Bullish on Barcelona

A Preview of Mobile Technologies

GSMA MOBILE. WORLD CONGRESS

Mobile Communications 2012

A Special Supplement to

Microwave Journal

Frequency Matters.

Mobile Communications

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Wireless Trends to Look for at MWC 2013

What technologies will increase capacity and address the network constraints that are a reality with the ballooning demand for data and video services? How soon will test equipment and RF modules be needed to support the rollout of LTE and other 4G services? What infrastructure changes will be needed to increase capacity and how will those affect testing needs? What other network options are available to address these challenges?

This year *Microwave Journal* asked some of the leading test & measurement and semiconductor device manufacturers what they think will be the hot topics and key technologies for GSMA Mobile World Congress 2013 in Barcelona. Participating on the test & measurement side are Agilent Technologies, Anritsu and Rohde & Schwarz. On the semiconductor device side are articles from RFMD, Skyworks and TriQuint Semiconductor.

The number of cellular bands is ever increasing and having a world phone with all the LTE bands plus compatibility with older generation networks becomes a challenge. Supporting all these bands in a small form factor also consumes more and more power. What are some of the solutions to reduce power consumption while still reducing the cost and size of RF modules? The device manufacturers will address this challenge along with ways to increase integration and improve time to market, including key trends in passive and active solutions for future handsets.

These are some of the challenges and questions that will be answered by these leading companies in the RF/microwave industry as we look forward to Mobile World Congress 2013. As you will read, there are some definite trends that each company mentions and key technologies to watch out for next year.

Patrick Hindle
Microwave Journal *Technical Editor*

MORE DATA, MORE ANTENNAS AND MORE CELLS

Agilent Technologies

The explosion of data traffic will continue in 2013. One of the main concerns for mobile operators is to optimize the use of the available frequency bands. It drives the industry to continue rapid deployment of new technologies and network infrastructures to face the ever growing need for greater capacity. There are three areas of focus that will challenge the industry in the coming year.

LTE-A & Carrier Aggregation

2013 will see an acceleration in development of LTE-A and carrier aggregation techniques. Wireless equipment manufacturers and chipset manufacturers will face more and more complex RF tests to develop further modems supporting those techniques. To address these challenges, there is a need to test components with an LTE-Advanced downlink and uplink signals compliant to the 3GPP Release 10 standard. Signal generation software must generate up to five component carriers simultaneously in both contiguous and non-contiguous carrier configurations and to place them anywhere within the modulation bandwidth of the signal generator — up to 100 MHz. For analysis, the LTE-Advanced application needs to support carrier aggregation for both FDD and TDD, UL and DL and contiguous and non-contiguous allocations. So test software needs to provide for analysis of up to five component carriers simultaneously and independent measurement setup for each component carrier, including varying bandwidths, for individual component carriers (CC).

LTE Infrastructure Volume Deployment

For network development, 2013 will see a massive LTE infrastructure deployment which will lead to a growing demand for system capacity enhancement tests (MIMO OTA testing, MIMO beamforming, WiFi fallback) and LTE conformance tests.

Operator Acceptance and Roaming:

Each operator has dedicated requirements and a feature set on the LTE network that need to be addressed in mobile device testing. Moreover, in 2014, all LTE devices will need to go through certification and GCF and PTCRB in order to ensure roaming capability between all service providers. Agilent is addressing these compatibility requirements with a product line that delivers RF, RRM and protocol certification with the most integrated and cost effective product platform on the market.

On the user equipment side, the future test challenges in the LTE Releases 9, 10 and 12 includes energy saving, battery drain and user profiling. Agilent provides solutions such as interactive functional test (IFT) software with an automated and simplified interface to qualify and characterize battery drain and user profiling that meets operator acceptance criteria and allows mobile device power management unit optimization.

Microcells, Picocells & Metrocells

Finally the third challenge next year is to increase capacity while reducing cost. There will be a growing use of microcells, picocells and metrocells. Those cells will need to be produced at a much lower cost than traditional ones and the test in manufacturing will need to be much faster. The challenge here is to perform more and more complex RF tests in less time and with lower cost than in the past. Vector signal generator (VSG) manufacturers need to increase the speed of testing to achieve lowest cost of test. Through exclusive baseband-tuning technology innovation, Agilent VSGs have enabled frequency and amplitude switchin g speeds as fast as 10 µs.

Source: Agilent Technologies

GETTING MORE CAPACITY

Anritsu

At MWC this year, Anritsu expects strong interest in measurement solutions addressing manufacturing and field testing, as LTE networks and devices become more prominent worldwide. Anritsu also expects attendees to look for test instruments that address a growing concern – Passive Intermodulation (PIM).

LTE

Rel 8 current deployments are focused on tuning and optimizing data rate throughput, managing coverage expansion (interference issues), and handovers. In addition, voice services (VoLTE) and supporting technologies like SRVCC will have a major push. On the applications side, the company expects to see the launch of new services that really begin to use LTE features such as capacity, peak rates and low latency.

Carrier aggregation offers up to 300 MB/s download rates, but importantly, allows operators with several small frequency band licenses to aggregate them together to offer

Source: Anritsu

customers high capacity and higher data rates. The other key technology is enhanced Inter Cell Interference Co-ordination (eICIC) to help interference in "full coverage" deployments. Currently, most LTE networks are "hotspot" coverage, and do not provide full coverage with no requirement for legacy networks to fill the gaps. When LTE is used with full coverage, interference can be a problem. This enhanced technology will reduce the problem and help operators provide full coverage.

Anritsu's LTE Signaling Tester has call-based LTE Advanced Carrier Aggregation testing capability. It can be used with its Rapid Test Designer (RTD) to create automated measurements, execute multiple test cases continuously, and generate test reports automatically. Also for LTE is another Signaling Tester that supports multiple formats, including LTE, W-CDMA, GSM/(E)-GPRS and CDMA2000. Optional VoLTE test capability has been added, with an internal CSCF server capable of authenticating and establishing loopback VoLTE calls, as well as providing the capability to select various server responses, including ignore and reject.

Vector signal generators today can generate test signals based on all leading technologies, including LTE and LTE Advanced, as well as W-CDMA/HSPA, CDMA2000, GSM and PDC, WLAN, Bluetooth® and ISDB-T. Anritsu's spectrum analyzer/signal analyzer is also well suited for multiple standards, as it offers advantages in measurement speed, dynamic range and ±0.3 dB (typical) total level accuracy.

WiFi

Offload and carrier WiFi are also key words being discussed. These are first steps in Heterogeneous Networks (Het Net), together with a big push for Home NodeB/picocells to help operators manage network capacity, and offload data from a 3GPP network to a WiFi network without affecting the user quality or experience.

To measure LTE and WiFi – as well as all other major wireless signals – in the field, some test and measurement manufacturers offer handheld analyzers. Anritsu's PIM analyzer incorporates patented Distance-to-PIM™, which shows the location of PIM problems within the antenna system, as well as distance to external PIM sources outside the antenna systems. Also available is a cost-efficient tool for tower contractors, installation and maintenance contractors, and wireless service providers to ensure optimum deployment, installation and maintenance of wireless networks.

LTE WILL RULE BUT DON'T FORGET 3G

Rohde & Schwarz

By mid-2011, the number of operators investing in LTE technology rose to 338 in 101 countries. Although growth was concentrated in U.S. and Asian markets, European (e.g., German) operators are also pushing on their LTE network deployments with the goal of reaching nationwide coverage. At roughly the same time, LTE became a true 4G technology according to the ITU definition. By adding features summarized in 3GPP Release 10 – also known as LTE-Advanced – the technology achieved IMT-Advanced performance requirements. The dominant feature of LTE-Advanced is carrier aggregation that provides a means of driving data rates up to 1 Gbps. The real driving force behind carrier aggregation, however, is to obtain much more efficient use of the fragmented spectrum allocations available to operators. Commercial introduction of carrier aggregation will start by the end of 2012. It will undoubtedly be a popular subject for many demonstrations at the Mobile World Congress in Barcelona 2013. This includes carrier aggregation testing solutions from R&S, which will be focused on R&D applications.

Although LTE has become the most popular technology, there are still plenty of improvements being added to 3G, mainly for data services based on HSPA. Therefore, achieving efficient operation of multiple technologies in heterogeneous networks remains a critical challenge. Data consumption will continue to grow exponentially and this will drive the development of strategies to move specific types of data services to WLAN on top of 3G/4G networks. This requires a closer integration of WLAN in mobile communication systems because the goal is to route mobile traffic based on the type of service that originated it. A particular operator, for example, may want to supply video services via LTE and e-mail services via WLAN whenever possible. This development will underscore the need for testing solutions that provide all relevant technologies and all required test scenarios – preferably in a single test device to shorten test time as much as possible. This is another important trend to look for at MWC 2013.

In addition to the need to verify that the technology is working as expected, there is the continuous trend to judge the performance on application layer. Network operators mostly care about their customers. Customer experience is just as important as verifying that a certain data rate is achieved. The discussion about how best to support voice-over-LTE – a technology that relies on packet switching – is a good example. Luckily, voice quality has been well understood in mobile communication since the early days of GSM and that makes testing voice-over-LTE a bit easier. On the other hand, video will be the main service driving data rate consumption. Its quality metrics are not nearly as well understood, particularly when the goal is to predict the end user's experience in a varying environment (for example, watching a YouTube video in a car in contrast to IP TV at home). Furthermore, there are several Internet services that people have become accustomed to using almost habitually. We are already well aware of so-

Source: Rohde & Schwarz

cial networking and online gaming, for example, but new applications will undoubtedly emerge. Consequently, the service experience as judged by a customer will matter more and more even though it may well be translated into KPIs like data rate, latency and (signaling) capacity.

The continuing strong growth in the smartphone and tablet market as well as M2M applications are the main drivers of the company's business for testing products in development and production. Although the economic situation in Europe must be taken into account by all multinational companies, Rohde & Schwarz is an independent company with a strong global presence.

EFFICIENCY, GLOBAL, MOBILE BROADBAND

RFMD

Key themes during MWC 2013 will likely be that mobile data usage continues to grow as rapidly as expected and mobile data creation is definitively on the rise. Additionally, cloud-based services will be larger than ever, providing access to streaming content, along with the security and convenience of not having files resident on an individual mobile device.

Consumer market demands inevitably have an effect on the RF platforms that suppliers create, and the combined changes ongoing in the cellular space are the most impactful seen over the last decade of cellular market growth. The RF-related topics most prominently displayed at MWC 2013 will be carrier aggregation (CA), envelope tracking (ET) and antenna control solutions (ACS).

The consumer's insatiable demand for data consumption is driving the rapid adoption of LTE at mobile operators (MO) across the globe. As discussed at past MWC events, the fragmented nature of LTE frequency bands across the world forces a tremendous increase in cellular RF content. With these LTE bands present, the mobile operators' aim is to maximize their operating frequency allocation to serve increasing consumer needs. CA helps address this MO need by maximizing utilization of available LTE frequencies. On the surface, CA is simply using the current frequencies in a different way; in practice, a highly complex CA implementation requires switch and filter innovation to effectively manage new functionality with minimal size and battery current penalty. Various solutions for CA, from discrete to highly integrated, will be prominent at MWC 2013.

