wireless data crunch will be simple or easy. The industry has to challenge conventional thought, which includes the design process. mmWave frequencies in particular were widely considered not suitable for cellular data and a network based on this spectrum unfeasible. Dr. Rappaport's work has essentially challenged this thinking. He has proven that reliable transmission and reception at these frequencies is possible but there is much work to do. Essentially, all the paradigms associated with communication below 6 GHz must change, creating research opportunities in RF front end design and antennas, beamforming, physical layer design and even new protocols.

What's encouraging is that while many of these technologies are new and have yet to be developed, there is history of rolling out new data capabilities overlaying the existing infrastructure. Even if you consider all of the research below 6 GHz in terms of physical layer, small cells, and RF front ends (MIMO), the network is still limited by the Shannon theory – a communication channel is limited by the bandwidth and noise. Heterogeneous networks will improve capacity but it is not clear that this alone will achieve 1000× capacity in 2020. If there is no available bandwidth, then new spectrum must be found somewhere.

YOU MENTIONED A NEW DESIGN APPROACH. CAN YOU ELABORATE ON THIS POINT?

A typical "design" approach has been to come up with an idea, simulate it and then prototype. Usually there are several iterations in the design and simulation stage before prototyping because of the large expense required to develop a working prototype. If there is a fundamental problem in the theory, then it is back to the beginning to start over again. Therefore heavy simulations are typically required before a prototype is even planned. With conventional methods, transitioning from concept to simulation to prototype takes a very long time and consumes many resources. In other words, it is very expensive. The most important goal of the design process is to deliver a working prototype sooner rather than later so that the real world conditions and system issues can be accounted for early in the design.

Most of today's simulations mostly use additive white Gaussian noise or AWGN to model the channel. As network operators will tell you, this is simply not a realistic scenario – perhaps a good start but far from realistic. With the new technologies being investigated for 5G, conventional channel models are not good proxies for the real world. System engineers and network designers must also consider the processing requirements and the feasibility of actually deploying a new algorithm/protocol on a platform that is both cost effective and low power (to conserve battery life). Getting to a prototype sooner rather than later is very important.

WHERE DOES NATIONAL INSTRUMENTS FIT INTO THIS 5G REVOLUTION?

National Instruments has been working with wireless researchers for a number of years through the RF/Communications Lead User program. Through this program, NI has been working directly with top researchers, such as Dr. Rappaport at NYU Wireless and also Dr. Gerhard Fettweis at TU Dresden, to explore a new approach to communications system design.

We already discussed Dr. Rappaport's work on mmWave, but also of significance is Dr. Fettweis' work on new physical layers for 5G. He is already prototyping a new physical layer called GFDM or General Frequency Division Multiplexing that addresses some of the shortcomings of OFDM – the standard in today's 4G communications. Through this work, Dr. Fettweis has gone from simulation to prototype in a matter months.

The Lead User program was the idea of National Instruments' CEO and founder, Dr. James Truchard. Dr. Truchard believes that a new design paradigm is needed for research not just in wireless but across many different areas. The tools used in research to transition from design to simulation to prototype have not really evolved over the last 20 years like so many technologies that have improved our everyday life. In particular, National Instruments focuses on a graphical system design approach to accelerate the process from design to simulation to prototype. The combination of this approach with tight hardware and software integration enables researchers to focus on their area of expertise rather than having to struggle with disparate tools and technologies that can take months and years to integrate into a working prototype.

Through the RF/Communications Lead User program, we are also working with leading researchers at commercial companies but I am not at liberty to disclose these relationships as they are confidential. However, I can say that you should stay tuned for some exciting demonstrations using NI tools and technologies on the 5G front. ■

James Kimery *is the director of marketing for RF, communications, and software defined radio (SDR) initiatives at National Instruments. In this role, Kimery is responsible for the company's communication system design and SDR strategies. He also manages NI's advanced research RF/Communications Lead User program. Prior to joining NI, Kimery was the director of marketing for Silicon Laboratories' wireless division, which later became a subsidiary of ST-Ericsson. With Kimery as director, the wireless division grew revenues from $5 million to over $250 million. The division also produced several industry innovations including the first integrated CMOS RF synthesizer and transceiver for cellular communications, the first digitally controlled crystal oscillator, and the first integrated single-chip phone (AeroFONE). The IEEE voted AeroFONE one of the top 40 innovative ICs ever developed. He also worked at NI before transitioning to Silicon Labs and led many successful programs, including the concept and launch of the PXI platform. Kimery was a founding member of the VXIplug&play Systems Alliance, the Virtual Instrument Software Architecture (VISA) working group, and the PXI Systems Alliance. He has authored over 26 technical papers and articles covering a variety of wireless and test and measurement topics. He earned a master's degree in business administration from the University of Texas at Austin and a bachelor's degree in electrical engineering from Texas A&M University.*

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Smarter Antenna Front End Modules

Once in a while, a technology has the numbers to back up the buzz it's generating, and that's the case with LTE. By the end of this year, ABI Research predicts that LTE subscriptions will hit 183 million worldwide. In the first two years it was commercially available – Q4 2010 to Q3 2012 – LTE racked up far more customers than W-CDMA did in that technology's first two years.

