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From HSPA to LTE and Beyond: Mobile Broadband [R]evolution

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From HSPA to LTE and Beyond: Mobile Broadband Evolution

The UMTS Forum (umts-forum.org) is an industry association committed to helping all participants in the mobile broadband ecosystem understand and profit from the opportunities of 3G/UMTS networks and their Long Term Evolution (LTE). As a Market Representation Partner in the Third Generation Partnership Project (3gpp.org), the UMTS Forum gratefully acknowledges the support of 3GPP in the preparation of this feature.

The promise of 3G mobile broadband has been borne out by more than 630 million UMTS and HSPA subscribers, supported by a vibrant industry ecosystem. Building on these foundations, the first commercial launches of Long Term Evolution (LTE) technology are enhancing the mobile user experience still further. However, even as LTE gains commercial traction, the Third Generation Partnership Project (3GPP) is cementing a new set of standards to shape a new generation of wireless communications.

MOBILE BROADBAND COMES OF AGE

In September this year, a *New York Times* article suggested that the video sharing web site YouTube—owned by search giant Google—generates 160 million mobile views a day. That's almost triple the corresponding figure from a year ago. Mobile now accounts for a significant proportion of all YouTube traffic. Indeed, for many viewers it is their only means of interacting with the site.

Around the same time, the social networking site Facebook claimed more than 150 million active mobile users. What is more, the number of people accessing Twitter from their mobile handset has shot up by 250 percent since the beginning of 2010. And with more than 350,000 fresh users signing up to Twitter every day, 16 percent of newcomers initially access the microblogging service from their phone. For these and millions of other users, the PC is increasingly seen as a secondary means of accessing the Internet.

3G mobile broadband—as delivered by over 350 W-CDMA/HSPA networks globally—has changed the way we work and play. For better or worse, it keeps business travelers connected to the office, wherever they are. It has added an irresistible new dimension to YouTube, Facebook and other services that were originally conceived with fixed Internet users in mind. Furthermore, 3G mobile has enabled the rise of a new breed of on-the-move services that have no counterpart in the fixed world. Since its launch in March 2009, location-based social networking site Foursquare has attracted three million users, with new additions running at nearly 20,000 per day.

Non-voice traffic on 3G wireless networks continues to rise organically, fuelled by a compelling user experience delivered by the current generation of feature-rich mobile devices. Smartphones are everywhere, supported by a fertile development ecosystem. Some 250,000 third-party applications are officially available

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Just as significant in terms of driving data consumption are PC dongles and netbooks with embedded wireless connectivity, plus a new wave of tablet devices. Aside from its primary nomadic application, Internet connectivity via 3G is increasingly seen as a substitute for fixed mobile broadband in many homes and offices. Indeed, PC usage—from big file transfers to HD-quality video streaming—represents a major chunk of all mobile data consumption.

At the end of September 2010, cellular market information provider Wireless Intelligence confirmed over 630 million subscriptions globally to 3G/UMTS networks. Of these, more than half are customers of high-speed HSPA and HSPA+ networks. Enjoying multi-megabit downlink rates that rival fixed broadband connections at home or at work, many of these customers are voracious data users. They rely on mobile to satisfy their thirst for streaming music and HD video, real-time maps, P2P file exchange and non-stop social networking status updates.

This explosion in mobile broadband usage confirms emphatically the success of 3G. It also underlines the pivotal role of the Third Generation Partnership Project (3GPP)—the body that unites six telecommunications standards bodies from around the world—in continually enhancing the performance of wireless networks to meet evolving market needs. Through successive standards releases, 3GPP offers the wireless industry a coherent framework to serve the evolving needs of its customers while optimising the value of operators' current network investments.

3G/UMTS builds directly on the extraordinary success of the original GSM system that now numbers well over 4.5 billion connections globally. The sheer size and reach of the GSM/UMTS footprint infers obvious economies of scale for both network equipment vendors and terminal equipment manufacturers. This, in turn, defrays development costs. Teamed with global competition, it also realises the possibility of lower end-user pricing for hardware and services, as evidenced by the rise of the $20 handset.

The universal success of GSM also impacts positively on 3G operators and their customers. The close family resemblance between second- and third-generation systems lets subscribers enjoy a transparent experience as their terminal switches seamlessly between 2G and 3G networks according to geographic availability. And for the hundreds of GSM operators—and W-CDMA/HSPA greenfield networks—the business case for evolving to higher data speeds via successive technology iterations is compelling.

Many of the performance enhancements delivered by successive 3GPP releases can be realised by relatively simple, cost-effective software upgrades to operators' existing networks. Even in the case of more fundamental upgrades, this transformation can be achieved while retaining key portions of their network assets, from cell site infrastructure and backhaul to billing and customer care functions.

Faced with the inexorable rise in network traffic, mobile operators must continue to evaluate their options for carrying these massive data volumes more efficiently while catering for further increases in future demand. The needs of today's data-hungry customers are already being met as operators roll out HSPA+ and now LTE, the latest commercial iteration of the 3GPP family that is already live in the US and Europe.

Even as LTE steadily gains commercial traction, 3GPP is currently fine-tuning a new set of standards that will shape a new generation of wireless communications over the next decade and beyond. Here, we briefly review the status of wireless standardisation in 3GPP and corresponding commercial activity. In particular, we examine the objectives and timescales for the ITU's IMT-Advanced project, examining how 3GPP has responded to the ITU's challenge with its own candidate for the 'true' fourth generation of mobile systems.

TOWARDS A NEW GENERATION: LTE-ADVANCED AND 'TRUE' 4G

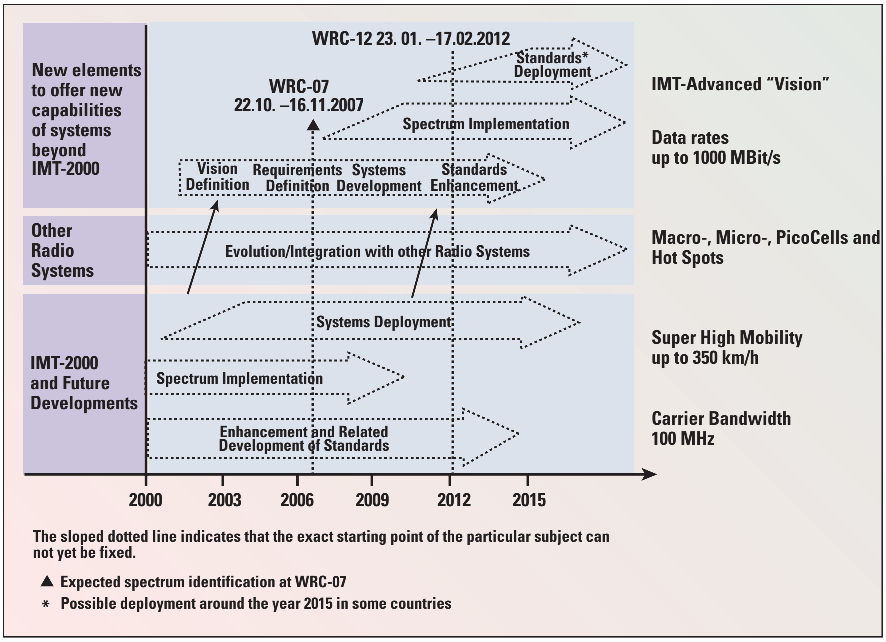
Standardised in 3GPP Release 8, LTE can be seen as the culmination of a globally co-ordinated development project over the past quarter of a century to create the first truly international broadband multimedia mobile telecommunication system.