Mobile devices are increasing their data creation capability — both video and picture — which has an RF impact by placing renewed emphasis on the efficiency of transmitting data up to base-stations. Unfortunately, the migration to higher order modulations (HOM) such as LTE to support higher upload speeds, combined with the move to multi-band power amplifiers, is having a negative influence on current consumption. ET has been discussed as the best way to lower current consumption, but remained an investigative technology — until 2013, when it becomes real. Multiple ET solution providers and multiple ET implementations will be available and leading the discussion on the ever-present topic of cellular RF current consumption reduction techniques.

The trend that will have the most dramatic impact on RF is the proliferation of cloud-based services. Increased demand for mobile download drives the need for receive diversity, MIMO, and CA technologies, while the increased need for upload extends the need for ET solutions to counter the increased transmit current consumption and perhaps extend battery life. In a mirror example, RFMD has an up-and-coming innovation in RF, which has a broad, positive impact on the ability to provide the best quality of service (QOS) for consumers — antenna control solutions. ACS, which includes the well-publicized antenna tuning technologies, seeks to provide much improved RF performance in the face of changing environmental conditions, such as antenna mismatch, and multiple antennas configurations, all while providing OEMs the ability to optimize antenna loading for both receive and transmit. Consumers should see direct impact of CA, ET and ACS though improved QOS and longer battery life.

Business, regardless of the market, is driven by consumer demand, and MWC 2013 promises to be rich with solutions and innovations for the RF industry.

PUT IT ALL IN ONE SMALL MODULE

Skyworks

Skyworks believes there are several important trends that mobile device manufacturers will be looking for at MWC 2013. These include higher levels of integration, envelope tracking and carrier aggregation.

With regard to higher levels of integration, manufacturers are seeking ways to incorporate all popular 2G, 3G and 4G bands, as well as switches and filters, into a single module for an unprecedented level of integration

Source: RFMD

and carrier coverage. These types of solutions will enable customers to design country-specific versions of a phone using the same printed circuit board (PCB) and simply changing several other components. In other words, no PCB change is required to offer multiple versions of the same model. This integrated approach will significantly reduce the amount of required design resources, enabling OEMs to utilize a single core design team to simultaneously release multiple handsets for multiple markets.

Manufacturers will also be seeking solutions that condense multiband power amplifiers (PA) and high throw switches along with all associated filtering, duplexing and control functionality into a single, ultra-compact package in an extremely small area. At the same time, they will require best-in-class linearity and power added efficiency (PAE) for smart RF integration — equating to significant board space savings, ease of implementation, performance and time-to-market advantages.

Envelope tracking, which improves the efficiency of PAs carrying high peak-to average-power-ratio signals, is yet another important trend. The drive for OEMs to attain high data throughput within limited spectrum resources requires the use of linear modulation with high peak to average power. Unfortunately, conventional fixed-supply PAs working in this environment have low efficiency.

Opportunities remain, however, to improve the PA efficiency by varying the amplifier's supply voltage in synchronism with the envelope of the RF signal.

Finally, given the need to achieve high data rate solutions that boost transmission bandwidths versus those that can be supported by a single carrier or channel, or carrier aggregation, this will be another topic of discussion at MWC. By using LTE advanced carrier aggregation, it is feasible to use more than one carrier and augment the overall transmission bandwidth.

ARE BRICK PHONES MAKING A COMEBACK?

TriQuint Semiconductor

The first cell phones were roughly the size of a two-liter soda bottle and weighed two pounds. They offered less than an hour of talk time, and the cellular radio required hundreds of RF components. It is absurd to think we would carry such unwieldy contraptions today, but as next-generation smartphones become increasingly complex, phone engineers face a daunting challenge: trying to squeeze ever more functionality and bigger batteries into sleek, lightweight form factors without compromising performance.

As multimedia applications like video streaming drive demand for faster connections through LTE and 802.11ac networks, RF content is increasing significantly. High-end super phones house a growing number of cellular and Wi-Fi bands to support 2G/3G/4G voice and data services, as well as global roaming. Because smartphones operate within the world's crowded RF spectrum, they also require more and better performing filters to ensure a satisfactory user experience.

Source: TriQuint Semiconductor

TriQuint is taking on this design challenge to simplify RF design and optimize performance by providing more capability in less space for their customers. They have made significant advancements in miniaturization, power efficiency and system performance leveraging active and passive process technologies to integrate the growing number of puzzle pieces into a few tiny modules — while conserving precious battery life.

TriQuint is seeing high demand for multi-band, multi-mode power amplifier modules (MMPA) so OEMs can support numerous cellular bands in less space. This gives them a common RF footprint to limit the proliferation of regional phones and speed design time. By streamlining their bill of materials, they can reduce costs and offer more affordable phones to spur greater adoption.

In addition to highly integrated amplifiers, TriQuint is seeing significant demand for filters. The filter market is expected to grow 10.5 percent annually, reaching $1.7 billion in 2016, driven by the adoption rate of WCDMA, LTE and Wi-Fi. SAW filters are a mainstay in today's smartphones, while BAW technology provides the only feasible means to meet the most demanding requirements for many LTE and Wi-Fi coexist filters.

As the company's engineers collaborate to optimize the RF front-end, TriQuint's operations and manufacturing teams are making packaging innovations to deliver better products faster. Newer technologies such as flip-chip use copper 'bumps' to replace wire bonds, which speeds assembly and improves performance along with wafer level packaging that enables smaller RF solutions with reduced height to help reduce cost and size.

TriQuint increased its manufacturing capacity by 40 percent in 2011 to support the one billion annual smartphone shipments forecast by 2016. TriQuint will utilize its integration capabilities to reach further and faster, to prevent the return of the brick phone. ■

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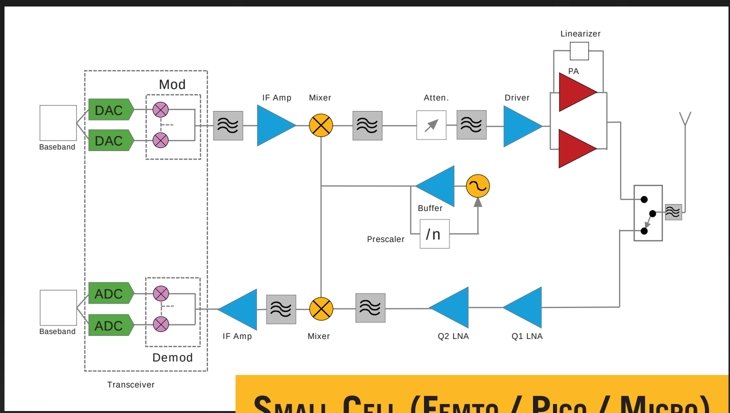

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Toward Full Coverage Voice Over LTE

As an all Internet Protocol (IP) packet environment, the Third Generation Partnership Project's (3GPP) Long Term Evolution (LTE) cellular radio standard was intentionally designed without support for existing circuit-switched voice services. The idea was that mobile operators would simply adopt this entirely new, IP-based infrastructure to replace their legacy 2 and 3G networks.

The industry may eventually move to LTE-only networks, with full coverage and all services – data, voice, SMS and Internet-enabled applications – being transported via IP on LTE. However, such an ideal could be 10 years or more in the future. Moreover, with devices available for use in both the home network and roaming situations, the cost to the operators of providing full LTE network coverage and the cost of legacy radio components being relatively low, it is unlikely that LTE-only devices will be made available any time soon, or that they would prove acceptable to consumers. Given the reality of this gradual migration to LTE, it is necessary to look at how LTE will interwork with voice services in 2G/3G. ***Figure 1*** illustrates how network technologies have evolved.

LTE uses a newer air interface technology based on Orthogonal Frequency Division Multiplex (OFDM) modulation, briefly considered for 3G, but available chipsets were considered too power-hungry for mobile devices at the time. Developments of other OFDM applications, such as digital TV broadcast and wireless LAN, have advanced chipset design so that this is no longer the case. To support its all-packet structure, a project concurrent with LTE defined Evolved Packet Core (EPC), a network architecture that simplifies signaling and moves more responsibility for in-session data management to the

Sandy Fraser
Agilent Technologies Inc., Santa Clara, CA

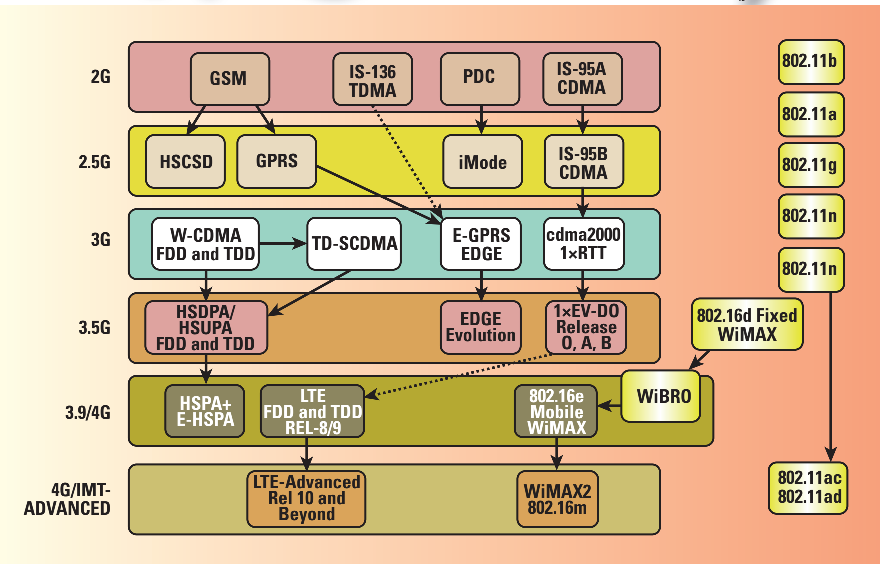

Fig. 1 Technology evolution from 2G to today.

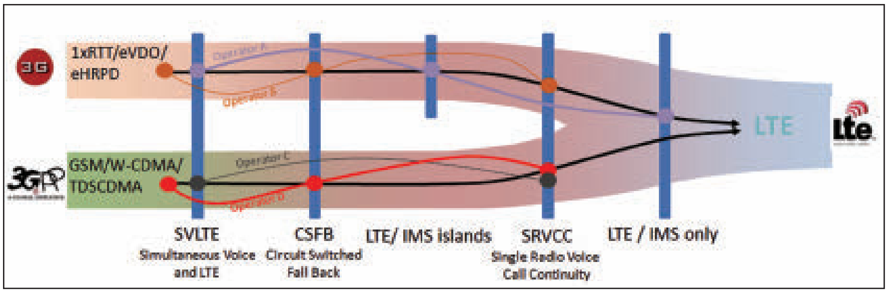

Fig. 2 Progress toward full voice service over LTE.

Evolved Node B (eNB) or base station. The resulting reduced latency makes packet-based voice services and high-speed data services, such as streaming video, possible.