For OEMs of smartphones, tablets, laptops and other devices, the message is clear: an LTE strategy including innovative devices is critical to stay ahead of the competition and remain relevant. But less obvious are the challenges, costs and competitive risks of choosing the wrong LTE RF solution. Mistakes are easy to make because LTE has fundamentally different requirements and considerations than those of 3G and 2G:

- **Highly fragmented spectrum.** LTE is designed for use in more than 40 bands between 450 MHz and 2.7 GHz. Roughly half of those are already in commercial use. To enable regional or global roaming on par with what 3G provides, or single-SKU products, OEMs currently must build support for a dozen bands into their devices. That increases cost, complexity and development time, all of which increases further when those bands are widely spaced. LTE-Advanced introduces carrier aggregation, which makes fragmentation even more challenging when the aggregated frequencies are far apart.
- **Operators prefer lower bands.** Many mobile operators prefer to use low frequency bands, 700 MHz, for LTE because lower frequencies require fewer base stations, thus reducing their CapEx and OpEx. But lower frequencies require electrically larger antennas, which are literally a bad fit for the trend toward thinner devices. In smartphones, for example, the amount of space available for antennas and other RF components is shrinking 25 percent annually to make room for bigger batteries while enabling increasingly thin, sleek form factors. Although M2M devices such as vending machines, smart meters, and telemedicine monitors appear to have ample room for large antennas, they are actually often as space-constrained as smartphones and tablets.
- **MIMO (Multiple Input, Multiple Output) is required.** MIMO increases the number of cellular antennas. The two antennas must have enough separation between them to benefit from the differences in signal conditions. That amount and spacing increase the challenge of finding enough room as devices become thinner.

Jeff Shamblin
Ethertronics, San Diego, CA

- **Multi-technology support is a must-have.** Although 193 LTE networks have launched and another 123 will debut over the next two years (according to ABI Research), the technology will not have ubiquitous coverage in most countries until late this decade. So in that interim, many LTE devices still need the ability to use other wireless technologies, such as 2G/3G fallback in places where LTE is not yet available, or WiFi when it's more cost-effective. GPS is another common requirement. Each additional technology increases the challenge of finding enough room for antennas and other RF components.

Device OEMs must overcome all of these challenges. If they do not, their products will not deliver the high performance and fast speeds that consumers and business users expect from 4G. Sub-standard performance would directly affect their competitive position and ultimately revenue. OEMs that rely on mobile operators for distribution also risk losing their sales channels if customers inundate operators with complaints about poor performance, or if those devices create problems that sap network capacity. To overcome these challenges, device OEMs need to focus on two things: the trend toward active antenna systems and where each RF vendor's products fit into that trend.

ACTIVE ANTENNA SYSTEMS

Active antenna systems are not just the future of LTE – they are also the present. An active antenna system went into production in August of 2011 in a medical device monitoring critical medication dispensing and inventories. Several months later, the Galaxy S II LTE SC-03D phone, using an active antenna system with active impedance matching techniques, launched on the DOCOMO network. Most recently, an ultrabook from a tier one OEM utilized band aperture techniques to provide global 3G and 4G coverage. Active antenna systems are gaining traction in the marketplace to help OEMs solve LTE's toughest challenges.

Unlike passive antennas, active systems can be dynamically tuned to cover significantly wider bandwidths, achieve smaller physical volumes, and provide more degrees of freedom in the design process. This flexibility reduces the cost, complexity and lead time of developing antenna systems capable of meeting unique device or application requirements, such as an LTE M2M module mounted inside a metal box or in an underground vault, or a smartphone that needs to be ultra-thin and capable of global roaming on LTE. This flexibility also increases the likelihood that a device will pass operator certification on the first try, which means faster time-to-market and faster time-to-revenue for the OEM.

Active antenna systems also enable single-SKU products, reducing the OEM's development and support costs while expanding those products' addressable market to the world rather than just a single region or country. For example, a single active antenna system can support multiple LTE bands, plus the bands for 3G and 2.5G fallback, ISM, WiFi, Bluetooth and ZigBee. Covering all of those bands with multiple passive antennas is somewhere between difficult and impossible, depending on both the amount of space available in the device and the requirements for cost and performance.

Unlike passive antennas, active antenna systems can seamlessly adjust the antenna's characteristics to compensate – all in real time – for frequency shifts due to environmental changes such as the position of the user's head and hand, or a large truck parked over an underground utility vault. Active antenna systems also can make those adjustments to overcome challenging installations, such as when an M2M module is mounted on a metal surface that would wreak havoc with a passive antenna.

The ability to mitigate detuning effects directly affects an LTE device's market potential and support costs, as well as its OEM's brand reputation. Active antenna systems enable those devices to provide data speeds, video performance and call quality that are noticeably superior to what's available from LTE products that try to make do with passive antennas.

Quality of Service (QoS) and reliability also affect mobile operators' cost of delivering service. For example, when M2M modules use active antenna systems to maintain connectivity even under difficult, changing environmental conditions, the mobile operator is under less pressure to increase its cell site density. The CapEx and OpEx of dozens, hundreds or thousands of additional cell sites would make it difficult for the operator to price its M2M services competitively, yet profitably.

WHAT MAKES AN IDEAL ACTIVE ANTENNA SYSTEM?

Not all active antennas, or tunable antennas, provide equal performance and integration benefits. That is a key point for OEMs, systems designers and others to keep in mind because many vendors are now talking about tunable antenna products. It is important to understand the key differences between them.

For starters, the ideal active antenna system for many applications is an all-in-one module that device OEMs can quickly and cost-effectively integrate into their products instead of spending weeks or months on custom designs with components from multiple vendors. The plug-and-play approach has obvious benefits, such as reduced development costs and faster time-to-market. A less obvious benefit is that OEMs now do not need to hire staff to create an RF engineering team to handle integration in house. That benefit is particularly valuable for M2M and consumer electronics OEMs, which typically have limited or no RF experience.