Today, the first family of standards derived from the ITU's original IMT concept—IMT-2000, or '3G' as it is commonly known to operators and end-users alike—has delivered voice and broadband data capabilities to almost 800 million subscribers. Of this total, the great majority (over 630 million) are connected to the UMTS/W-CDMA/HSPA family of 3G systems as specified by 3GPP. They are complemented by an estimated 150+ million subscriptions to 1xEV-DO networks, based on the CDMA-based IMT-2000 family member as standardised by 3GPP2.

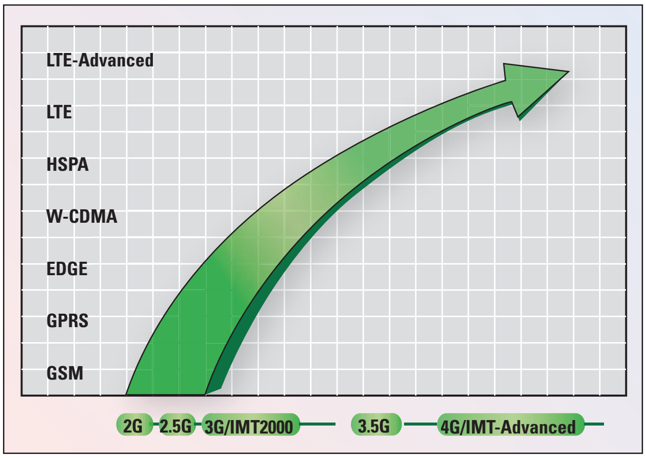
However, with IMT-2000 requirements now over 10 years old, it is time to set a fresh direction for the next major epoch in mobile communications. User expectations have changed dramatically since the first set of radio interfaces were approved for IMT-2000 in 1999. A decade ago, affordable, ubiquitous, high-speed Internet access—even in the fixed world—was still a dream. Outside the office and academia, access to the web was slow via dial-up connection. On the move, 'mobile data' effectively meant SMS.

> "The requirements for IMT-Advanced are a significant milestone in capability when compared to those of IMT-2000. IMT-Advanced is a leap beyond. It offers new capabilities for the physical layer of the radio interface and brings into play a greater level of radio resource management and control, advanced capabilities from spectrum channel and bandwidth aggregation, and improved performance at all levels, including quality of service aspects. IMT-Advanced represents a wireless telecommunication platform that has the flexibility to accommodate services that are yet to be imagined." (See ***Figure 1***)
>
> Stephen M. Blust, Chairman of ITU-R Working Party 5D

In this context, the ITU's original goals for IMT-2000—data speeds of 384 kbps at pedestrian speeds rising to 2 Mbps indoors—are impressive in themselves. More than a decade on, the ITU's fresh vision for a completely new generation of mobile systems is equally ambitious. A decade from now, the wireless landscape will look very different. Users will access a new breed of ultra-high speed mobile broadband services and applications via a heterogeneous blend of radio ac-



▲ *Fig. 1 Phases and expected timeline for IMT-Advanced development and deployment (source: Telefónica 02).*



▲ *Fig. 2 Meeting the ITU's formal requirements for IMT-Advanced, LTE-Advanced is one of the first true 4G systems (source: 3GPP).*

cess methods, network topologies and radical approaches to spectrum usage: a 'network of networks'.

Users will connect and interact with these services via radically new types of terminal devices. Wireless connectivity will not be restricted to phones, PCs and tablets. It will be embedded as a matter of course in domestic appliances, vehicles and consumer electronics devices. Machine-to-machine communications will be ubiquitous, with the 'Internet of things' numbering not millions but billions of end-points.

Building on the extraordinary global success of 3G, including W-CDMA, HSPA and now LTE, the ITU has articulated a new vision for this next era of global wireless communications. Termed 'IMT-Advanced', it is a name that echoes the ambitions of the previous century's original IMT project. This time, however, the goals are still higher.

According to the ITU's definition: "IMT-Advanced is a leap beyond new radio interface physical layer capabilities and brings into play a greater level of radio resource management and control, advanced capabilities for spectrum aggregation, and improved performance at all levels including QoS [Quality of Service] aspects."

"International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities of IMT that go beyond those of IMT-2000," states a contribution from ITU's Radiocommunication Sector (ITU-R) Working Party 5D in March 2008. "Such systems provide access to a wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based."

The description hints strongly at a heterogeneous future, where mobility is characterised by a total user experience across a mesh of fixed and mobile networks: "IMT-Advanced systems support low to high mobility applications and a wide range of data rates in accordance with user and service demands in multiple user environments. IMT-Advanced also has capabilities for high quality multimedia applications within a wide range of services and platforms, providing a significant improvement in performance and quality of service."

In its earliest discussions about IMT that date back to the early years of this millennium, the ITU was circumspect in describing this new generation of advanced systems as '4G'. By October 2009, however, ITU explicitly used the term when it announced that six candidate technology submissions for 4G had been received in response to an open invitation in March 2008 (see ***Figure 2***).

Currently, several operators and vendors have branded their LTE (and WiMAX) offerings as '4G'. However, this nomenclature is potentially confusing when seen in the light of the ITU's official terminology. LTE and WiMAX certainly offer a significant step forward in terms of data rates compared with previous approaches. Their capabilities, however, fall some way short of the ITU's formal requirements for IMT-Advanced.

As such, LTE and other systems are better described as '3.9G'—the last evolutionary step before LTE-Advanced. From the customer's perspective, discussions about what properly constitutes 3G or 4G are of little interest. The immense, globally coordinated standardisation effort by 3GPP is easily obscured by the seamless simplicity of today's mobile user experience. Whether I am updating my Facebook status or uploading some slides before a meeting, all that I am aware of is an experience that is slicker and quicker than it was a year ago… and the year before that.

A BREAK WITH THE PAST

The 'LTE-Advanced' name reflects its roots in LTE and the systems that preceded it—from HSPA+