Until voice service on LTE is generally available, there are two development paths. For operators in much of the world, where current networks are 3GPP GSM/W-CDMA/HSPA, there is a natural evolution to LTE and standards-based support for full backward and forward compatibility, both in the radio access network and the core network that lies behind it. Until LTE voice service is implemented, making or receiving a voice call will cause an automatic fall-back to the best 3G or 2G bearer available, where both voice and data service can be provided. Voice service is then provided by the inherent circuit-switched mechanism and continuing data service managed by radio resource release and re-assignment messages. This technique is known as Circuit-Switched Fall Back (CSFB). Fallback scenarios all the way to basic 2G GSM voice and GPRS data are defined.

In countries where current networks are 3GPP2 (cdma2000/1xRTT/1xEV-DO), integration issues are harder to resolve. Without exception, operators have chosen 3GPP LTE as their next-generation technology. While there is support in LTE for the discovery and measurement of neighbor 3GPP2 cells, the core LTE and 3GPP2 networks have major differences. The first LTE implementations will support only "non-optimized" data handovers where, when the client device (technically "User Equipment" or UE) loses LTE service, it has to acquire 1xEV-DO service. In idle mode this is not really an issue, but during an active data session it will cause some disruption. Later implementations will support "optimized" data handovers, where the UE will be directed to a new serving cell and have much more information about it. Voice service in both cases is supplied by a separate cdma2000 radio in the UE and known as simultaneous voice and LTE (SV-LTE); there is no integration of voice and data services and battery power consumption is compromised. ***Figure* 2** shows the steps to full voice service over LTE for both 3GPP and 3GPP2 networks.

VOICE SERVICE OVER LTE

Voice over LTE (VoLTE) provides a standardized system for transferring voice traffic over an LTE air access network and involves the use of Voice over IP (VoIP) and a core network, based on an IP Multimedia Subsystem (IMS), to provide rich voice services, including video calling. IMS provides the framework for delivery of IP multimedia. The main protocol for setup and connection control of these services is Session Initiated Protocol (SIP), which was designed to work with generic open IP networks. SIP provides the call setup and high level call controls and also provides extended services (in 2G/3G sometimes called supplementary services) such as call hold, multi-party calls, delivery of SMS, video calling, etc.

A number of operators worldwide have stated their intention to use the introduction of this technology to refocus attention on voice services and voice quality rather than on data connection speeds and have already set an expectation of the introduction of "premium quality" or "high definition" voice services. The preferred solution is Single Radio Voice Call Continuity (SRVCC), an approach that enables operators to deploy voice over LTE, seamlessly handing over to existing GSM W-CDMA and CDMA 1x installed coverage as needed, to provide a robust voice service with global reach to their LTE Smartphone users. (It is also possible that an operator may choose to confine such a premium voice service to LTE coverage areas only and simply disconnect the call if the quality of service cannot be maintained.)

Once VoIP/IMS service is available in an LTE network, there remains the challenge of moving a voice call to a legacy network if, for instance, the UE moves out of an LTE coverage area. SRVCC provides the ability to transition a voice call from the VoIP/IMS packet domain to the legacy circuit domain, when no LTE coverage is available. Variations of SRVCC are defined to support both the GSM/UMTS and CDMA 1x circuit-switched domains. If the legacy circuit-switched network also has an associated packet capability and is capable of supporting concurrent circuit/packet operations, the subscriber's data sessions can be handed over to the legacy network, in conjunction with switching the voice call from the packet to the circuit domain. In this case when the voice call finishes and the mobile re-enters LTE coverage, these packet sessions can be handed back to LTE. While SRVCC does not require modifications to the legacy radio access network (RAN), it does require a significant modification of the operator's legacy core and full deployment of IMS circuit-packet continuity services.

BUT (AND THERE IS ALWAYS A BUT...)

While the industry hype is all about LTE, many 3GPP-based operators have chosen HSPA+ (or evolved HSPA) as a more cost-effective short-term upgrade strategy. For these operators, most of whom have already deployed HSPA, HSPA+ is a software upgrade – ideal in these days of tight budgets. The option to have the HSPA+ network operate fully in packet mode for both voice and data updates the backhaul network to make future LTE deployment simpler: only the physical (base station radio) layer would need major upgrade.

The major goals of HSPA+, as defined by the 3GPP standards organization include:

- Exploiting the full potential of the CDMA physical layer before moving to the OFDM physical layer of LTE
- Achieving performance comparable with LTE in a 5 MHz channel bandwidth
- Providing smooth interworking between HSPA+ and LTE
- Achieving co-existence of both technologies in one network
- Allowing operation in a packet-only mode for both voice and data
- Being backward compatible with earlier user devices

Current visions show "HSPA+ Advanced" supporting over 300 Mbps downlink and almost 70 Mbps uplink – easily high enough to give a similar user experience to LTE – in proposed 3GPP Specification Release 11, scheduled late in the decade. It remains to be seen how the trade-offs between the further developments of HSPA+ and LTE will evolve.

An emerging industry term, "Voice over Mobile Broadband" refers to the end-to-end routing of VoIP/IMS voice service over not just LTE, but also over HSPA+. Whichever air interface technology is used, VoMBB allows carriers the opportunity to manage and optimize the flow of mobile VoIP traffic generated by Over the Top (OTT) applications and services (that is Internet-enabled Smartphone applications and services provided by third parties). This can potentially open up new models for charging of voice services and even possible relationships between carriers and OTT application developers.

IT IS MOBILITY THAT MAKES THE DIFFERENCE

Voice over Internet Protocol (VoIP) is not new – it has been around for many years in the fixed network and is the backbone behind much of today's landline voice traffic. Nor are many of the other technologies involved with packet-based networks – the IPv6 device addressing standard is probably the most recent – but there are new challenges in applying them to mobile networking.

We still see the landline as an analog copper pair, but in reality once it reaches the local exchange the network is all-digital. Designed initially for high-speed data services and adapted for voice, VoIP is a packet-switched environment that breaks transmission into manageable chunks and routes them from end to end in the most efficient way for the network. In the fixed network, effects such as error rate and latency are virtually zero and can be ignored, whereas in the mobile air interface environment they are major issues. Typical error rate in a fiber backbone is of the order of 1×10^{-20} where mobile devices make do with a threshold of 1×10^{-3}, so coding algorithms, error correction and re-transmission of failed packets absorb much more of the mobile network's time and bandwidth. Inherent latency in 2 and 3G systems means that packet-based voice services are impossible: a circuit-switched architecture with its built-in waste of resources, with either the forward or back channel silent part of the time, had to be provided. (Typical conversations are half-duplex, unless there is an argument going on!)

When VoIP packets are small, signaling overhead may be as high as 60 percent. Again, this is not an issue in high-speed fiber networks, where ultimate bandwidth is virtually limitless, but the same is not true in the mobile air interface. A single base station radio (eNB) may be communicating with many UEs at the same time – some idle, some in voice calls and others in data sessions – and has a finite total data bandwidth available to it. Consumers pay only for their net data usage, the operator absorbs the cost of the overhead and so would like it to be the least possible percentage of the traffic. Two of the mechanisms defined in the LTE standards to alleviate this signaling burden are semi-persistent scheduling (SPS) and transmit time interval (TTI) bundling.

Semi-Persistent Scheduling

In true dynamic scheduling, each sub-frame SF (1 ms) has to be allocated individually, leading to a high usage of the Physical Downlink Control Channel (PDCCH), a shared logical channel in the 3GPP LTE structure, where allocation information for each UE is carried. Voice by its nature involves lots of small resource allocations to many users, which, in a truly dynamically allocated network, leads to possible scheduling conflicts if everyone wishes to speak at once.

Fully Persistent Scheduling

Fully persistent scheduling – equivalent to a circuit switched call, where resources are permanently assigned to a UE – would waste valuable network resources, but would dramatically reduce the requirement on PDCCH resources. Semi-persistent scheduling (SPS) provides temporary but regular allocations, reducing load on the PDCCH without over-committing Physical Downlink Shared Channel (PDSCH) resources.

SPS is a compromise between fixed and dynamic scheduling, where a user is allocated a small amount of resource for a fixed period at regular intervals. It enables radio resource to be semi-statistically configured and allocated to a UE for a longer time period than one sub-frame, avoiding the need for specific downlink assignment messages or uplink grant messages over


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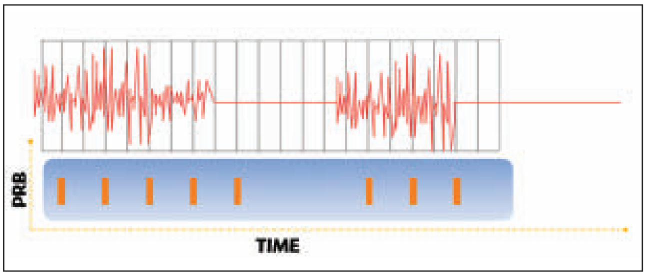

Fig. 3 *Semi-persistent scheduling.*

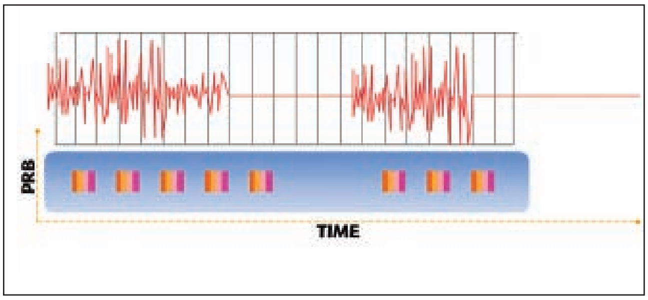

Fig. 4 *Transmit time interval bundling.*

the PDCCH for every sub-frame. It is useful for services such as VoIP, for which the data packets are small, periodic and semi-static in size; that is for the kind of service where the timing and amount of radio resources needed are predictable. Thus, overhead of the PDCCH is significantly reduced, compared to the case of dynamic scheduling. ***Figure 3*** gives an illustration. There are several studies available online discussing the various benefits of SPS versus Dynamic scheduling.

Transmit Time Interval Bundling

If it is at the cell edge, a UE can either increase power or increase coding rate to ensure good reception at the eNB. However, if a UE at the cell edge has reached its maximum available transmission power, it may not be able to transmit an entire VoIP packet during one TTI, since the required coding rate may make the instantaneous source data rate too high for the necessary relatively-well-protected transmission.

The eNB gets power headroom status reports from each UE, telling the network when the UE is at its power limit. The UE can also provide buffer status reports to say how much information the UE has in its stack. Using these pieces of information, the UE may be instructed by the eNB to use TTI bundling.

In TTI bundling, a VoIP packet is transmitted as a single packet data unit (PDU) during a bundle of subsequent TTIs, without waiting for the HARQ feedback. HARQ feedback is only expected for the last transmission of the bundle. Downlink signalling is reduced (less ACKs/NACKs) and round trip delay is minimized, but Uplink Shared Channel (ULSCH) capacity is slightly reduced. ***Figure 4*** shows an example.

MEASURING VOICE QUALITY

When testing the voice quality of a VoIP device, whether by Perceived Evaluation of Speech Quality (PESQ) or a Perceptual Objective Listening Quality Assessment (POLQA), there is a long list of test needs. The testing can be performed using audio analysis, signaling test (including connections to servers, conformance testing, radio aspects, and handovers for fall back support), battery drain analysis and SMS/video call testing. Operator-specific test plans and field testing may also be necessary. ***Figure 5*** shows a typical test setup for parametric audio quality and noise suppression test.