The turnkey plug-and-play module approach includes being able to dynamically sense and optimize the antenna system without external control signals from the device. That is possible by using advanced antenna architecture, tunable capacitors and adaptive algorithms designed and integrated in conjunction with a microprocessor.

To achieve the highest performance and ease integration, an active antenna system needs to perform dynamic impedance matching at the feedpoint rather than farther back in the system, such as in the transceiver chipset. The feedpoint approach maximizes performance because the tuning is focused entirely on the antenna. When tuning is done farther back in the signal chain, the process can be undermined by the transmission line's electrical delay and losses.

Band switching is another important feature to look for. Also known as active aperture, this technique dynamically changes the electrical length of the antenna element to shift its frequency response. An alternative method is active matching, where a tuning circuit at the feedpoint changes the antenna's impedance. The main difference between the two methods is that active aperture/band switching is a coarse tuning of the antenna element followed by active impedance matching for a fine tuning of the frequency response at the feedpoint. This allows the device to quickly tune across the required frequency bands in the smallest antenna volume.

OEMs used to have to choose between the two techniques because of the cost of implementing multiple components. Impedance matching requires tunable capacitors, while band switching requires a switch. OEMs are always looking for ways to reduce costs given the competitive nature of the wireless industry.

The latest active antenna solutions minimize the cost factor by combining a four-port switch and multiple tunable capacitors in a single RFIC. These products combine the active aperture/band switching technique to quickly tune across frequencies and then use the active impedance matching function to fine tune the impedance to the desired frequency for the best performance.

Many of LTE's biggest RF challenges occur below 1 GHz because above that, antennas do not have to get larger to the point that they're difficult to integrate inside space-constrained devices. That is why these next-gen active antenna system solutions focus on impedance matching at the lower frequencies.

Device OEMs have been asking RF vendors to provide single-RFIC active antenna systems to maximize performance benefits without significant cost increases, so it is a milestone that they are now commercially available. They also do not come with many tradeoffs. For example, multiport switches and tunable capacitors typically have low current consumption – well under 200 micro amps – so the performance and reliability that they enable do not come at the expense of battery life.

Even so, not all RFIC active components are equally effective. The reason is the heritage of the companies that produce them. For example, some RFIC vendors know chips but not antennas, so they are developing products that are unnecessarily expensive because they conduct tuning at higher frequencies.

By comparison, a chipset vendor with extensive antenna experience knows that all the tunable components in the world will not compensate for a poorly designed, inefficient antenna. An experienced antenna vendor also knows that a systems approach is a key to performance: the antenna, chips and algorithms need to be designed together in order to deliver the easiest integration, best performance and the lowest cost. By comparison, a chip vendor will design an RFIC that will attempt to work with as many bands, antenna types and impedances, which inevitably translates into compromises in performance and higher cost.

Single-RFIC chips and active antenna systems are an idea whose time has come because they solve a variety of unique challenges created by the arrival of LTE. They're also the first in a wave of next-gen active antenna solutions, which will feature even more complexity to enable higher performance and lower costs. ■

Broadband LDMOS FETs for Land Mobile Radios

Handheld and vehicle-mounted transceivers used by public safety and other agencies may look much like their predecessors, but peering inside reveals a profound difference, thanks to the "digitization" of functions formerly performed by analog components. Nevertheless, although the transmit section (and some receive components) remain the last bastion of RF technology within these increasingly digital products, advancements are being made in performance and functional integration as well as size reduction and power consumption. Two additions to Freescale® Semiconductor's Airfast™ RF power solutions family have been designed to address these challenges by reducing amplification stages and covering multiple frequency allocations with a single device.

The AFT09MS007 and AFT05MP075 are broadband LDMOS FETs that can be optimized for operation over wide bandwidths between 136 to 941 MHz and 136 to 520 MHz, respectively. The AFT09MS007 operates from a supply voltage of 7.5 VDC making it compatible with handheld radio power supplies. The AFT05MP075 delivers 70 W or more and operates from a 12.5 to 13.6 VDC supply, typically a vehicle battery.

Both devices can operate into a VSWR greater than 65:1 without degradation, even when driven with twice their rated input power from a supply voltage of 10.5 (AFT09MS007N) and 17 VDC (AFT05MP075). They have built-in protection against electrostatic discharge, are housed in Freescale's over-molded plastic packages, and are available in tape and reel.

The ability of both devices to cover more than one frequency allocation (such as 136 to 174 MHz or 350 to 520 MHz) provides significant benefits for manufacturers as they can rely on a single device to serve all or most of their entire product line. The manufacturer's portfolio will typically have a lower bill of materials, fewer circuit designs, and lower cost than if different devices were used. It also allows manufacturers to address the need of agencies that operate at frequencies other than the standard public safety bands, whether they require small or large quantities of radios.

It is obviously advantageous for radio manufacturers to use as few different RF power transistors as possible throughout their product lines. This is often not the case, as transceiver manufacturers typically use different RF power transistors over a specific band or split bands such as 350 to 520 MHz into two or even three parts to optimize for efficiency or another parameter. The Airfast devices eliminate this requirement. The devices achieve their performance without use of internal matching, so rather than being optimized to operate over a relatively narrow, fixed band they can, through external matching, be optimized over any bandwidth within their specified range of operating frequencies.