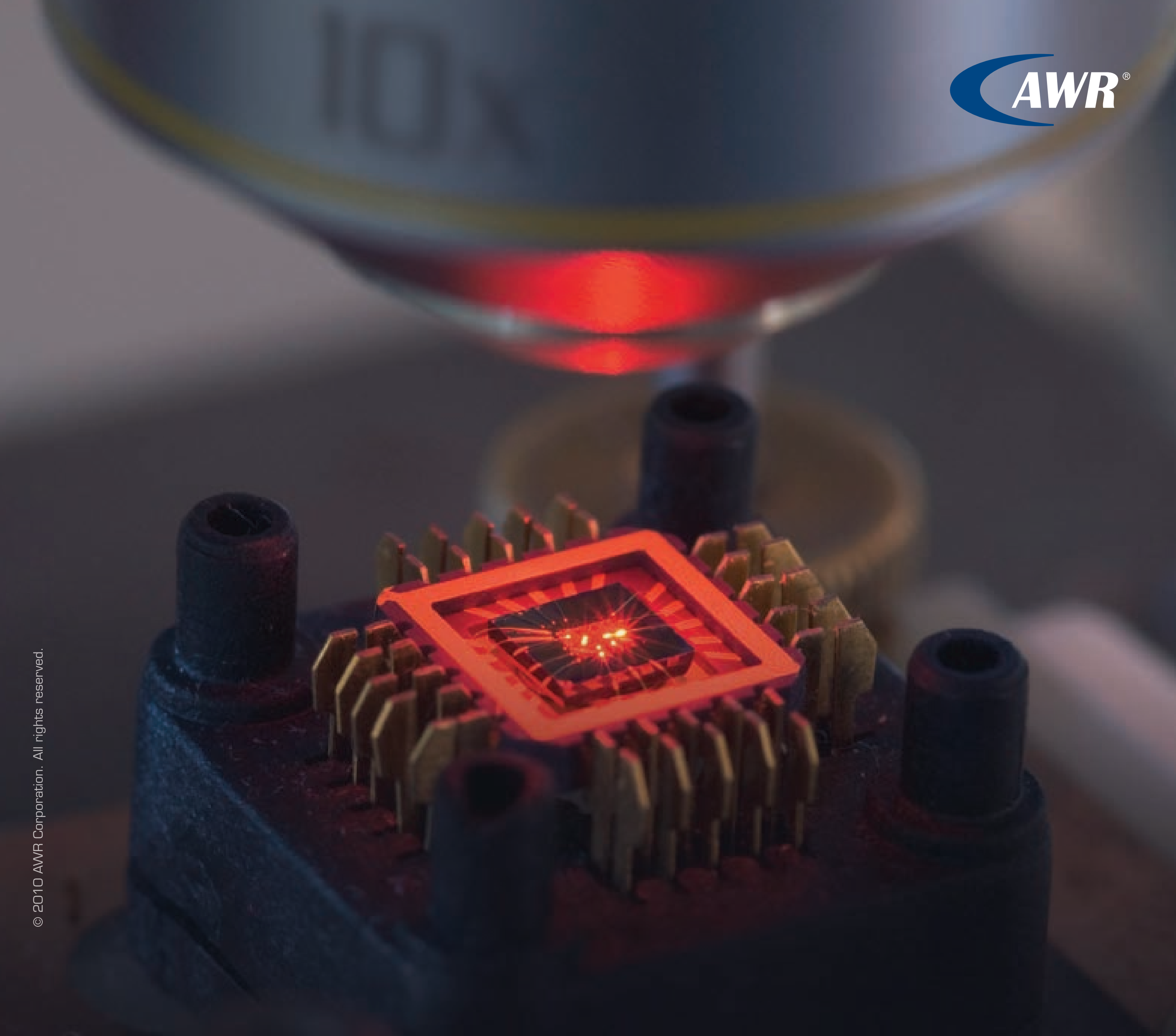


TABLE I

2G/3G/4G TECHNOLOGIES COMPARED

	Technology	Carrier BW	UL Peak Data Rate	DL Peak Data Rate	Latency	Spectrum (MHz)	Peak Spectral Eff. (Bit/s/Hz)
2G	GSM/GPRS EDGE (MCS-9)	200 kHz	56 Kbps 118 Kbps	114 Kbps 236 Kbps	500 ms 300 ms	900/1800	0.17 0.33 EDGE
	W-CDMA	5 MHz	384 Kbps	384 Kbps (2 Mbps)	250 ms	900/1800/ 2100/2600	0.51
	HSPA	5 MHz	5.7 Mbps	14 Mbps	-70 ms	DD/900/ 2100/2600	2.88
3G	HSPA+ (16 QAM) (64 QAM +Dual)	5 MHz	11.5 Mbps	-28 Mbps (42 Mbps)	-30 ms	DD/900/ 2100/2600	12.5
	LTE (Rel.8) (2×2 MIMO)	var. up to 20 MHz	-75 Mbps	-150 Mbps (@ 20 MHz)	-10 ms	DD/900/1800 2100/2600	16.32
	WiMAX IEEE 802.16e	10 MHz	70 Mbps	70 Mbps 134 Mbps	-50 ms	2600/3500	3.7
4G	LTE-Advanced*	var. up to 100 MHz	>500 Mbps	>1 Gbps	<5 ms	IMT	DL: >30 UL: >15
	"IMT-Advanced"	var. up to 100 MHz	270 Mbps 675 Mbps	600 Mbps 1.5 Gbps	<10 ms	IMT	DL: >15 UL: >6.75

Source: 3GPP/Telefonica 02
**To be confirmed with 3GPP Ref. 10 by end 2010*

and HSPA though W-CDMA right back to GSM.

Specified in 3GPP Release 10, LTE-Advanced has been explicitly dimensioned to meet—or even exceed—the requirements of IMT-Advanced. Building on the pyramid of previous releases, LTE-Advanced is also backward compatible with Release 8 (LTE), helping operators to effectively leverage their current wireless investments.

The advanced performance requirements of 4G mandate a break with the past. While interworking with 2G and 3G legacy systems will be supported, 4G demands radically new transmission technologies, plus fresh approaches to spectrum usage. Building on the agenda now being set by LTE, 4G will represent a total break from a circuit-switched world. (By comparison, while a number of approaches are currently being considered, it is likely that at least some operators will initially support voice in LTE via circuit-switched fall-back to 2G/3G.)

So what exactly will 3GPP Release 10 offer? As you would expect, the key dimensions where LTE-Advanced scores over previous technologies include speed, spectral efficiency and flexibility, capacity, coverage and interworking.

Captured in Report ITU-R M.2134, the basic requirements of IMT-Advanced are as follows:

- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- Compatibility of services within IMT and with fixed networks;
- Capability of interworking with other radio access systems;
- High-quality mobile services;
- User equipment suitable for worldwide use;
- User-friendly applications, services and equipment;
- Worldwide roaming capability;

One of the standout attractions of LTE-Advanced is its ability to exploit variable, ultra wide carrier bandwidths of 40 MHz, right up to 100 MHz. This, in turn, supports extremely high data rates in the mobile environment. A new transmission scheme—based on OFDMA/SC-FDMA plus sophisticated MIMO techniques and other measures—will together achieve theoretical peak data rates of 100 Mbps in high mobility situations.

In stationary environments, this theoretical performance rises as high as 1 Gbps—an order of magnitude faster than LTE. Uplink transmission is similarly enhanced, targeting data rates up to 500 Mbps. To realise these performance targets, Release 10 boosts peak spectral efficiency in both uplink and downlink by an order of magnitude compared with HSPA. Other measures, like relay functionality, will boost cell edge coverage, improving the end-user experience in rural and non-optimal coverage areas.

Physics dictates that data rates of the order of 1 Gbps in 4G systems require bandwidths approaching 100 MHz. This infers that spectrum sharing—either through regulatory measures or technology developments involving spectrally agile systems—will inevitably be part of future considerations about maintaining a competitive environment in mobile broadband.

Of equal appeal to real-world users, LTE-Advanced cuts round-trip latency times to 10 ms or less, a fraction of even the 30 ms (approx.) attained with HSPA+. For comparison, HSPA (corresponding to Releases 5 and 6) manages a latency performance no better than 70 ms, while the original W-CDMA standard (Release 99) lags

[Continued on pg. 26]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How Mobile Device Users are Impacting the Future of RF Front Ends

In the last decade, cellular mobile devices have undergone dramatic changes. What began as a mobile phone simply used for people to talk or text with one another has now turned into a handheld device that provides multi-functionality such as a phone, web browser, text messenger, camera, gaming unit, MP3 player, and many other useful functions to satisfy our need for information on-the-go. Not only do today's mobile device users want all of these features included, they also want them readily available to them at all times, irrespective of time or location. This type of on-demand mobile technology requires compatibility of multiple frequency bands and modulation standards. This type of complex functionality, along with the consumer's desire for smaller form factors, has placed great demands on mobile designers to deliver products at a lower bill of materials (BOM) cost and within record-breaking time to satisfy the market's expectations generation over generation. Such stringent requirements have forced designers to undergo a change in the way that RF front ends are benchmarked. This article discusses some of these impacts and how a new approach can be embraced to enhance the consumer experience when using a feature-rich mobile device.

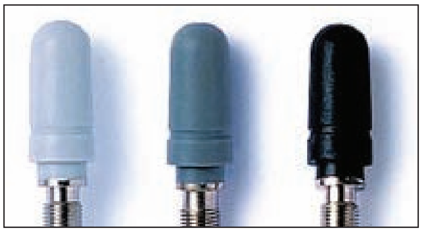
Fig. 1 External stub antennas.