CONCLUSION

Regardless of the history and route to full packet-based voice services, the result is the same – a whole new slew of challenges for developers tasked with creating a range of different, more complex and more capable devices. Testing handovers between different radio access technologies (RAT) is becoming ever more important in the verification of LTE UEs. When out of the LTE service area, the UE will typically fall back to the network's 2G or 3G infrastructure. For a positive end-user experience, UEs need to transition smoothly between these technologies. Many of these test challenges will stem from the needed interoperability between legacy 3GPP or 3GPP2 technologies and LTE. Addressing these challenges and ensuring VoLTE delivers the standard of voice call the network operators want to provide, will require developers and operators to increase their focus on testing real-world performance, before deploying a new device on a live network. ■

Sandy Fraser *is a 25-year veteran of the RF and microwave industry with expertise spanning from DC to 100 GHz. Fraser's career includes over 15 years of experience with a cellular radio focus, including 12 years for Agilent, working on base station emulators for manufacturing test systems including the 8922 and the E5515. Today he is a leader in LTE technology awareness and training, specializing in LTE protocol and signaling. He holds a BSc in Mechanical Engineering from Glasgow University.*

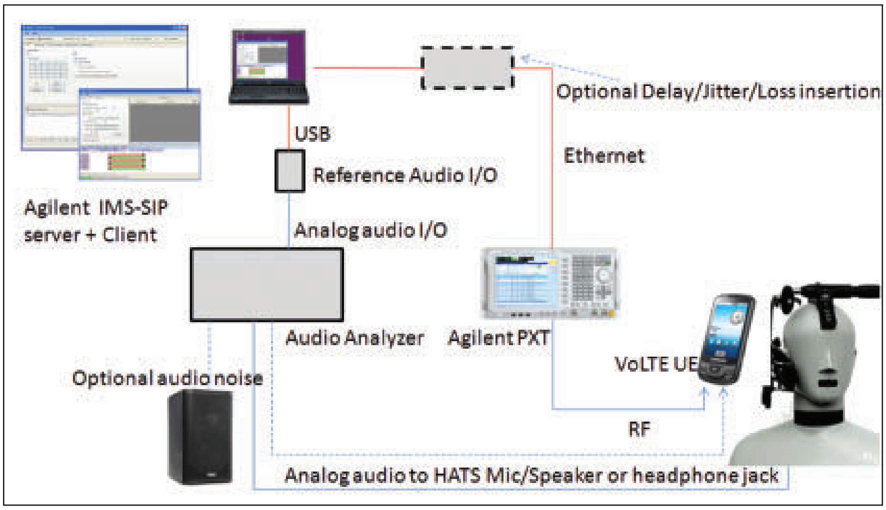

Fig. 5 *Typical parametric and noise suppression test setup.*

LTE-Advanced: The Challenges and Opportunities of "True 4G"

The cellular industry today is patiently looking forward to the deployment of LTE-Advanced, also known as Release 10 of the 3GPP's Long-Term Evolution (LTE) technology. While the "4G" label has been used to describe many of the services provided by cellular networks today, insiders know that true 4G LTE, as originally defined by the International Telecommunications Union, begins with LTE-Advanced.

The intended goal of 4G technology is to provide higher data throughput rates and better coverage. In order to meet the ITU's original 4G requirements, the technology must deliver a peak (low-mobility) downlink throughput of 1 Gbps and peak uplink throughput of 500 Mbps. LTE-Advanced also intends to deliver greater peak spectral efficiency of 30 b/s/Hz in the downlink and 15 b/s/Hz in the uplink, approximately double the efficiency of today's commercial-deployed "4G" technologies.

Toward that end, the industry has focused on three critical areas of improvement in LTE-Advanced: relay nodes, improved radio antenna techniques and carrier aggregation. The latter two directly affect the design and implementation of mobile devices (UE) and are further discussed in this article.

MIMO AND BEAMFORMING

Neither Multiple-Input-Multiple-Output (MIMO) nor beamforming antenna techniques are new with LTE-Advanced. Both techniques have been used in other radio communications technologies, besides cellular communications, for some years. In one of the industry's more interesting challenges, the two techniques are being combined into "MIMO beamforming" and will be a highly significant factor in the TD-LTE rollouts being readied in major markets in Asia.

Technically, MIMO beamforming transmission modes have been defined since the 3GPP's Release 8. However, the stated performance goals of Release 10 (specifically the data throughput rates in both downlink and uplink) were created based on the assumption that MIMO would be fully implemented. Release 10 introduces a new downlink transmission mode (Transmission Mode 9) that implements beamforming in an 8 × 8 MIMO scheme. It also officially introduces the use of MIMO in the uplink.

In MIMO beamforming, multiple antennas are used to create a polarized "beam" of

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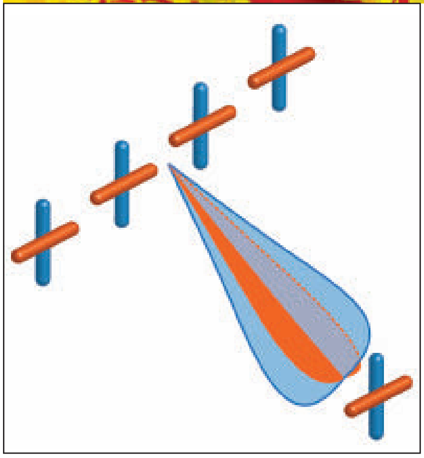

Fig. 1 *MIMO beamforming – two cross polarized beams.*

focused energy (shown as orange in ***Figure 1***). A second set of antennas (shown as blue in the diagram) creates a second beam that is cross-polarized in relation to the first. All of this happens in the same frequency band at the same time. The result is that the system can deliver multiple data streams (due to MIMO's ability to differentiate between the polarized beams) and can target those data streams in specific directions (due to the beams formed).

Both of these techniques are extremely complex, but at a high level, MIMO uses multiple antennas at both the transmitter and receiver to exploit space as a domain in which to increase data rates, or share time/frequency resources between users. At an equally high level, beamforming uses multiple antennas at the transmitter or receiver (or both) to increase coverage by focusing energy in specific spatial directions.

While it is important to note that TD-LTE technology is not characteristic of LTE-Advanced (it has been a part of the LTE family since Release 8), the combination of MIMO and beamforming is extremely important in TD-LTE. The timing of their availability coincides with large-scale TD-LTE deployments being planned in China, India, Japan and elsewhere. More significantly, MIMO and beamforming both require that a transmitter has some knowledge about the radio channel on which it is transmitting; in FDD-based LTE systems, this knowledge is acquired through feedback systems.

TD-LTE has a distinct advantage when it comes to deploying MIMO and beamforming. Since the uplink and downlink frequencies are the same, the eNodeB (base station) transceiver can analyze a received signal and use the collected information to form a reasonable estimate of the transmission channel. This eliminates the need for a feedback loop from the mobile device, which both expedites and eases the implementation of MIMO, beamforming and MIMO beamforming.

While this goal is well worth the effort, this added value comes at the cost of complexity in testing. Today's specifications include 8 × 8 MIMO beamforming mode, meaning that in the not-too-distant future, eight antennas will be transmitting and eight will be receiving, all at the same frequency and at the same time. The UE will have to process all received data in order to differentiate between all these data streams. In addition, certain radio characteristics (such as signal phase) take on new importance in MIMO beamforming, bringing complexity and the requirement for a new level of accuracy in the emulated channels used in lab-based testing. A new generation of channel emulation solutions, such as the Spirent VR5, has been developed to address this evolving need.

CARRIER AGGREGATION

Based on the throughput and spectral efficiency requirements of LTE-Advanced, a quick calculation shows that both the uplink and downlink require more than 20 MHz of bandwidth to achieve these targets. Due to the reality of the fragmented spectrum allocated to cellular technologies, finding sufficient contiguous spectrum is not an option in most cases. For this reason carrier aggregation, a distinct feature of Release 10, which addresses this spectrum fragmentation issue, is the most likely LTE-Advanced feature to be deployed on a large scale in the near future.

Carrier aggregation enables high data rates by combining multiple Release 8 carriers to support transmission bandwidths of up to 100 MHz. This approach provides several advantages:

- Backward compatibility with Release 8 and Release 9 channels
- Flexible dynamic scheduling to mitigate varying channel conditions
- Increased throughput rates

The spectral "building blocks" of an aggregated carrier are called "component carriers," each of which is the equivalent of a Release 8 carrier delivered by a separate serving cell. A UE using carrier aggregation will establish a link with one Primary Cell (PCell) and one or more Secondary Cells (SCells). Three types of carrier aggregation are defined: inter-band, contiguous intra-band and non-contiguous intra-band. ***Figure 2*** offers a graphical explanation of these terms. Because of global spectrum fragmentation, most deployments will implement inter-band carrier aggregation.

Carrier aggregation relies on new elements of the Radio Resource Control (RRC), Medium Access Control (MAC) and Physical (PHY) layers:

- RRC layer modifications deal with cell connection and handover processes and are outlined in the 3GPP RRC protocol specification (TS 36.331) and UE radio access specification (TS 36.306)
- MAC sub-layer changes accommodate the use of multiple cells and are described in detail in 3GPP TS 36.321
- PHY layer changes allow such options as cross-carrier scheduling, which enacts all scheduling on a single carrier (thereby reserving SCells for user data)

Other protocol layers such as the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) are not impacted by carrier aggregation. In fact, from the perspective of the user plane the aggregated carrier is a single bearer just like any other.

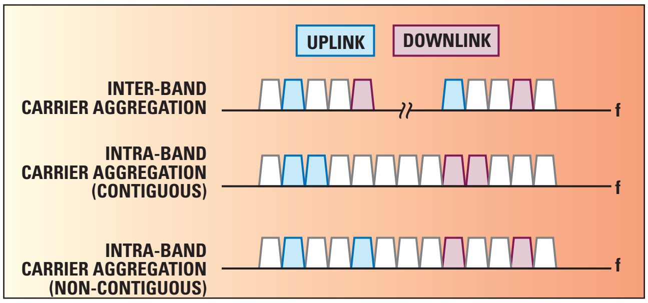

Fig. 2 *Three types of carrier aggregation.*

TABLE I
CARRIER AGGREGATION BANDWIDTH CLASSES

Carrier Aggregation Bandwidth Class	*Aggregated Transmission Bandwidth Configuration*	*Maximum Number of Component Carriers (CC)*
A	$N_{RB,agg} \le 100$	1
B	$N_{RB,agg} \le 100$	2
C	$100 \le N_{RB,agg} \le 200$	2
D	$200 \le N_{RB,agg} \le [300]$	Under Study
E	$[300] \le N_{RB,agg} \le [400]$	Under Study
F	$[400] \le N_{RB,agg} \le [500]$	Under Study

OTHER CONSIDERATIONS

UEs that support carrier aggregation are classified by aggregate bandwidths as a function of frequency, with each resource block occupying up to 200 kHz.