Figure 1 shows the performance of the two devices in typical mobile radio broadband circuits. The AFT05MS075 shows excellent performance characteristics across VHF frequencies from 136 to 174 MHz. At 12.5 V operation, the device has typical gain of 18.8 dB, producing 84 W nominal with 1.1 W of input drive. Efficiency under these conditions is typically 76 percent. The AFT05MS075 is also characterized for 13.6 V operation. When operated at the higher voltage, power gain increases approximately 0.5 dB and output power increases to 94 W nominal when tested with

Freescale Semiconductor
Tempe, AZ

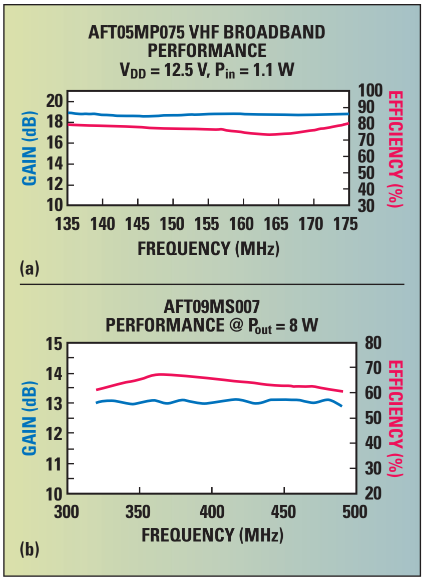

Fig. 1 *Only an inexpensive driver and the AFT09MS007 are required to provide the 7 W required for handheld radios or the AFT05MP075 to produce a 55 W+ amplifier for vehicle-mounted radios.*

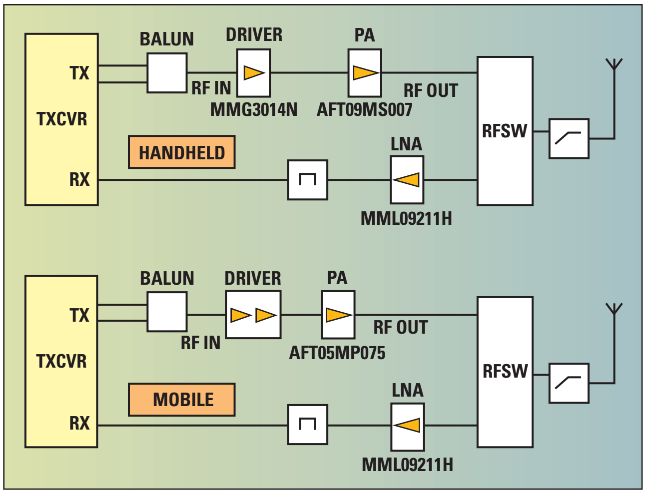

Fig. 2 *Typical circuits for handheld and vehicle-mounted radios using these new devices.*

the same 1.1 W input. Efficiency is similar at the higher power condition.

The AFT09MS007 is shown operating into a single broadband UHF fixture. The fixture shown is tuned for 350 to 490 MHz. At a power output of 8 W, the device exhibits typical gain of 13 dB and efficiency of greater than 60 percent across the band. For lower power operation, the device has also been tested at a power output level of 6 W. Under this condition, the device shows typical gain of 11.8 dB and typical efficiency of 63 percent.

In addition, as the devices have high gain and efficiency, the rated output power of the end product can be satisfied using fewer amplifier stages, further building on the previously mentioned advantages of reduced parts count, board space and cost. Both the AFT09MS007 and AFT05MP075 employed as the final amplifier in a handheld and vehicle-mounted transceiver (respectively) can deliver their rated power when driven by a single, inexpensive driver amplifier.

Figure 2 illustrates typical circuits for handheld and vehicle-mounted radios using these devices. In the handheld circuit, Freescale's MMG3014 directly drives the AFT9MS007 in the transmit path and Freescale's MML09211H low-noise amplifier is employed in the receive path. In the vehicle-mounted radio diagram, a broadband general-purpose amplifier directly drives the AFT05MP075. In both cases, rated output power is achieved using only two devices (see ***Table 1*** for key device parameters).

Both Airfast devices also have integrated stability enhancement circuitry, which is particularly desirable for the AFT05MP075 as it draws its DC power from a vehicle battery. Although vehicle power supplies are regulated, their voltage can vary dramatically from 12 VDC to as low as 10 VDC and as high as 17 VDC depending on environmental and other conditions. Transceivers typically have power monitoring circuits that maintain stable RF performance under varying power supply voltages, but when voltage drops, the circuit boosts the RF input power to driver amplifier to compensate. The stability enhancement circuits within the devices compensate for the effects of these conditions, so they remain stable in severe under- and over-voltage conditions produced by idling, a faulty regulator or battery, hot underhood temperatures, as well as varying ambient temperatures encountered throughout the seasons.

The two new devices join a growing family of Airfast LDMOS and GaN RF power transistors for land mobile radio applications as well as "MRF" series LDMOS FETs that operate from 7.5 to 12 VDC. The AFT09MS007N and AFT05MP075 are available now and are supported by reference designs, evaluation boards, and other designer resources.

Freescale Semiconductor, Tempe, AZ (800) 521-6274, www.freescale.com/rfpower.