Readers who were in the industry several years ago can remember that voice was the primary driver for performance, and the most widely used modulation format was GSM/GPRS. Handset designs were much larger, with more printed circuit board (PCB) real estate dedicated to the RF front-end section, and performance was the primary focus of the project. The antennas were external to the handset, as depicted in ***Figure 1***, taking the form of a stub or slider that pulled out and retracted with efficiencies that were much better than what a user can find in a handset today. Phones were designed to be operated in voice-only calls with the handset or mobile device held in a fairly predictable position relative to the user's head. The consistency allowed the antenna to be designed in a fairly known environment that allowed for optimization of the design. This is still critical today since the power amplifier (PA) can be a significant drain on talk time, which is directly correlated to a user's experience with a certain model of device as well as the company brand of mobile device. If the designer can optimize the current consumption in a real-world environment, the better positioned the mobile device is in the consumer market. The consistency of antennas and their real-world behavior has given handset designers the flexibility to optimize their design by impedance matching

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RFMD, Greensboro, NC

Fig. 2 PIFA antenna.

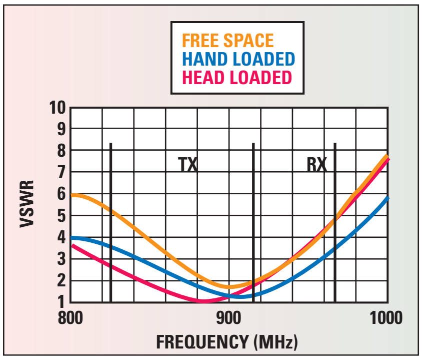


Fig. 3 VSWR performance of a PIFA antenna in a mobile device.

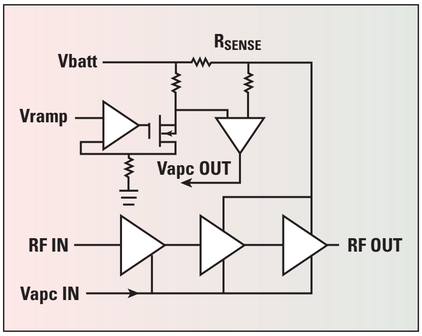


Fig. 4 Current control block diagram.

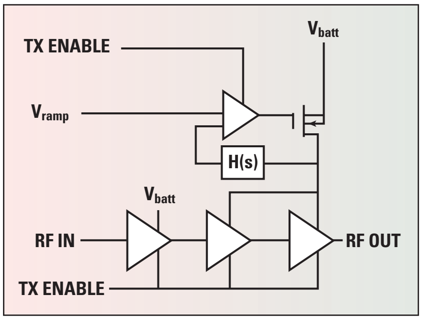


Fig. 5 Voltage control block diagram.

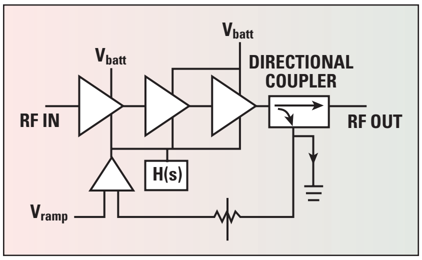


Fig. 6 Power detection block diagram.

antennas and PAs in order to deliver the maximum amount of power as efficiently as possible.

MOBILE DEVICES: THAT WAS THEN, THIS IS NOW

Fast forward a couple of years and the mobile device market has changed dramatically. Real estate is now dedicated to applications processors and components that are more focused on software applications than enhancing the consumer experience. Mobile devices are now designed with much smaller form factors and performance has been traded off in many cases to achieve these unique form factors. Handsets today have integrated patch or Planar Inverted F Antennas (PIFA) (illustrated in ***Figure 2***) that in many cases are far less efficient to their predecessors. Even today, some handsets are now reverting back to a stub antenna due to the issues that many designers are facing. This performance versus form factor tradeoff directly impacts a consumer experience in the form of battery life, talk time and network availability since the antenna choices and their environment affect the PA.

One example of how this affects PA performance is in the form of voltage standing wave ratio, or VSWR. Mobile devices today are operated in three basic configurations. Users talk on the mobile device with the handset next to the head in a conventional manner, out in front of their head using the speaker phone and in a free space environment where the phone is not held. These are just three scenarios in which the VSWR response of the antenna can change. In reality, there are numerous configurations determined by the position of the fingers and hand, but for simplicity this article is going to focus only on these three scenarios. The difference in performance of the antenna VSWR is illustrated in ***Figure 3***.

These frequency responses illustrate the different VSWR requirements that the PA faces in a current generation handset. At the band edges, the PA will be exposed to VSWR ranges from 5:1 to 2:1 in this particular mobile device. The RX sensitivity is also affected due to the VSWR performance as well. Common practice used today by many handset designers for benchmarking RF front ends is measuring performance in a 50 ohm lab environment. This method is no longer practical in today's designs due to the unpredictability of the impedances that are seen by the PA. A designer who wants to optimize his or her solution to provide the best talk time to the end user must begin to examine their RF front ends under VSWR conditions.

Standard governance boards such as 3GPP set the requirements for over-the-air (OTA) requirements. These requirements are usually much more relaxed than typical carrier requirements as they require more stringent OTA performance. A typical value a carrier may set for their mobile devices is -11 dB from conducted RF output power. In terms of the GSM 850 standard, this would equal a value of 22 dBm OTA requirement since conducted output power requirement is set to 33 dBm with -11 dB of loss due to antenna efficiency and propagation effects which are frequency dependent. These OTA requirements are directly applicable to the 50 ohm power if RF front ends are benchmarked and compared with these requirements in mind.

GSM POWER CONTROL ARCHITECTURES' EFFECTS ON TALK TIME

The three different architectures most commonly used in the industry today for GSM mobile applications are current control, voltage control and power detection. A simplified block diagram of each of the three architectures is illustrated in ***Figures 4, 5*** and ***6***.

Numerous articles have been published on the theory of these three architectures; therefore, this article will provide only a brief description as background. The current control architecture in Figure 4 is an indirect control scheme in which the current is monitored and held constant. This method relates current to power and provides a very good method of power control as long as the relation between current and power remains constant (which occurs only if the resistance of the load does not change). Power is controlled by adjusting the base bias of the amplifier controlling the gain, which results in power control. Figure 5 is an illustration of voltage control, which is very similar to current control in the sense that it is an indirect method relating voltage to power instead of current. This method—much like

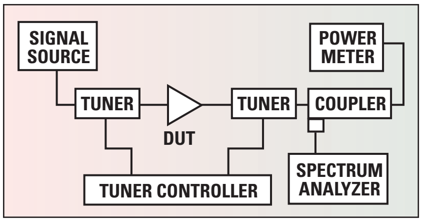


Fig. 7 Load pull setup.

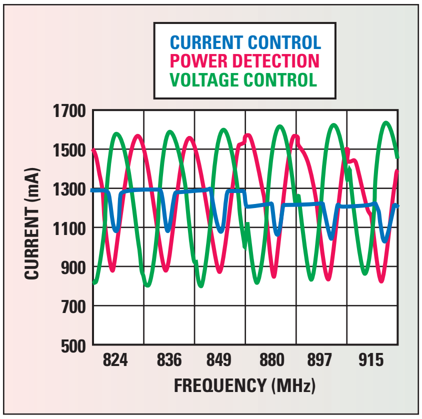


Fig. 8 Current measurement into 3:1 VSWR with 50 Ω power set to 33 dB.