Release 10 includes provisions for six classes, but has only fully defined class A, B and C (as of the time this article was written). ***Table 1*** lists the definition of each class by the number of component carriers (CC) supported, as well as the aggregated resource blocks ($N_{RB,agg}$). Note that the aggregate bandwidth (BW_{agg}) is a function of frequency, with each resource block occupying up to 200 kHz.

As of Release 10, a UE must be able to report which bands are supported and the carrier aggregation capability for each band. Since some of the operators most interested in deploying carrier aggregation do not own spectrum in the bands defined in Release 10, they will likely deploy the technology in the bands they have available. A more widely-applicable set of configuration scenarios is likely to be defined in Release 11.

Meaningful testing of carrier aggregation techniques needs much more than just a radio-channel emulation solution. It requires the ability to readily create the protocol interactions that can exercise the UE's ability to manage all the possible combinations of carrier-aggregation scenarios.

CONCLUSION

LTE-Advanced introduces new device and network capabilities that will have a profound influence on the success or failure of next-generation cellular technology. Two of the more critical features are carrier aggregation and enhanced MIMO beamforming, technologies that add significant complexity to device development and bring us much closer to "True 4G." Due to the combination of feature importance and complexity in LTE-Advanced, UE testing takes on a new level of consequence. Realization of LTE-Advanced will not only require updates to existing testing tools, but also the creation of new and innovative tools designed specifically to help drive the success of this next generation of global wireless technology. ■

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Linearization and High-Efficiency RF Design Techniques for Small Cells

Three years ago, the concepts of "small cells" and "heterogeneous networks" were just beginning to be discussed and their importance as possible solutions to the growing consumer demand for data services was just starting to be understood. Today nearly the entire wireless infrastructure ecosystem including operators, original equipment manufacturers (OEM) and component vendors recognize that small cells deployed within a 3G/4G heterogeneous network will soon be necessary to maintain or establish highly competitive broadband service offerings. Based on the ever increasing demand for data services brought on by the popularity of smartphones and tablets, some dense urban environments have already run out of capacity causing dropped or limited data connections. Operators and equipment vendors will put forth different solutions to optimize cell size and coverage based on specific environments and consumer behaviors. In many cases, operators will support areas of high demand with small cells in order to offload the macro base-stations, thus creating an efficient voice overlay and data underlay.

The timing of broad small cell deployments will vary by region and operator, but it will tip in favor of subscribers when operators recognize that capital expenditures are necessary to maintain and grow revenues. This shift will likely be driven by dissatisfied subscribers who will switch carriers in an attempt to gain access to higher data bandwidth (BW) and more reliable and consistent coverage. By some estimates, the small cell market will experience this tipping point and see widespread adoption by mid-2014. However, between today and mid-2014, the cellular industry will need to solve some challenges including frequency planning, network deployment, management and maintenance, back-

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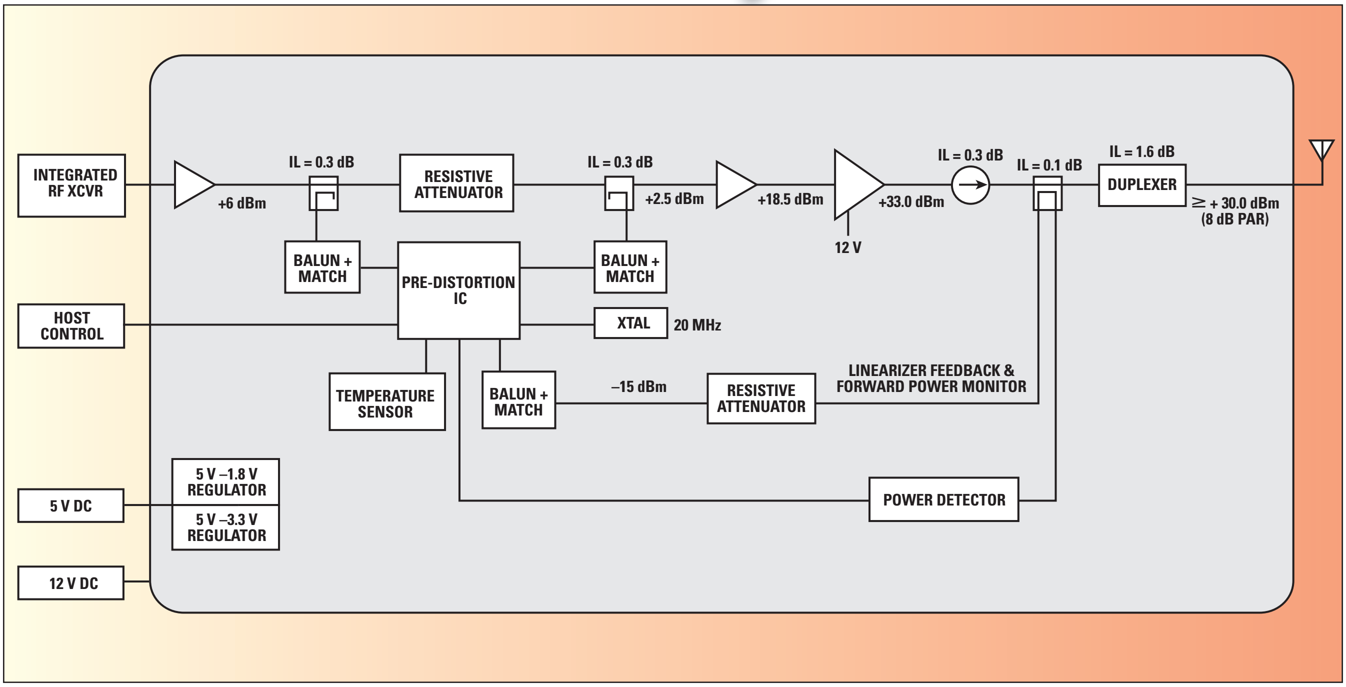


Fig. 1 Compact and efficient linearized 1 W (rms at antenna) transmitter design for small cells.

haul and siting. Furthermore, working backwards from mid-2014, one quickly reaches the conclusion that component solutions are required now in order to develop, test and deploy small cells in a timely manner. These high-level challenges can, to an appreciable degree, be translated as requirements down to the component level including control of output spectrum (RF power and ACLR), low power consumption (enabling low cost enclosures and power over Ethernet as possible backhaul and low cost indoor deployments) and long-term reliability (minimize in-field failures).

There is no widely accepted definition for small cells, but in order to offer a context for the solutions provided, the following definition will be used. Largely speaking, there are two types of small cells: unmanaged and operator-managed. Unmanaged small cells are those typically bought commercially and deployed by individuals or enterprises. These small cells like residential femtocells transmit at very low power, typically less than 0.25 W (rms) at the antenna, have limited coverage area and are not required to meet stringent performance specifications. For the most part, these unmanaged small cells are outside the scope of this article. As would be expected, operator-managed small cells have more stringent requirements than non-managed cells. First, these cells have higher output levels depending on the type of small cell. Average output power at the antenna ranges from 0.25 to 0.5 W for an indoor carrier small cell, 1 to 5 W for an outdoor picocell and 10 to 30 W for a microcell. Increased power provides increased coverage area thus reducing the number of units that need to be deployed, but also presents challenges for designers of these units.

Many vendors of small cells have started designs and face the decision of scaling down a macrocell design, scaling up residential femtocells or initiating a brand new design. Scaling down a macrocell design has proven to be expensive, power inefficient and suffers from long design cycles. These designs must carry forward a complex digital pre-distortion (DPD) and digital signal processing (DSP) architecture requiring an expensive field programmable array (FPGA) and a broadband transmit path accommodating both the desired signal and the correction signal – typically 5× of desired signal BW – thus forcing the use of a high-performance wide bandwidth discrete transceiver. Furthermore, the design cycle for such architectures can be quite long, even exceeding 18 months simply to optimize the DPD portion of the design. Therefore, many vendors have chosen the latter two paths in order to achieve low cost, low power consumption and a small footprint while still meeting the stringent performance requirements. This article will focus on design of a 1 W (rms at the antenna) outdoor picocell though the design can easily be migrated up in power by simply changing the PA and the pre-distortion solution within the RFPAL family.

Scintera and TriQuint working together with integrated transceiver vendors have developed a solution allowing rapid design of an outdoor 3G/4G picocell supporting LTE and WCDMA while also lowering the overall bill of material and system power consumption. This design (see ***Figure 1***) supports all major global cellular bands including 700, 900, 2100 and 2600 MHz and, based on the performance of the integrated transceiver, support up to 20 MHz of signal BW making it ideal for the large majority of designs that require support of a 10 or 20 MHz LTE (TDD or FDD) carrier, or of one to four WCDMA carriers.

The pre-distortion solution is a fully-adaptive, RF_{in}/RF_{out} predistortion linearization solution that precisely compensates PA nonlinearities including AM/AM and AM/PM distortion, spectral regrowth, memory effects and other system level impairments (see ***Figure 2***). It is optimized for Class A/AB and

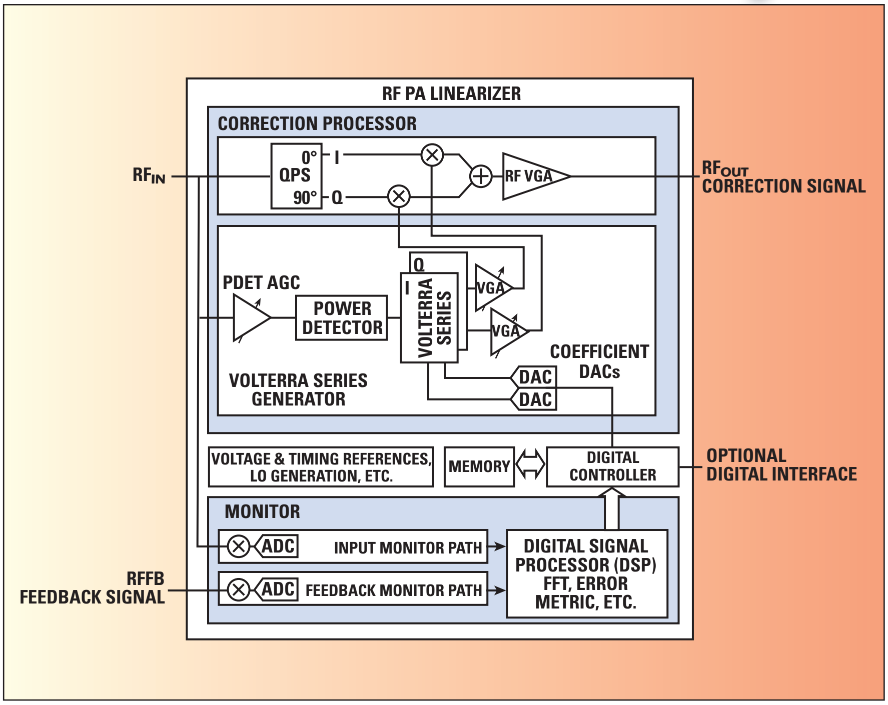


Fig. 2 Pre-distortion integrated circuit block diagram.