TABLE I

KEY AIRFAST DEVICE SPECIFICATIONS

	AFT09MS007N	*AFT9MP075*	*MMG3014 (driver)*
Frequency range (MHz)	136 to 941	136 to 520	40 to 4000
RF output power (W)	7.3	57	0.3
Gain (dB)	14.6 to 15	14.6 to 21	10 to 19.5
Drain efficiency (%)	71	68	19.5
Maximum RF input power	200 mW	1.5 W	316 mW
Load/mismatch ruggedness with no signal degradation, CW input signal	More than 65:1 input VSWR at all phase angles, 3 dB overdrive, 10.8 VDC (AFT9MS007) or 17 VDC (AFT9MP075)		
Matching	External	External	Internal
Power supply (VDC)	7.5	12.5 to 13.6	3 to 5
Other features	ESD protection, Internal stability enhancement		Active bias control
Plastic package	PLD-1.5	TO-270WB-4 or TO-270WB-4 gull	SOT-89

Battery Powered PIM Tester

Beginning in 1996, Kaelus, formerly Summitek Instruments, has focused on providing test solutions for passive intermodulation (PIM). The Kaelus PIM test instruments defined a global standard in manufacturing and field test. As technology evolved toward remote radio heads and installation at the top of the tower, a new instrument architecture was required in the interest of personnel safety and test convenience.

Kaelus seized this opportunity to start with a blank sheet of paper and designed a solution built for purpose and that capitalized on all of the lessons learned in delivering more than 4000 PIM solutions for field use over the last five years. The resultant product, named the iPA, is uniquely suited for top-of-tower test as well as the more traditional applications of bottom of tower, rooftop and in-building. The obvious configuration change needed was to get smaller and lighter without sacrificing functionality. This meant higher levels of integration and creative mechanical layout.

MECHANICAL: ROBUST, RUGGED, WEATHERIZED

To withstand the abusive environment of field testing and hoisting units to the top of the tower, Kaelus focused on creating a toughened design. This is immediately evident upon first glance. The rubberized enclosure, the solid metal enclosure, the shatter resistant display and the strategically located dual handles assure long term survivability. It is so tough, you can even drive a vehicle over it.

There are no open portals to allow water penetration and no fans, as it is passively cooled. And, for good measure, the iPA includes four integrated lifting hooks eliminating the need for special packaging to get it to the top of the tower.

SAFETY AND CONVENIENCE

Testing at the top of the tower is dangerous; particularly, if the test personnel are simultaneously trying to run the test equipment, observe the results and dynamically stress the RF path (flexing cables, tapping on connectors, tapping on the back of the antenna, etc.). To minimize the demand on personnel at the top of the tower, Kaelus integrated in a WiFi wireless access point and provides a WiFi-enabled tablet to accommodate remote control of the test by ground personnel. The remote control is a great convenience on rooftops where the PIM tester is connected back at the BTS and the test operator is remotely located near the antenna doing dynamic testing.

KAELUS (A SMITHS COMPANY)
Centennial, CO

TEST EFFICIENCY

Test site certification can be a time-consuming and costly exercise that must be performed with precision and the results accurately communicated to the customer – most often the wireless network operator. The iPA requires no time-consuming calibration process prior to use and the operator interface is simplified to minimize opportunities for taking errant data or misinterpreting the results. The Kaelus industry leading reporting developed for the iQA has been incorporated and enhanced in the iPA.

LOW COST OF OWNERSHIP

A key aspect of any test instrument is availability. The iPA builds on the experience of the industry stalwart of field PIM test equipment, the Kaelus iQA. The iPA's robust mechanical design has already been described. Complementing this is the high reliability of the electronics as well as the focus on serviceability and low cost to repair.

RF PERFORMANCE THAT MATTERS

The IEC specification for PIM test methods guides the design and the performance capability of nearly all PIM test solutions. Kaelus/Summitek has been active with the IEC committee on PIM for more than 15 years and helped define the test standard. Whereas the IEC recommends the test methods (two test tones at 20 watts per tone and measurement of IM3), for making a PIM measurement, it does not recommend what is an acceptable performance standard. This is left to the customer and the manufacturers.

Typical PIM specifications for manufacturing test are –107 dBm (–150 dBc) or better. For field testing, this is typically relaxed to –97 dBm (–140 dBc). This sets the performance requirements of the PIM tester. To keep measurement uncertainty to acceptable levels, the noise floor of the test instrument must be at least 10 dB better than the level being verified. It is important to note that the measurement noise floor is set by the thermal noise floor of the receiver, or the residual PIM (the PIM generated by the test setup), whichever is greater.

Implementing a high performance receiver subsystem with a noise floor better than –107 dBm is relatively straightforward. The iPA specification is significantly better than this at –128 dBm. The challenge is providing low residual PIM – not just at time of manufacture, but with a design that maintains this performance despite the abuse the unit will absorb as a field test tool. This is where the Kaelus PIM test solution excels. The Site Solutions division of Kaelus is known for designing, manufacturing and delivering high performance, low PIM. These same engineers provide the technology used in the PIM test equipment. The residual PIM is conservatively specified at –117 dBm (–160 dBc), but is typically better than –125 dBm (–168 dBc).

The Kaelus iPA family of battery powered PIM test equipment builds on the legacy and experience of more than 15 years addressing this measurement application. The iPA is a superior solution providing the very best in ruggedness, reliability, performance and utility.

Kaelus (a Smiths Company),
Centennial, CO
(303) 768-8080,
www.kaelus.com.

Connector System for Mobile Communications Market

The newly developed 4.3-10 connector system is designed to make the deployment of mobile communications infrastructure easier, more reliable and more powerful. The new connector system has been developed from scratch with the increasing demands of the modern communications market in mind. In comparison with previous connector systems that have been developed for other purposes, this brand-new system has several advantages.

With the new 4.3-10 connector family, the industry is responding to the changing demands for modern mobile communications infrastructure and addressing the fact that as base stations and antennas become more compact, the large size of existing connectors can be a restricting factor. In particular, as more and more frequencies are released for mobile communication carriers, the problem of passive intermodulation (PIM) is increasing. And in the field, the connectors that would normally be used often resulted in problems if they were not mated with the correct torque.