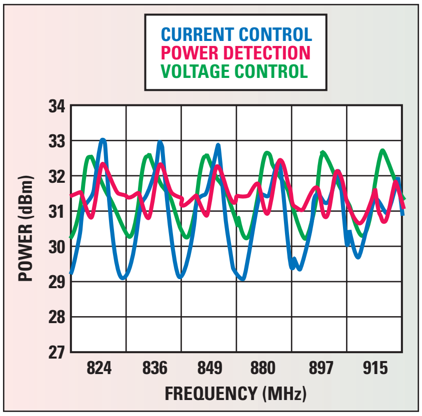


Fig. 9 Delivered power into 3:1 VSWR with 50 Ω power set up to 33 dB.

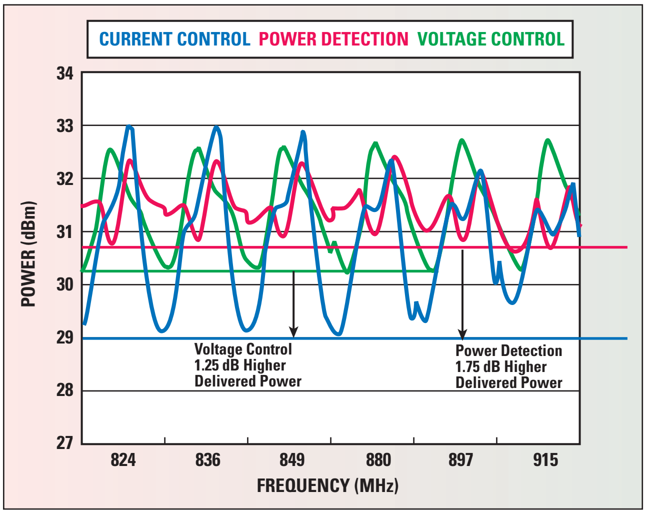


Fig. 10 Deltas in delivered power.

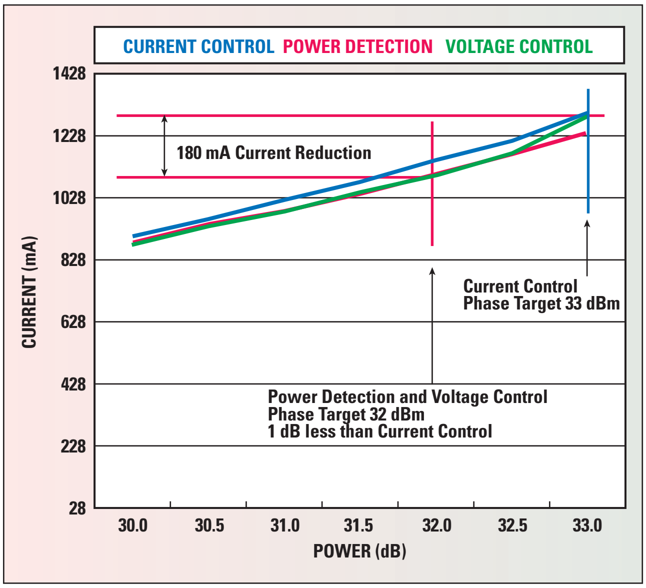
current control—works well as long as the resistance of the load remains constant and the relationship between voltage and power is maintained. The collector voltage is adjusted to control power instead of the base bias like in current control. The final architecture to be compared in this article is power detection, which is illustrated in Figure 6. In this method, power is detected by coupling a portion of the signal back to a detector that compares the output voltage and the reference voltage. The accuracy of this power control scheme is great as well and the mismatch performance is greatly dependent on the directivity of the coupler and the error in the feedback loop. The disadvantage of this architecture, however, is the added output loss of the coupler and the cost of the component, as it takes more circuitry to accomplish the power control function.

After reviewing a very simplistic view of basic power control architectures, one can focus on benchmarking the devices in such a way that reflects real-world performance and has a direct impact on the consumer satisfaction with talk time, battery life and call reception. First, to understand the real-world environment, the antenna performance must be characterized, as illustrated in Figure 3. As mentioned previously, the VSWR can range from 2:1 to 5:1, depending on the end user and how the phone is positioned. Based on these measurements, a good benchmark for comparison is determined to be a 3:1 VSWR. A VSWR of 3:1 is chosen as this will provide a good indication of part performance in the real world without providing unrealistic reflections back to the PA that may distort the results of the comparison. In order to characterize these products appropriately, a load pull must be performed where the designer has precise control over mismatch, phase angle and delivered power accuracy. Such a method is shown in ***Figure 7***.

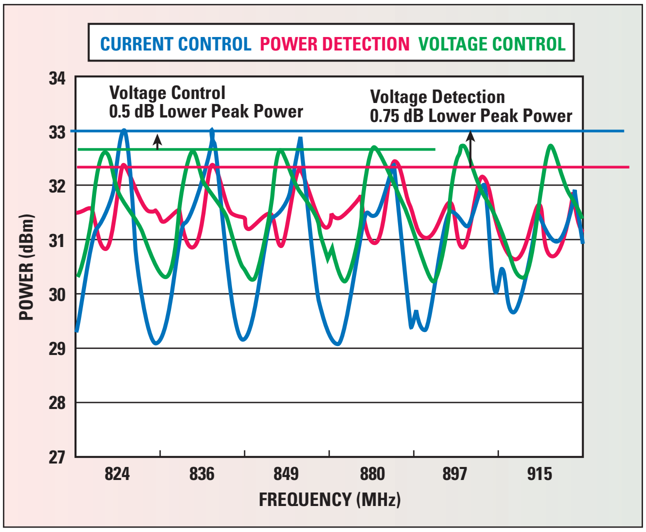
After examining ***Figures 8*** and ***9***, one can see that even though the power control function is achieved with different architectures, the performance in a real-world environment is very different. What does this mean and why is this so important? First of all, as previously discussed, what really matters is OTA performance, which is a direct correlation with delivered power. As Figure 9 shows, current control is the least desirable solution of the three for maintaining a constant delivered power into the load. There is almost 1.5 dB of difference between current control and power detection in the GSM 850 band. The disadvantage of the power detection scheme is that the current is allowed to increase, whereas the current is maintained reasonably well in the other solution. Although this would result in better talk time in this condition, in a real-world environment it would not.

For example, if the mobile device is operated at 29 dBm, which is the power level that has the greatest probability in a GSM system, the base station would actually request that the handset increase its power level by moving from 29 to 31 dBm since the delivered power cannot be met at current power control level (PCL). This in turn would increase the current consumption and therefore decrease the talk time. Another aspect to consider is the current consumption advantages that can be realized. In a mobile device, if the current control scheme is providing enough delivered output power under these conditions to meet the carrier's OTA requirements, then there is no need to be concerned about power into VSWR. Since the reduction of delivered power is good enough, substantial current consumption savings can be realized with a solution that provides better VSWR performance. In examining ***Figure 10***, consider the following question: If the delivered power could be made equal between all solutions, what effect would this have on the end user?

For voltage control and power detection, the 50 ohm calibration could be set 1 dB lower in power and still meet the equivalent delivered power. ETSI conducted specification specifies that for PCL 5 the power is 33 dBm ±2 dB under nominal conditions. This means that to meet conducted



▲ *Fig. 11 50 Ω phasing target delta in current for equivalent delivered output power.*



▲ *Fig. 12 Delta in peak power.*

performance the mobile device can output a minimum of 31 dBm for PCL 5. Understanding the need for margin, the safest level that the mobile device should be calibrated to is 31.5 dBm. If more margin is desired, the designer could gain substantial current savings by phasing the mobile device to 32 dBm in a 50 ohm environment. How this correlates to 50 ohm performance is shown in ***Figure 11***.

In Figure 11 the currents of the three solutions are compared versus output powers. This demonstrates that if the designer can achieve equal delivered output power to meet OTA requirements, then the current control solution would need to be calibrated for 33 dBm of output power compared to 1 dB less for power detection. This would result in 180 mA savings in the 50 ohm environment at full power, which can extend battery life and talk time. This current savings is realized without sacrificing any real-world delivered output power OTA performance. The other advantage to lower phasing targets is more margins to specific absorption rates (SAR) as well as lower harmonic generation since harmonic energy is much lower at 1 dB back-off from full power. This results in fewer emissions issues and faster time to market.