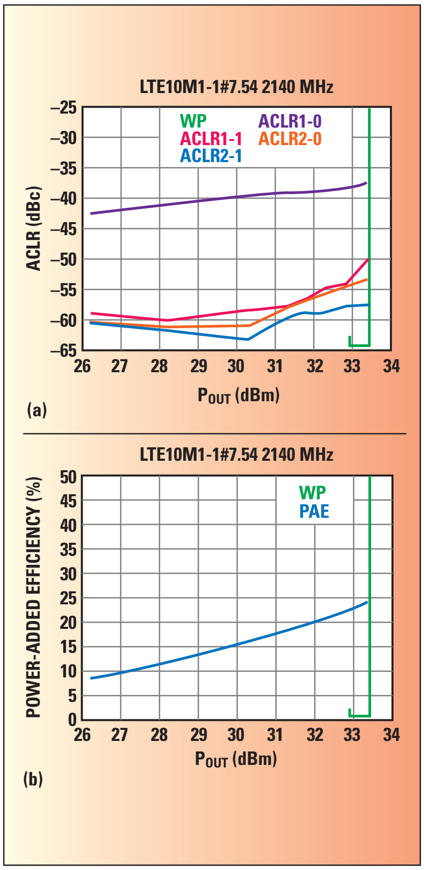


Fig. 3 ACLR performance (a) and PAE performance (b) vs. power.

Doherty RF power amplifiers operating at an average power level of 500 mW to 10 W (rms). The module measures the feedback signal from the power amplifier output, and optimizes the correction function by minimizing distortion. The correction function is based on a Volterra series with memory terms but uses a unique linearization architecture that shifts complex signal processing from the digital domain into the more computationally efficient analog RF domain thus allowing it to operate with very low power consumption.

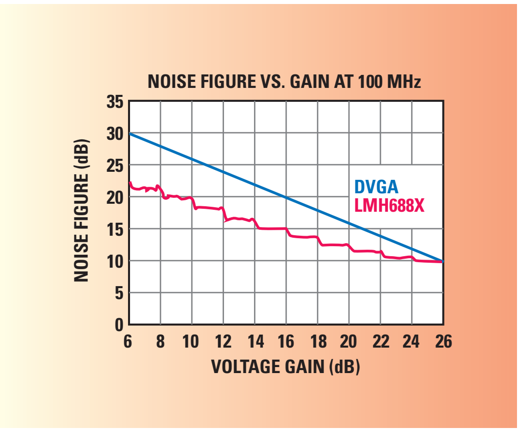
By compensating for these system level impairments, the integrated circuit allows a PA to transmit higher power at higher efficiency while still maintaining or exceeding the required system ACLR or distortion requirements. It can typically enable an existing Class A/B PA to transmit at least 3 dB more than the same PA operating in backoff. Now assuming that two different Class A/B PAs are transmitting the same power, the PA linearized will benefit from a 30 to 50 percent reduction in power consumption compared to the PA operating in backoff depending on the PAR and BW of the signal. The power consumption improvement even includes the integrated circuit power consumption which can be configured to be as low as 400 mW. It is important to note that some PAs may never reach desired linearity regardless of the amount of backoff with which they are operated. This situation may be experienced more often with wide BW and/or high PAR waveforms.

Using an example PA (TriQuint AP561) operating in linear mode and transmitting a 7.54 dB PAR waveform typical of what can be experienced with an LTE signal, the PA would in theory have an maximum rms operating point of 31.46 dBm – still more than 1.5 dB less than the required 33 dBm needed at the output of the PA in order to achieve 30 dBm at the antenna. However, when the PA is optimized for peak power in conjunction with the pre-distortion integrated circuit, the performance of the entire transmit path is significantly improved. As can be seen in ***Figure 3***, the pre-distortion provides 16 dB of correction easily enabling the PA to meet the –50 dBc linearity requirement at an operating point at nearly 33.5 dBm. Additionally, since the PA is able to operate at a much higher operating point, it is now able to achieve efficiency of greater than 24 percent.

This combination provides designers an innovative platform solution that may be brought to market very quickly using components available and in production today. With minor changes to the bill of material and no changes to the printed circuit board design, this solution can support all global cellular bands, 3G and 4G protocols including WCDMA, LTE. The solution can also support other protocols as well as varying numbers of carriers adding up to a total signal BW of up to 20 MHz or less. ■

A New Class of Amplifier, Programmable Differential Amplifiers

Texas Instruments recently introduced a new class of amplifier, the programmable differential amplifier (PDA), combining the best of fully differential amplifiers (FDA) and digital variable gain amplifiers (DVGA).



▲ *Fig. 1 The LMH688x PDAs offers better and more consistent noise and distortion performance over the entire gain range.*

Designing with high speed operational amplifiers (op amps) is often challenging. Simultaneously achieving high levels of performance across multiple specification requirements such as bandwidth, noise, distortion and impedance can be tricky. Anyone who has had an “op-amp afterthought” design experience will vouch for how tedious it can be to redesign and optimize the signal chain for a different gain value. The 2.4 GHz LMH6881 single-channel PDA and 2.4 GHz LMH6882 dual-channel PDA enable flexible and effortless signal chain design, allowing engineers to use one chip and one design for a broad range of applications.

In order to change the gain with a traditional FDA, an engineer would have to change the value of the external resistors, and then re-optimize the entire design. Additionally, the performance of a balanced signal path system

Texas Instruments
Dallas, TX

TABLE I

COMPARISON OF PDA VERSUS FDA AND DVGA

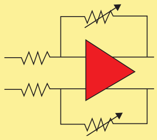
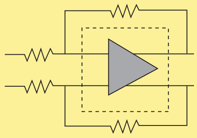
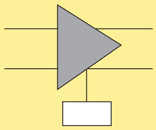
Feature	*LMH688x PDA*	*FDA*	*DVGA*
			
Gain Control	• Superior flexibility and accuracy • SPI control or dedicated pins	• Need to change external resistors for each gain setting	• Programmable gain control
Noise/ Distortion Performance	• Maintains noise and distortion performance over entire gain range	• Noise figure dependent on external resistors and changes with gain	• Noise figure increases dB-for-dB as gain is decreased from maximum gain
External Resistors	• No need for external resistors	• Four precision external resistors required per amplifier	• No need for external resistors
Bandwidth	• Nearly constant across gain range	• Bandwidth goes down as gain goes up	• Nearly constant across gain

TABLE II

KEY SPECIFICATIONS OF THE SINGLE-CHANNEL LMH6881 AND DUAL-CHANNEL LMH6882

Specification	*LMH6881*	*LMH6882*
Small Signal Bandwidth (GHz)	2.4	2.4
Gain Range, Gain Step Size	6 to 26 dB, 0.25 dB step size	6 to 26 dB, 0.25 dB step size
Noise Figure (dB)	9.7	9.7
OIP3@100MHz (dBm)	44	42
HD3@100MHz	-100	-100
Channel-to-Channel Matching: Gain/Phase	Not Applicable	0.2 dB/1.5 deg
Package	24-pin, 2.6 × 2.6 mm QFN	36-pin, 4.6 × 4.6 mm QFN

depends on precise matching of the external resistors. Unlike an FDA, the gain control in a PDA is programmable and does not require external resistors, thereby reducing both BOM cost and board space. Furthermore, gain is tightly controlled and performance is improved since well-matched external components are no longer required.

Next, consider signal chain design using DVGAs. While the DVGA does allow the same flexible programmable gain control as the PDA, its noise performance is not as good. A typical DVGA does not maintain its noise performance across the entire gain range. As attenuation is reduced, the DVGA's noise figure increases dB for dB. In contrast, the PDA's noise figure remains relatively flat across the gain range. Hence, PDAs offer better dynamic range performance across a wider range of gain settings versus traditional DVGAs (see ***Figure 1*** and ***Table 1***).

Both the LMH6881 and LMH6882 offer a gain range from 6 to 26 dB, with a 0.25 dB gain step size. The wide gain range and fine step size enables flexible gain scaling. The gain for these devices can be controlled in either of two modes: a serial mode control through the SPI bus, or a parallel mode control through dedicated pins. The parallel pin control mode provides a simple and quick design approach for engineers who do not want to write code to program their PDAs via the SPI bus. Both PDAs also exhibit high linearity: the single-channel LMH6881 provides an OIP3 of 44 dBm at 100 MHz input frequency, and the dual-channel LMH6882 delivers OIP3 of 42 dBm at 100 MHz. This excellent linearity helps address the demand for ever increasing bandwidth in communications channels.

With an input impedance of 100 ohms, both PDAs can be easily driven from a variety of sources including mixers and filters. Both PDAs support either DC- or AC-coupling, and single-ended (50 ohm) or differential inputs while driving differential output, eliminating expensive and space consuming external baluns. Additionally, the output impedance remains low, allowing the PDAs to drive a wide range of loads with excellent performance.

The versatility and excellent performance of the LMH6881 and LMH6882 over the entire gain range make them a universal design choice for any flexible or scalable platform that would typically use an FDA or DVGA (see ***Table 2***). They address many applications including wireless communications, microwave backhaul, industrial and medical, test and measurement, as well as military and defense equipment. In addition, the LMH6882 offers exceptional channel-to-channel gain matching of 0.2 dB and phase matching of 1.5 degrees, giving it superior image rejection capability for I/Q- or zero-IF sampling applications.

In order to speed up development with the LMH6881 and LMH6882, TI provides a comprehensive support ecosystem. Evaluation modules, reference designs and TINA-TI SPICE models are available, in addition to the E2E support forums for answering high speed amplifier questions. Both the single LMH6881 and dual LMH6882 are available and ready to simplify the way engineers design with differential amplifiers.

Texas Instruments Inc., Dallas, TX, www.ti.com/lmh688x, www.ti.com.

High-Performance 13 GHz PLL Synthesizer

The ADF4159 from Analog Devices is a 13 GHz PLL synthesizer that achieves a phase detector operating frequency of 110 MHz while simultaneously consuming less than 100 mW of power. The device contains a 25-bit fixed modulus as well as on-chip functionality to generate highly linear ramp profiles, making it an ideal solution for frequency-modulated continuous-wave (FMCW) radar applications, including automotive radar systems. The ADF4159 is also ideal for microwave point-to-point (PtP) systems, communications infrastructure, instrumentation and test equipment.

ADI's ADF4159 fractional-N PLL synthesizer consists of a low-noise digital phase frequency detector (PFD), precision charge pump and a programmable reference divider. It can be used to implement frequency shift keying (FSK) and phase shift keying (PSK) modulation. There are also a number of frequency sweep modes available that generate various waveforms, such as sawtooth and triangular waveforms. The functional block diagram of the ADF4159 is shown in ***Figure 1***.

APPLICATIONS

ADI's high-performance ADF4159 PLL features industry-leading phase noise performance of –223 dBc/Hz and 1/f noise performance of –120 dBc/Hz. The very high maximum PFD frequency allows for very good in-band phase noise while it also allows for very wide loop bandwidths if extremely fast settling time is required.

The ADF4159 supports a 25-bit fixed modulus which allows for very fine resolution. The minimum channel spacing is calculated by dividing the PFD frequency by 2^{25}, so for a 100 MHz PFD frequency, the minimum channel spacing is 2.98 Hz. Lower minimum channel spacing can be achieved by reducing the PFD frequency using the internal reference divider. The overall N divider value is calculated from the programmed INT and FRAC values.

$$N = INT + \left(\frac{FRAC}{2^{25}}\right) \quad (1)$$

The ADF4159 is powered by a 2.7 to 3.3 V analog power supply and a 1.8 V digital power supply. The typical current drawn by the part is 33 mA.