SMALLER & LIGHTER

When designing the new connector, the most important requirement was to decrease size and weight compared to the 7-16 connectors used previously but without losing the possibility of feeding the signals of several mobile carriers over a single line. With a maximum 500 W CW transmission power at 2 GHz, the 4.3-10 connector system has more than enough power capability for today's and even future demands. An inner diameter of 4.3 mm combined with a 10 mm outer conductor are more than adequate for this kind of power. Furthermore, the footprint of the fixed socket has been reduced from 1.26 × 1.26 inch in the 7-16 system to 1 × 1 inch, and the weight reduced by 60 percent.

A totally new connector design was required because of the well-known PIM problems of existing connectors. The PIM performance of all currently used systems relies on the torque applied to the coupling nut. If the nut is acci-

SPINNER GmbH
Munich, Germany

▲ *Fig. 1 The three coupling mechanisms include the existing screw type and two new ones: a hand screw version and a push-pull type.*

dentally not tightened correctly, poor intermodulation values are the result – a nightmare in today's multi-carrier and multi-frequency mobile networks.

SPRING LOADED RADIAL BUSHING

The 4.3-10 connector system separates the mechanical and electrical reference planes, which was not the case in previous systems. Instead of a direct contact dependant on the torque of the coupling nut, a spring loaded radial bushing is used for the outer conductor. This means that no additional coupling force is needed and the connector is immune to PIM. PIM is excellent even when mechanical force is applied to the connection, which is also a requirement of IEC 62037.

The concept of the separated mechanical and electrical reference planes has some other advantages too. Since mechanical pressure was no longer an issue, besides the existing screw type, it was possible to design two new coupling mechanisms that do not require any installation tools: one hand screw and a push-pull type. All three (shown in ***Figure 1***) have excellent PIM performance even under mechanical stress, allow for a very high packaging density of one inch and use the same universal socket.

With these characteristics, the new connector system is very versatile and allows for installation in confined conditions where tools cannot be used. In effect, the 4.3-10 connector system opens the door for a new and more compact generation of mobile communication components.

ALL STANDARDS COVERED

The 4.3-10 connector system is designed for frequencies up to 6 GHz, which covers all the current mobile communication standards. All contacts and seals are protected against mechanical damage, which gives the system excellent mechanical properties and ensures its role as a modern alternative to the established connector systems in mobile communications.

The new system is currently in the standardization process at DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) and the International Electrotechnical Commission (IEC). Connectors, test and measurement equipment as well as jumpers will be available by the end of 2013.

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www.spinner-group.com.


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High Isolation, Carrier-Grade Wi-Fi Switch

Peregrine Semiconductor has developed one of the highest performance carrier-grade Wi-Fi switches on the market. With the very high isolation, Peregrine's switch also sets a high bar in linearity, which makes it ideally suited for the fast-growing market of 802.11ac Wi-Fi access points. Based on Peregrine's UltraCMOS® technology, the PE42423 is the first in its class to offer 41 dB of port-to-port isolation at 6 GHz. This best-in-class isolation enables multi-radio access points to perform at peak levels without interference between the radios. Exceeding the stringent 802.11ac standard, Peregrine's switch also offers 65 dBm of linearity to achieve higher data rates.

In addition, UltraCMOS technology delivers equally high performance at either 3.3 or 5 V, unlike GaAs switches that experience performance degradation below 5 V. Peregrine's switch gives networking-product designers the flexibility to operate at lower power supplies and reduce energy consumption.

Peregrine's PE42423 is a single-pole double throw (SPDT) RF switch featuring low insertion loss (0.8 dB at 2.4 GHz, 0.95 dB at 5.8 GHz), fast switching time (500 ns) and high ESD ratings (3.0 kV HBM on all RF pins). It operates over a wide frequency range from 100 MHz to 6 GHz and supports 802.11 a/b/g/n/ac. In addition, it has high power handling of 38.5 dBm at 2.4 GHz and 37.0 dBm at 6.0 GHz. The switch supports +1.8 V standard logic control. It provides stable and consistent RF performance over a power supply range between 2.3 and 5.5 V. The packaging is RoHS compliant, 16-lead QFN and measures 3 × 3 mm. Peregrine is committed to meeting the Wi-Fi data-rate and capacity demands of the future, and it is already helping networking vendors achieve unprecedented performance using this switch in their Gigabit Wi-Fi access points.

Peregrine Semiconductor,
San Diego, CA,
www.psemi.com.

Space Saving Components

Aeroflex / Weinschel is a leading manufacturer of high power attenuators and terminations, covering 25 to 1000 W. Although these are good as free standing units for a lab environment, they are not suitable for system integration with package density constraints. To meet that demand, Aeroflex / Weinschel has introduced a new series of slim, low profile (flat pack) conduction cooled coaxial fixed attenuators and terminations to be utilized by cellular carriers and defense integrators who find the need to deploy broadband high power, high performance RF components needed at a system level.

Aeroflex / Weinschel's newer flat pack design provides the end user the capability to design smaller form factor solutions for tightly confined telephone closets, cable end heads, DAS cellular repeater stations and tactical RF transmission systems. Optimized for use in the most common communications bands, these new designs offer DC to 6 GHz frequency range coverage in 50, 100, 250, 400 and 550 W average power handling and 10 kW peak, conduction cooled configurations with a choice of Type N or SMK (2.92mm) male or female connector options. Attenuators are available in values of 6, 10, 20, 30 and 40 dB.