If the designer is not interested in this approach and would like to have more output power, this can also be accomplished with a better VSWR tolerant device. The concern with higher output powers that every designer shares is the possibility of failing the SARs requirement for radiating energy in a multi-slot GPRS case. A much better, well-behaved VSWR tolerant device allows the handset to operate at higher power levels while still meeting SAR requirements under these conditions by limiting the amount of output power that is delivered in a low impedance state (see ***Figure 12***).

Figure 12 illustrates that if a mobile device designer would like to optimize OTA performance, the phasing target could be increased in the mobile device 0.5 to 0.75 dB higher in the voltage and power detection solution compared to the current control. Phasing for higher targets statistically compromise SAR performance. As Figure 12 shows, however, the peak power swings are now equal for all three solutions, and the 50 ohm set power is much higher than the current control solution. This allows the designer to develop a superior product compared to the competition when compared at the carrier for OTA capabilities.

The final consideration is the tradeoff between transmit (TX) and receive (RX) performance and the ability to customize performance based on region. From Figure 3, the VSWR plot of a mobile antenna, there is room to shift the tuning to trade off TX performance for RX performance, if desired. Examining the purple trace, in the case where the phone is head loaded, one can see that if the GSM 850 TX and RX performance was degraded slightly by shifting the frequency response higher in frequencies, then the GSM 900 RX VSWR would actually improve. Having a VSWR tolerant TX path can allow the designer to have the flexibility to make the tradeoffs between the parameters that are most important in his or her particular design.

In conclusion, the importance of benchmarking solutions under mismatch conditions needs to be seriously considered. This method opens a new way of thinking that exposes designers to tradeoffs that can be made at the system level that may have not been considered before. Only examining solutions based on 50 ohm lab testing can and will cause misconceptions on selecting the right architecture for one's design. In Figure 10, it is clear that almost all three solutions can perform the function and are very similar in performance. Although this is true in the 50 ohm environment, it is not the case in real world application. Considering OTA performance can result in greater flexibility for the designer to customize their product for better current consumption, high OTA power, or RX performance. All of these options are revealed if the designer is open to a new way of benchmarking RF front ends and making decisions that truly affect consumer satisfaction in terms of fewer dropped calls and longer battery life. As the end consumer experience improves, so does the brand image of that particular mobile device, which results in greater demand from consumers and higher adoption rates by the carriers. ■

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A High Linearity Darlington Intermediate Frequency (IF) Amplifier for Wide Bandwidth Applications

This article describes the design of a very high linearity, wideband intermediate frequency (IF) amplifier. The design has a very flat gain response and most of the circuit components are integrated. It achieves a third-order intercept point (IP3) greater than 43 dBm and a noise figure (NF) less than 2 dB across a wide frequency range of 30 to 1000 MHz.

IF amplifiers are used in many applications, including base stations, cable TV and instrumentation. High linearity is one of the most desired features of an IF amplifier. New applications, such as amplifiers used in cable TV, also require very flat gain and low noise. Darlington amplifiers with single or dual RF feedback topologies have been shown to have higher gain, flatness and linearity over a wide bandwidth.[1,2] Various device process technologies, including HBT, SiGe and PHEMT among others, have been used in the past. Each technology has its unique advantages. Different active, dynamic and passive biasing techniques have also been used to improve performance over temperature and over the frequency band of operation.[3,4] Capacitive peaking techniques are used to further increase the bandwidth, with a trade off in input and output return loss.[5] The drawback in most high linearity designs is the big trade off in noise figure (NF).

The design of a high linearity Darlington RF feedback amplifier with less than 2 dB NF has been achieved. The design uses a source capacitive peaking technique for optimum gain flatness across a wide band. Source degeneration inductors are used for improving the input and output return loss and stability at lower frequencies. Additional stability improvement circuits are used to ensure unconditional stability at higher frequencies.

CIRCUIT DESIGN

The frequency range of operation is from 30 to 1000 MHz. With a Darlington design topology, the first and second stages can be biased at different conditions. Individual voltage and current adjustment of each stage provides extra flexibility for performance optimization. The Darlington configuration provides twice the gain bandwidth product over single stage circuit topologies. Furthermore, good input and output return loss across a wide frequency range can be achieved with RF feedback optimization.

The IP3 can be further improved by presenting different impedance terminations to the device.[6] When more voltage and current are available, the drain voltage and current can be increased to improve IP3 and the 1 dB compression point (P_{1dB}) with minimal impact on other performance parameters.

The device process used in this design is a depletion (D)-mode low noise pseudomorphic high electron mobility transistor (PHEMT) with a thin film resistor (TFR). The PHEMT process inherently has low noise and very high linearity. This makes it suitable for this specific application. However, the design shown in this article is not limited to this type of process.

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Figure 1 shows the circuit schematic of the die. Resistors at the sources (R_4 and R_6) are used to set the positive source DC voltage and the drain currents. The value of these resistors can be easily calculated using the current equation

$$I_{DS} = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2 \tag{1}$$

where the gate-to-source voltage (V_{GS}) and the pinch-off voltage (V_p) values are both negative. Once the drain bias current (I_{DS}) is determined, V_{GS} can be calculated. The gate voltage is chosen to be small. It is applied through the resistive divider (R_1 and R_2) and a very large value of shunt resistor (R_3) connecting to the gate. Given the gate voltage, the source voltage and resistor can be calculated. The total current consumption is 100 mA at 5 V supply voltage. It is also important to consider the thermal design of the output transistor. For this reason the LNFET device layout is optimized using thermal calculators.

Two of the design constraints, NF and input return loss, are the main factors in determining the first stage design. An optimum device sizing and inductive degeneration technique are used for simultaneously optimizing noise figure and input match. The second stage is designed for optimum IP3 performance. The biasing conditions for each stage are crucial in determining the best overall IP3. One can choose the optimum biasing conditions such that second-order and third-order intermodulation products are cancelled.[6]

The drain current is controlled by the gate and drain voltages. In the small-signal case, it can be represented by a two-dimensional Taylor series expansion as an incremental drain current[7,8]

$$\begin{aligned} i_d(v_g, v_d) &= I_d(v_g, v_d) - I_d(v_{g0}, v_{d0}) \\ &= \frac{\partial I_d}{\partial V_g} v_g + \frac{\partial I_d}{\partial V_g} v_d + \frac{1}{2}\left[\frac{\partial^2 I_d}{\partial {V_g}^2} {v_g}^2\right. \\ &\left. + 2\frac{\partial^2 I_d}{\partial V_g \partial V_d} v_g v_d + \frac{\partial^2 I_d}{\partial {V_d}^2} {v_d}^2\right] \\ &+ \frac{1}{6}\left[\frac{\partial^3 I_d}{\partial {V_g}^3} {v_g}^3 + 3\frac{\partial^3 I_d}{\partial V_g \partial {V_d}^2} v_g {v_d}^2\right. \\ &\left. + 3\frac{\partial^3 I_d}{\partial {V_g}^2 \partial V_d} {v_g}^2 v_d + \frac{\partial^3 I_d}{\partial {V_d}^3} {v_d}^3 + \cdots\right. \end{aligned} \tag{2}$$

where V_{g0} and V_{d0} are the DC bias voltages and v_g and v_d are the small-signal gate and drain voltages.