RAMP GENERATION

ADI's ADF4159 PLL can generate a variety of frequency sweeps or ramps. The ADF4159 is initially programmed once and will contin-

Analog Devices
Norwood, MA

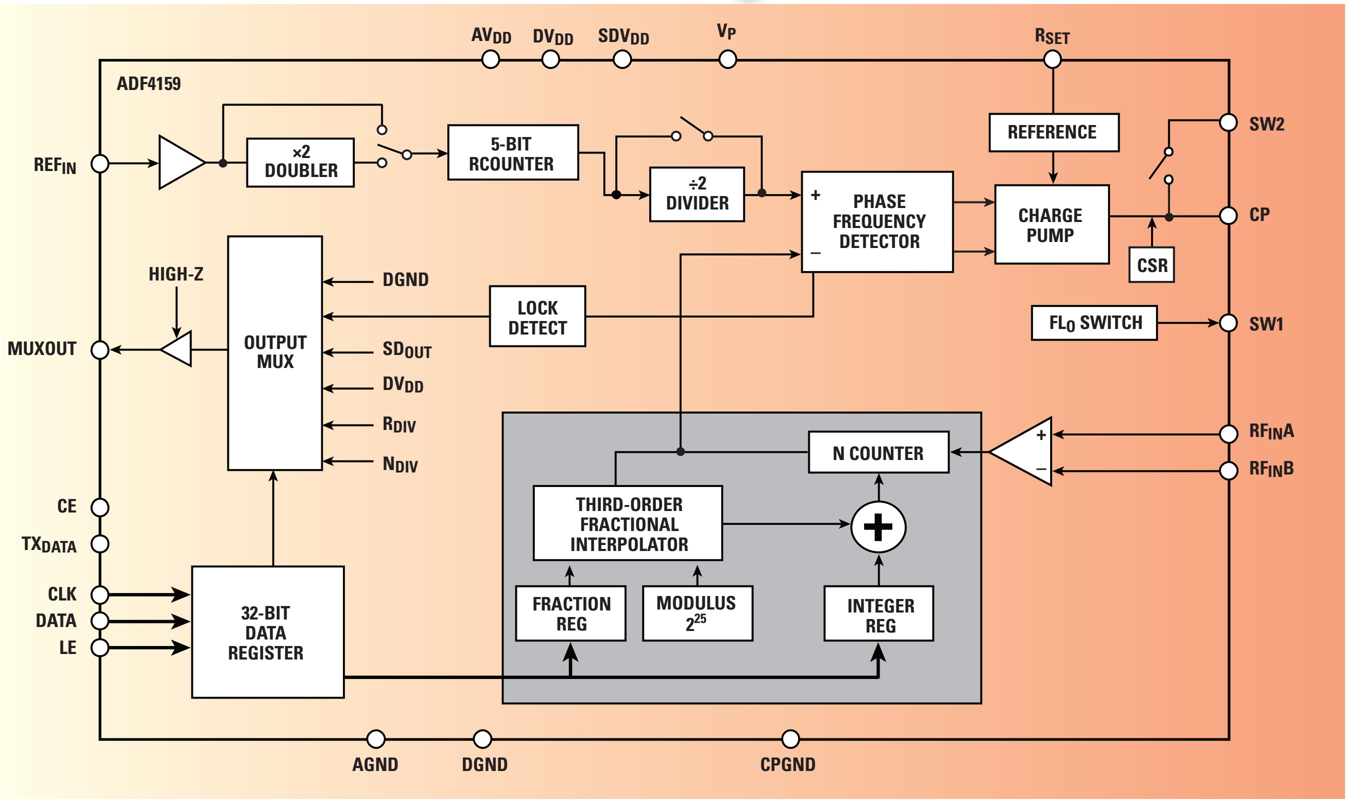


Fig. 1 ADF4159 functional block diagram.

ue to output the changing frequency without the need to re-program the part for each frequency. The frequency deviation of each step, the number of steps and the time each step takes can be individually controlled to optimize system performance. The ramp can be clocked by the internal clock or by an external pin for synchronous control.

Ramps can range anywhere from hundreds of megahertz in tens of microseconds, to tens of hertz in minutes. Some of the frequency ramps that the ADF4159 generates can be found in ***Figure 2***. Time delays can be added to any of the ramps, either at the start of the ramp or between ramp cycles. FSK, PSK and sawtooth waveforms with FSK superimposed onto the signal can be implemented on the ADF4159 by toggling the logic level on an external pin.

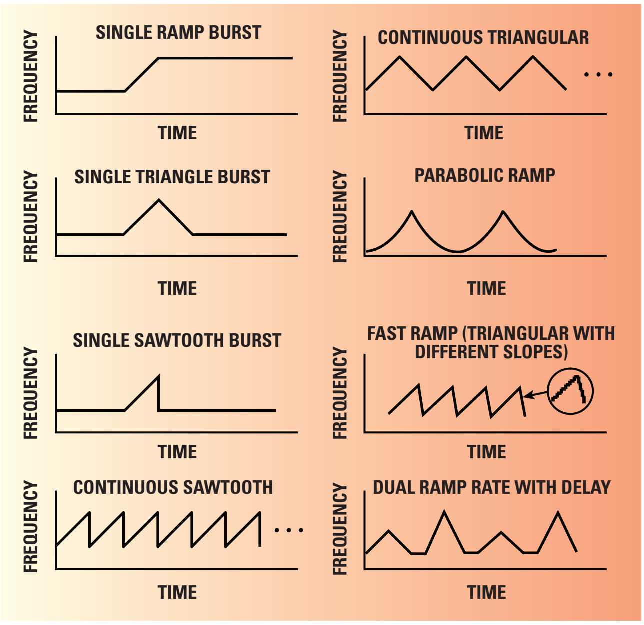


Fig. 2 Some of the frequency ramps that the ADF4159 can generate.

In addition, the ADF4159 is supported by Analog Devices' ADIsimPLL™ design tool, which simulates and optimizes ramping profiles. This software is a free download available at www.analog.com/adisimpll.

ADF4159 IN FMCW RADAR

A block diagram of an FMCW radar is shown in ***Figure 3***. The sweeping frequency is transmitted from the Tx antenna, bounces off the target (for example, a vehicle in the next lane) and is received by the Rx antennas. The received signal can then be compared to the transmitted signal to establish the distance to the target. The distance to the target is calculated as follows:

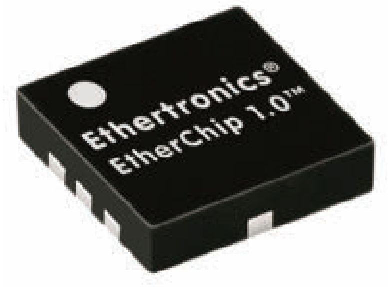
$$R = \frac{f_B c}{2A}, \text{ where} \tag{2}$$

- R = Distance to target (m)
- f_B = Beat frequency (Hz)
- c = Speed of light (3×10^8 m/s)
- A = Sweep rate of modulating waveform (Hz/s)

For example, a FMCW radar is operating by sweeping frequency from 24 to 24.1 GHz in 5 ms. It is modulated by a sawtooth signal. That gives A = 20 GHz/s. The measured difference between the transmitted and received signal is f_B = 1.3 kHz. This means that the target is 9.75 m away.

For a 24 GHz radar system, the ADF4159 can be locked to the divide-by-2 output of a 24 GHz VCO. Alternatively, the VCO can operate around 12 GHz and its output frequency multiplied by 2 to generate the Tx signal.

(Continued on page 31)

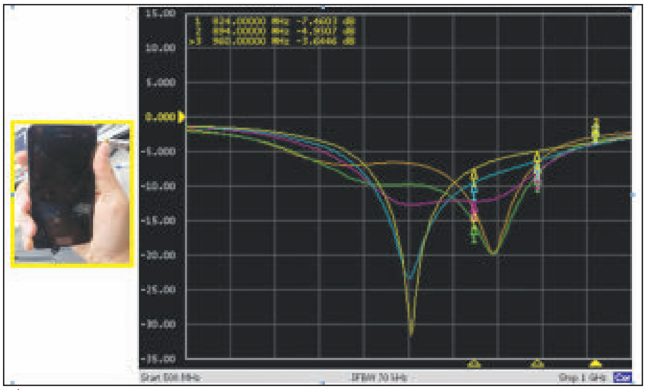


Innovative RF Front End

Just look at any recent smartphone or tablet, and it is a safe bet that it will be noticeably thinner than models of just a year ago. It is a trend that will continue. On the one hand, devices are getting thinner, and on the other hand, batteries, displays and functionalities are growing. The amount of space left for antennas, the device's connection to the network, decreases by 25 percent each year.

In the past, mobile phones handled voice calls across two bands, and in some cases had Bluetooth®, GPS and Wi-Fi functionalities too. Today's devices have to cover 2G, 3G, 4G, Bluetooth, GPS and Wi-Fi plus large amounts of data while still supporting voice calls. LTE makes that situation even more challenging:

- There are more than 40 potential LTE bands. To enable global roaming, a device would need to support at least 13 LTE bands.
- Some countries, including the U.S., use the low frequency 700 MHz band.
- The number of LTE cellular antennas is double their 3G counterparts because LTE requires two antennas (MIMO) for receive diversity.



▲ *Fig. 1 Hand and head effect correction.*

Traditional passive antennas will struggle to support LTE because they require more volume to cover the additional bands and/or the low frequency 700 MHz band. The good news is that innovations in antenna system technology can help to solve these challenges. Active antenna systems, advanced antenna structure combined with active components such as tunable capacitors and/or switches, can be used to provide advanced capabilities not possible with traditional passive antennas.

CHANGING THE RF LANDSCAPE

Ethertronics developed EtherChip 1.0™ to address the challenges facing today's product designers. EtherChip 1.0 uses Ethertronics' Air InteRFace Digital Conditioning (AIRFDC™) technology to provide a tuning function through tunable capacitance for the antenna system; seamlessly adjusting the cellular antenna's characteristics to its dynamic requirements for optimal connectivity:

- Reducing the antenna's physical volume by up to 50 percent without performance tradeoffs
- Making a wideband antenna by correcting the impedance mismatch
- Retuning the antenna for frequency shifts
- Offsetting hand and head effects

So even when the user's head or hand covers the antenna, causing the antenna to detune or a frequency shift, EtherChip 1.0 adjusts the antenna to maintain the call, file download or video stream (see ***Figure 1***).

Thin form factors will not come at the expense of voice, video and data performance with this product. All that the user notices is consistently great performance, giving the OEM's smartphone, tablet or notebook a market differentiator. This consistency and reliabil-

Ethertronics Inc.
San Diego, CA

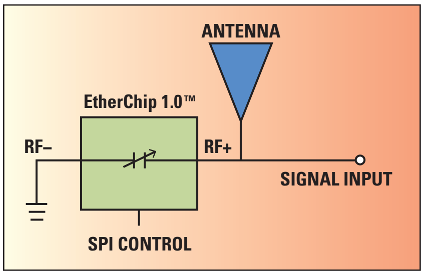


Fig. 2 Tunable antenna block diagram.

ity also benefits the mobile operator because those customers are far less likely to report problems. That translates into lower contact center costs, potentially making for a more positive relationship between the operator and the device OEM.