Other key features include:

- Low IM distortion option
- Precision connectors with high temperature support beads
- Designed to meet the environmental requirements of MIL-DTL-3933
- Rugged construction
- Custom configurations available.

VENDORVIEW

Aeroflex / Weinschel,
Frederick, MD,
weinschel-sales@aeroflex.com,
www.aeroflex.com/weinschel.

COMPANY SHOWCASE

Pulse Measurement

VENDORVIEW

Agilent Technologies Inc. introduced a pulse measurement option for its FieldFox handheld analyzers that is designed to further simplify radar field testing. Testing radar in the field can be challenging due to the multitude of instruments engineers and technicians are required to carry. With the new pulse-measurement option, Agilent's FieldFox analyzers allow users to carry a single instrument into the field to verify and measure radar pulse characteristics, S-parameters, spectrum analysis and transmitter power.

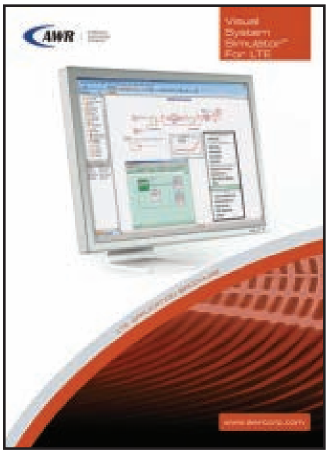
Agilent Technologies Inc.,
www.agilent.com.

RF and Microwave Technology

VENDORVIEW

Anaren Inc. is a Syracuse-based, global leader in RF and microwave technology used by in wireless infrastructure, satellite, defense and consumer-electronics applications. The company has approximately 1000 employees and five state-of-the-art facilities worldwide. Product lines include: standard passive components (e.g., couplers, power dividers, baluns, resistors, attenuators, terminations), RF multichip modules, high-reliability softboard and ceramic PCBs, and complex assemblies (e.g., switching, beamformers, antenna feed networks, DRFMs, IMAs).

Anaren Inc.,
www.anaren.com.

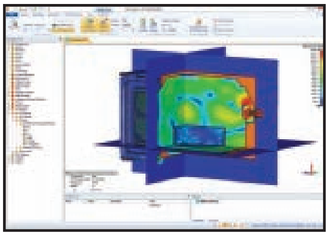


Visual System Simulator Software

VENDORVIEW

The new AWR Visual System Simulator™ for LTE brochure provides information for RF/analog engineers on effortlessly evaluating and providing the best performance possible for today's demanding LTE communication systems. The capabilities in VSS for LTE help designers cut system costs by ensuring that components are not over-specified and needlessly expensive and reduce time-to-market by eliminating iterations and rework. Learn more about VSS for LTE online and download the brochure at www.awrcorp.com/VSS.

AWR Corp.,
www.awrcorp.com.

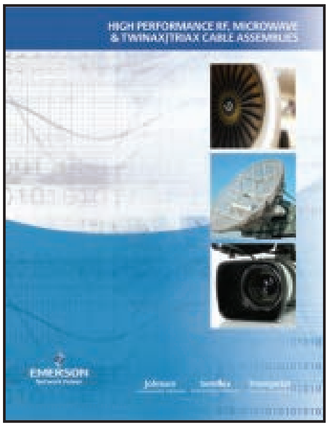


EM Simulation for Mobile Communications

VENDORVIEW

As mobile communication devices become thinner, smaller and more complex with every generation, designs need to meet new standards of performance. Using electromagnetic (EM) simulation, engineers can not only design and optimize the antenna of mobile devices, but also test its performance within the handset, for example, by evaluating coupling effects and the impact of dielectric materials, and investigating the influence of the human body on performance. Find out more about CST STUDIO SUITE®, an EM simulation tool, at the company's website.

CST, Computer Simulation Technology AG,
www.cst.com.



Cable Assemblies Catalog

Emerson Network Power Connectivity Solutions has a wide range of cable assemblies suited for RF and microwave signal transmission. Emerson Connectivity Solutions is a vertically integrated supplier of custom, fixed length and semi rigid cable assemblies from DC to 50 GHz. The company can create custom cable assemblies to satisfy your specific application requirements, also with manufacturing in the United States, United Kingdom and China; it has a cable assembly to meet any price requirement.

Emerson Network Power Connectivity Solutions,
www.emersonnetworkpower.com.

4.3-10 Connectors

HUBER+SUHNER 4.3-10 connectors offer very low PIM performance together with weight and compactness advantages. A key feature of this connector is the separation of the electrical and mechanical plane, which results in a lower coupling torque and the possibility of offering the connector with screw, hand-screw and quick-lock design, thus simplifying the installation effort and offering for all mechanisms a very high electrical performance. The 4.3-10 connector system is designed to meet the rising performance needs of mobile network equipment while also reducing its size.

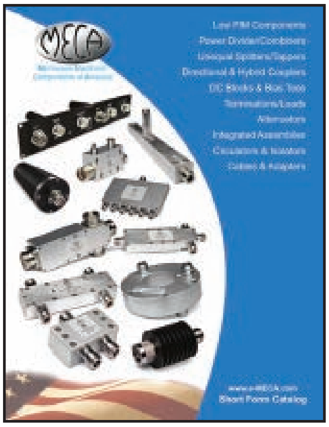
Huber + Suhner,
www.hubersuhner.com.