If the higher order terms are ignored and the coefficients simplified, the small-signal incremental drain current can be written as

$$\begin{aligned} i_d(v_g, v_d) &= g_m v_g + G_{ds} v_d + \frac{1}{2} g'_m {v_g}^2 + \frac{1}{2} G'_{ds} {v_d}^2 \\ &+ m_{11} v_g v_d + \frac{1}{6} g''_m {v_g}^3 + \frac{1}{6} G''_{ds} {v_{ds}}^3 \\ &+ \frac{1}{2} m_{12} v_g {v_d}^2 + \frac{1}{2} m_{12} {v_g}^2 v_d \end{aligned} \tag{3}$$

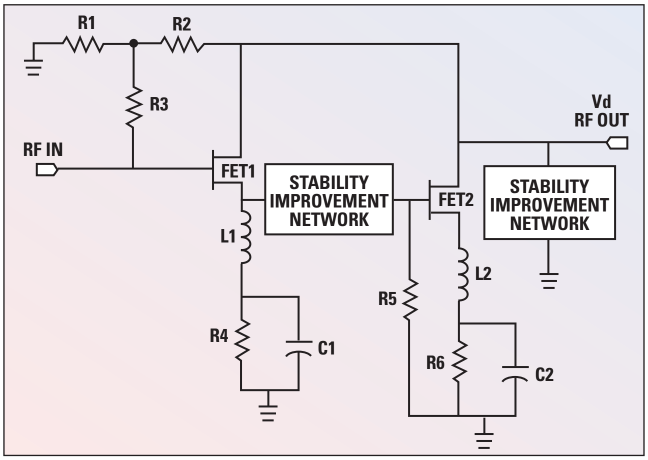

Fig. 1 Die circuit schematic.

where the coefficients g_m, g'_m and g''_m are the transconductance and its first and second derivatives with respect to v_g.

$$g_m = \frac{\partial I_d}{\partial V_g}, g'_m = \frac{\partial^2 I_d}{\partial {V_g}^2} \text{ and } g'' = \frac{\partial^3 I_d}{\partial {V_g}^3} \tag{4}$$

G_d, G'_d and G''_d are the drain-to-source transconductance and its first and second derivatives with respect to v_{ds}.

$$G_d = \frac{\partial I_d}{\partial V_d}, G'_d = \frac{\partial^2 I_d}{\partial {V_d}^2} \text{ and } G''_d = \frac{\partial^3 I_d}{\partial {V_d}^3} \tag{5}$$

And m_{11}, m_{12} and m_{21} are cross terms defined as

$$m_{11} = \frac{\partial^2 I_d}{\partial V_g \partial V_d}, m_{12} = \frac{\partial^3 I_d}{\partial V_g \partial {V_d}^2} \text{ and } m_{21} = \frac{\partial^3 I_d}{\partial {V_g}^2 \partial V_d} \tag{6}$$

The drain to source transconductance, in the saturation region where V_{ds} is high, can be assumed to be small. The cross terms above are also generally small and can be ignored. Therefore, the id equation above can be further simplified to

$$i_d(v_g) = g_m v_g + \frac{1}{2} g'_m {v_g}^2 + \frac{1}{6} g''_m {v_g}^3 \tag{7}$$

The above equation gives rough guidance for optimizing the second-order intercept point (IP2) and IP3. It shows that the lowest second-order and third-order distortion products are achieved when the first and second derivatives of transconductance, g'_m and g''_m, are minimized. It is ideal to have both IP2 and IP3 products lowered. This can be accomplished by carefully selecting the bias points as well as optimizing the amplifier transconductance profile over a wide bias range. The analysis above also shows the sensitivity of this method to wafer uniformity and gain profile. The sensitivity can be reduced by process parameters[9] as well as topology selection and feedback techniques.[2]

The Darlington topology with source degeneration allows gain optimization and high linearity. Capacitors C1 and C2 on the die are chosen for achieving the best gain flatness without seriously degrading input and output return losses. These capacitors are also used to bypass the source resistors and hence improve the NF. R1 and R2 on the die are used for setting the gate voltages.

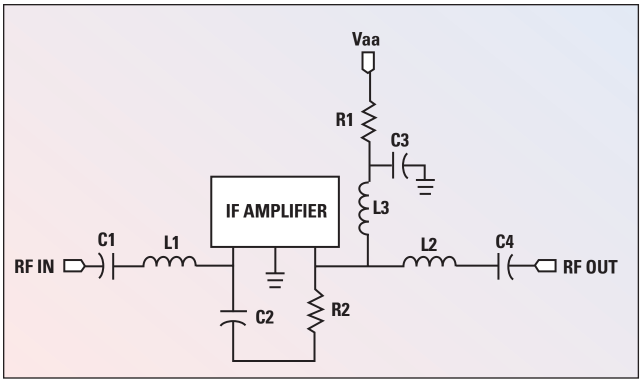

Fig. 2 Evaluation board schematic.

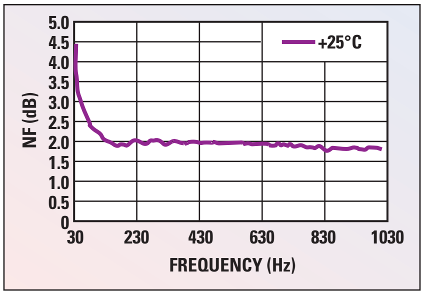

Fig. 3 Noise figure vs. frequency.

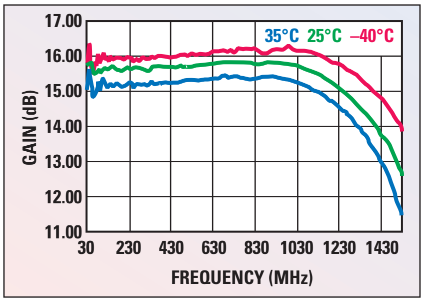

Fig. 4 Small-signal gain vs. frequency.

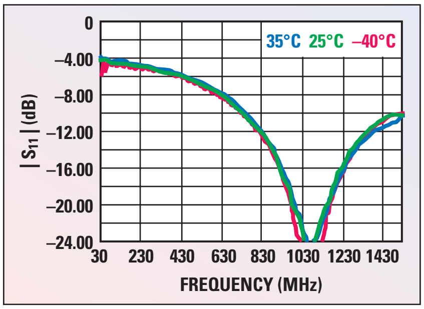

Fig. 5 Input return loss.

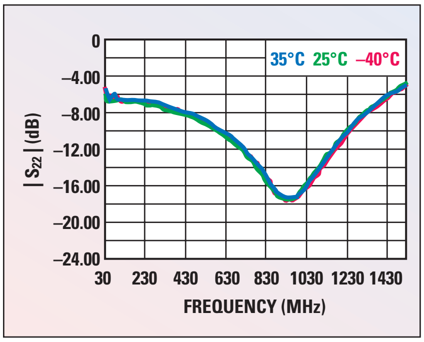

Fig. 6 Output return loss.

Figure 2 shows the test board schematic with external components. The external RF feedback resistor, R2, is chosen for the best input and output return losses and gain trade-off. C1, C2 and C4 are used for DC blocking.

DESIGN FOR STABILITY

Typical specifications dictate unconditionally stable operation up to 18 GHz. This amplifier is designed for unconditionally stable operation, including the external components and biasing under all conditions. For this purpose, various stability design techniques have been employed and integrated into the amplifier. In order to solve stability problems at low to operating frequencies, a source inductor of some value is often used.

COMPONENT SELECTION CONSIDERATIONS

External feedback circuit components R2 and C2 can be tuned if a gain adjustment is needed. The input and output matching networks are composed of L1 and L2, respectively. The input and output matching circuits are designed to be centered at approximately 700 to 1200 MHz. This can also be tuned by the external matching components L1, C1 and L2, C4.