EtherChip 1.0 is designed specifically for tunability on the matching of the antenna in a shunt configuration (see ***Figure 2***). All of the controls are linked to an SPI bus.

The capacitance versus the hexadecimal input shows a variation from 0.85 to 3.4 pF at 900 MHz and from 0.85 to 4.6 pF at 1800 MHz with 16 states (see ***Figure 3***). Operational frequency is from 100 to 3000 MHz.

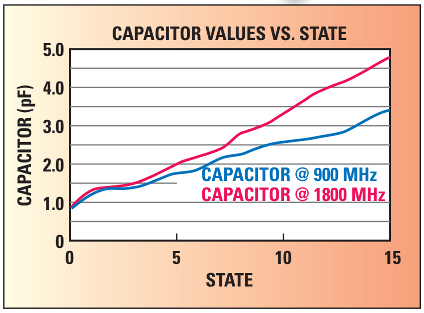


Fig. 3 Capacitance value at 900 and 1800 MHz.

Mechanical specifications include dimensions of 2.0 × 2.0 × 0.45 mm in an 8 pin QFN package. The chips are designed for surface mounting and are packaged in tape and reel. EtherChip 1.0, through a joint design with the antenna, supports all major bands and air interfaces, including 3G, LTE, LTE-Advanced and Wi-Fi, so it is a solution that OEMs can leverage across multiple product lines.

THE FUTURE IS A VERSATILE ANTENNA FRONT END MODULE

EtherChip 1.0 is the first in a series of chips that will enable the integration of the antenna front-end module (AFEM) in the space that the antenna once occupied. Leveraging the antenna's characteristics, the AFEM architecture will be changed progressively to enable a more cost-effective, higher performance approach.

The ultimate goal for the OEMs will be to significantly reduce cost and lead-time for developing new smartphones, tablets and other mobile devices. Those savings give OEMs a competitive advantage, such as getting a hot new design to market ahead of a rival's big launch, or reducing overhead costs so a new product can be priced profitably yet affordable enough for the mass market.

The EtherChip™ family of chips pioneers a much-needed new approach to RF front end design, one that gives device OEMs a way to turn shrinking form factors from a challenge into an opportunity. It is an idea whose time could not come soon enough.

Ethertronics Inc.,
San Diego, CA (858) 550-3820,
www.ethertronics.com.

(Continued from page 29)

Signals for 77 to 79 GHz radar systems can be generated in a similar manner.

To generate a system where the output sawtooth ramps from 24 to 24.1 GHz in 128 µs, the ADF4159 needs to be programmed to output a ramp from 12 to 12.05 GHz in 128 µs. If the system requires 256 frequency steps per ramp, the frequency deviation of each step is determined by dividing the total ramp frequency, 50 MHz, by the number of steps, 256. This results in a frequency deviation of 195.3125 kHz per step. Alternatively, if the frequency deviation per step is fixed, then the calculation can be reversed to find the number of steps, for example, 50 MHz divided by 200 kHz is 250 steps. The ADF4159 can be programmed to output any amount from 1 step to over 1,000,000 steps.

To generate the ramp in 128 µs, with 256 steps, each step will take 0.5 µs. The 0.5 µs is generated by programming two timers on the ADF4159. To achieve 0.5 µs per step, the loop filter bandwidth (LBW) must be wide enough to allow the loop to lock quickly enough. On the ADF4159, with its high maximum PFD frequency, this is easily achievable.

The maximum PFD frequency of the ADF4159 is 110 MHz. In order to maintain loop stability, the LBW cannot be greater than 1/10 of the PFD frequency. The ADF4159 is a fractional-N PLL, so care should be taken to attenuate sigma delta modulator (SDM) noise. Ideally, to suppress the SDM noise to acceptable levels, the LBW cannot be greater than 1/100 of the PFD frequency. Using ADIsimPLL, the optimum loop filter can be designed and simulated to ensure sufficient lock time and noise attenuation.

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

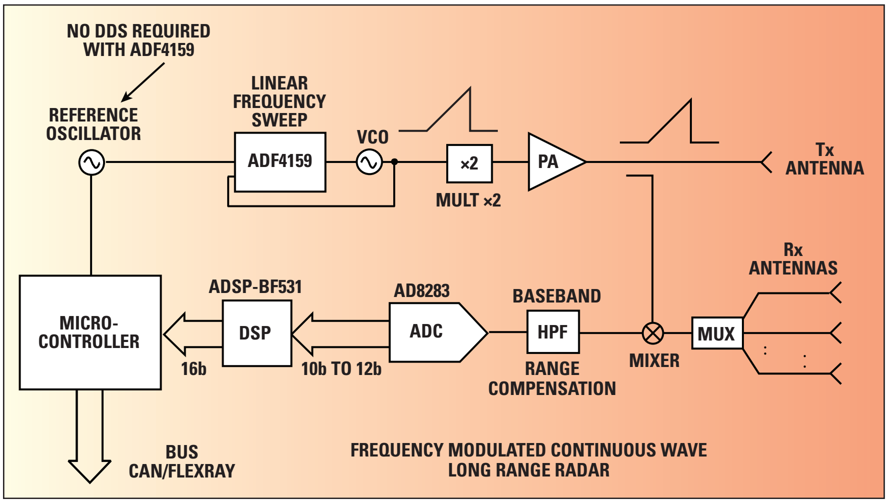


Fig. 3 FMCW radar block diagram.

Mobile Communications

Company Showcase

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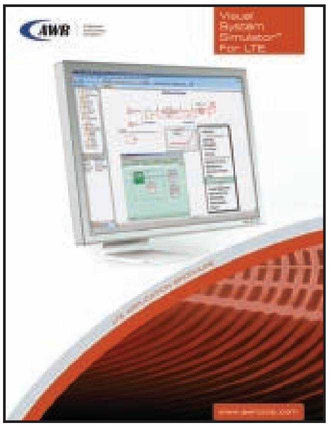

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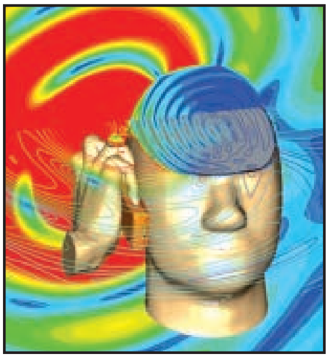

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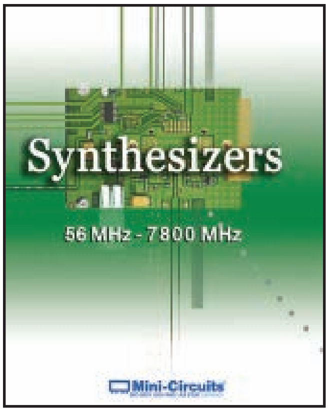

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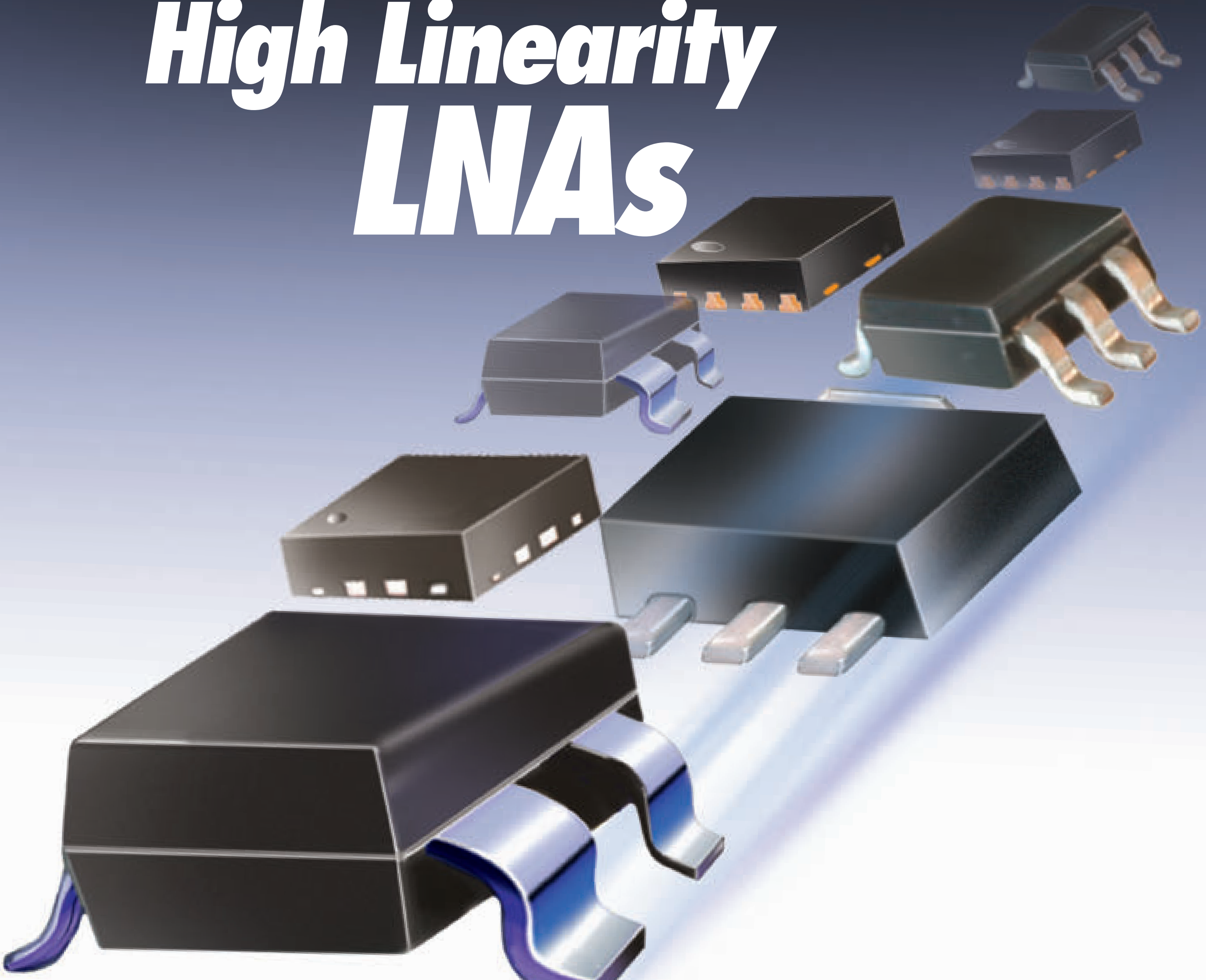

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PSA-5453+	50-4000	14.7	**1.0**	**37**	19	60	1.49
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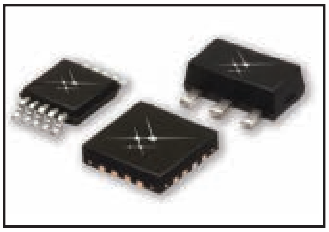

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