COMPANY SHOWCASE

Passive Intermodulation Testing

The iPA is the first battery powered PIM test analyzer versatile enough to support multiple test scenarios such as testing at the top of the tower, base of tower, roof top and in-building for DAS systems. Designed for purpose, the iPA features a rugged design and robust software to assure the product is available when you need it, performs as expected and provides reliable results. And the integrated wireless access point makes remote control easy to configure and use.

Kaelus,
www.kaelus.com.



Components Catalog

VENDORVIEW

Celebrating its 52nd anniversary, MECA (Microwave Electronic Components of America) designs and manufactures an array of RF/microwave components with industry leading performance, most recently low PIM products. MECA is recognized worldwide as a primary source of supply for rugged and reliable components to commercial and military OEMs, service providers and installers by only providing products made in the USA. Download the company's components catalog at www.e-meca.com/pdfs/MECA_Short_Catalog2013.pdf.

MECA Electronics Inc.,
www.e-MECA.com.

Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW

Reactel offers a variety of filters, multiplexers and multifunction assemblies for the mobile communication industry. Reactel's experienced engineers can come up with a creative solution for all of your Tx, Rx or Co-site requirements. Reactel has designed a broad range of filters from high power units operating to 5 kW and beyond to extremely small ceramic units that are suitable for handheld or portable applications. The company's product line includes bandpass, lowpass, highpass and notch filters as well as multiplexers and multi-passband filters. Offering fast turnaround, competitive pricing and high quality, Reactel can satisfy most any requirement you may have.

Reactel Inc.,
www.reactel.com.

Communications, Power Conversion and Renewable Energy Products

VENDORVIEW

Richardson RFPD Inc., an Arrow Electronics company, is a global leader in the RF and wireless communications, power conversion and renewable energy markets. Relationships with the industry's top component suppliers enable Richardson RFPD to meet the total engineering needs of each customer. Whether it's designing components or engineering complete solutions, Richardson RFPD's worldwide design centers and technical sales team provide support for all aspects of customers' go-to-market strategy, from prototype to production. More information is available online.

Richardson RFPD Inc.,
www.richardsonrfpd.com

Switch Matrix

VENDORVIEW

Mini-Circuits has introduced the USB-1SP4T-A18 switch matrix to its growing lineup of switch matrix test equipment. This new unit covers a wide frequency band from DC to 18 GHz and is useable for most test lab applications. A durable RF switch promises exceptional longevity of 100 million cycles and typical switching time of 25 milliseconds. Extremely low insertion loss (0.2 dB typical) and high on/off isolation (85 dB typical) make the USB-1SP4T-A18 a versatile, high-performing, and economical solution for a wide variety of RF applications.

The USB-1SP4T-A18 is packaged in a rugged metal casing small enough to fit in a brief case with room to spare. It is configured with five SMA(F) connectors (COM, 1, 2, 3 and 4), a 2.1 mm DC socket and a USB type B control port. Switch position is clearly indicated both on the control screen with a simple schematic and on the device itself with green light "on-position" indicator located on the front panel adjacent to each of the output ports. Like all Mini-Circuits portable test tools, the USB-1SP4T-A18 is supplied with easy-to-install, easy-to-use GUI software with an API DLL com object. USB-1SP4T-A18 switch matrices are available off-the-shelf for immediate delivery at an outstanding value.

Mini-Circuits,
www.minicircuits.com.

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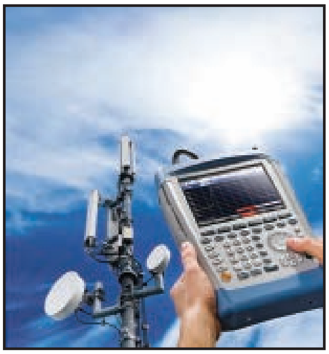
COMPANY SHOWCASE

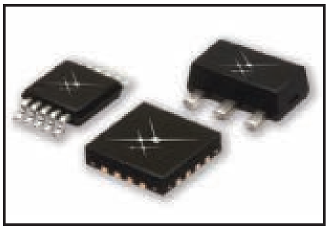


Test Solutions

VENDORVIEW

Rohde & Schwarz is the only test equipment vendor to provide solutions for the entire lifecycle of a mobile network; from planning and installation to optimization and operation. This approach enables operators to ensure the performance of their network. At Mobile World Congress 2014 Rohde & Schwarz and its subsidiaries SwissQual and ipoque will be exhibiting solutions for all network phases. Visit booth B50 in hall 6 to learn more about this integrated set of test solutions.

Rohde & Schwarz GmbH & Co. KG,
www.rohde-schwarz.com.



Discrete and Integrated RF Solutions

VENDORVIEW

Skyworks Solutions Inc. is an innovator of high performance analog semiconductors. Leveraging core technologies, Skyworks supports automotive, broadband, cellular infrastructure, energy management, GPS, industrial, medical, military, wireless networking, smartphone and tablet applications. Visit the company at GSMA Mobile World Congress to learn more about its broad product portfolio of highly integrated front end solutions as well as discrete components for mobile platforms including smartphones, tablets, data cards and GPS systems.

Skyworks Inc.,
www.skyworks.com.

Mobile Communication Portfolio

SPINNER is a global leader in developing and manufacturing state-of-the-art RF components. The company's mobile communication portfolio, which includes jumper cables, surge protectors, and diplexers, supports all major communications networks worldwide, such as LTE, WiMAX, UMTS, GSM, GSM-R, TETRA. It provides all passive components between base station and antenna. The portfolio delivers innovative solutions and systems for multiple uses by outdoor and indoor antennas and is internationally registered with all major system houses and network operators.

SPINNER GmbH,
www.spinner-group.com.