MEASUREMENT RESULTS

An amplifier was fabricated and tested on the test board shown previously with a supply voltage V_{dd} of 5 V and a total supply current I_d = 100 mA. ***Figure 3*** shows the measured noise figure in a bandwidth of 30 to 1030 MHz. The input connector and board trace are not de-embedded from the measurement. The loss of the input transmission line was measured as 0.1 dB in this band. The NF is measured as approximately 2 dB from 100 to 1000 MHz, including the input transmission line loss. ***Figure 4*** shows the measured amplifier gain as a function of frequency at several temperatures with an input power of -20 dBm. The gain is measured to be 15.6 dB at 450 MHz. The plots show that the gain changes less than 1 dB across the whole temperature range of -40° to 85°C.

Figures 5 and ***6*** show the measured input and output return losses, respectively, with an input power of -20 dBm. The output third-order intercept point (OIP3) measured within the operating band was above 43 dBm. The OIP3 measurements were done using two signal sources with frequencies of 433.25 and 449.25 MHz at P_{out} = 5 dBm per tone.

CONCLUSION

Many performance aspects must be considered in the design of IF amplifiers. The next generation IF amplifiers require careful topology selection and competitive design techniques to meet the increasing demands of future applications. An optimized IF amplifier design, using a depletion mode PHEMT technology, is discussed in this article. It will be required to meet the challenging performance requirements of new circuit applications. ■

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Design of a Broadband MIMO RF Transmitter for Next-generation Wireless Communication Systems

The development of a broadband MIMO RF transmitter fulfilling the requirements of the IMT-Advanced wireless communication system is presented. The channel bandwidth of the transmitter is 100 MHz operating in the TDD mode with more than 25 dBm linear output power and 60 dB output power control range. Excellent EVM performance is obtained. The RF transmitter can support up to 6 × 6 MIMO configuration and has been successfully integrated with the MIMO RF receiver and the baseband modules. The average data rate in the field test is approximately 1 Gbps.

The last decade has seen a great burst in wireless communication technologies and their commercial implementations. Until now, the third generation (3G) mobile networks (such as UMTS and cdma2000) and 3.5G mobile networks (such as UMTS/HSPA and CDMA 1xEvDO), which can deliver data rates up to several Mbps to individual users, have been deployed in many countries and adopted by more and more people. However, the pursuit for higher data rates never stops, and a number of wireless technologies are under development to meet future needs: Long Term Evolution (LTE) and WiMAX, both of which can support far higher data rates than existing networks. According to the definition of IMT-Advanced (4G) systems by the International Telecommunication Union (ITU), the next generation network should support data rates up to 100 bps for high mobility and approximately 1 Gbps for low mobility. Unfortunately, neither LTE nor WiMAX can fulfill these requirements. Currently, much work is going on to enhance these exiting standards in order to meet the requirements of the IMT-Advanced system.[1,2] The roadmap of evolutions of various candidates toward the IMT-Advanced system is shown in ***Figure 1.***[3]

To meet the requirement of the data rates defined in the IMT-Advanced system, the channel bandwidth will be up to 100 MHz. Moreover, the MIMO technique is needed to obtain higher channel capacity or spectrum efficiency. When the channel bandwidth approaches 100 MHz, RF designers have to face many challenges, both in the system scheme and the circuit design. It is known that the 6 × 6 MIMO configuration can provide more than 10 bit/Hz in the spectrum efficiency in many typical wireless channels without too much difficulty. In this article, a detailed description of the design of a high performance MIMO RF transmitter with a novel direct-conversion architecture is provided. The RF transmitter operates in the 3.45 GHz frequency band with 100 MHz channel bandwidth and excellent EVM and gain flatness performance. Experimental results are reported. The transmitter can support the 6 × 6 MIMO configuration and has been successfully used in an IMT-Advanced experimental network.

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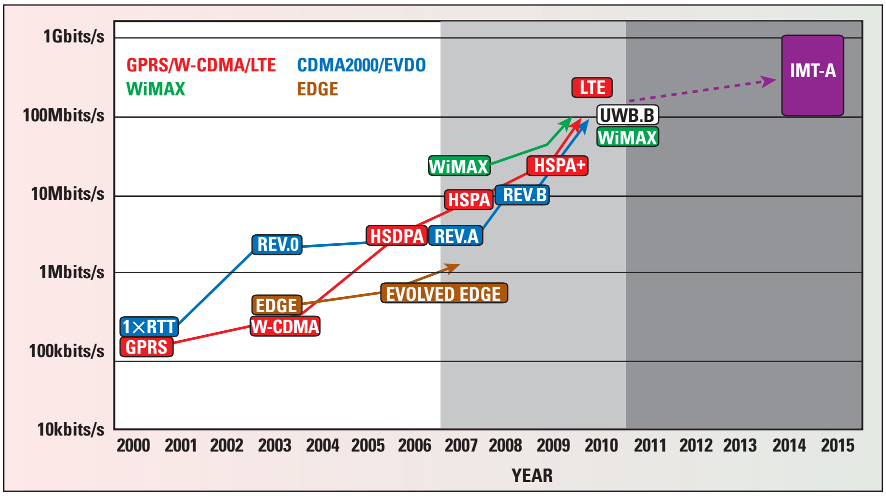

Fig. 1 Evolution of mobile technologies toward the next generation system.

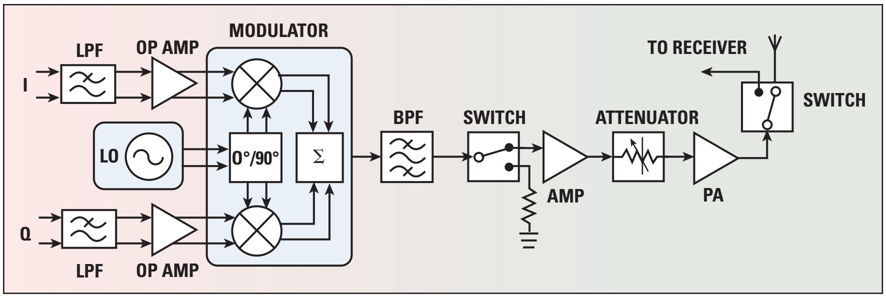

Fig. 2 System diagram of the direct conversion transmitter.

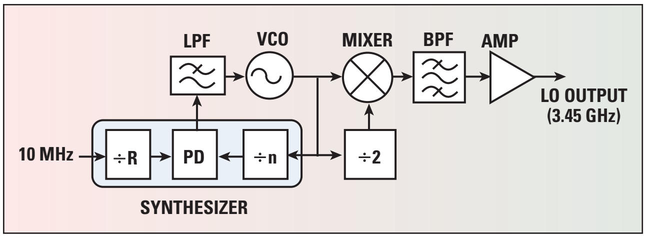

Fig. 3 Architecture of the LO generator.

SYSTEM ARCHITECTURE

Compared to the conventional superheterodyne architecture, the direct-conversion solution has gained more and more attention and applications in various low-cost and compact wireless communication systems.[4-6] Unlike the direct-conversion receiver, which has design challenges still needed to be resolved in order to achieve high performance, it is relatively easier to build a direct-conversion transmitter.[7]

The transmitter reported utilizes a direct-conversion architecture illustrated in ***Figure 2***. This diagram is just an abstract illustration and only essential components are outlined. Other necessary circuits, such as the control circuit, power supply circuit, etc., are omitted for brevity.

The configuration of the PLL is shown in ***Figure 3*** and will be introduced later. As shown, the transmitter utilizes differential analog I/Q inputs, which are used not only to get a better signal-to-noise ratio due to common mode noise rejection, but also to suppress the even order distortions resulting from the nonlinearity of the quadrature modulator. The low pass filters following are used to further reduce the out-of-band emission level and aliasing products.

Next, the operational amplifiers can provide a certain DC offset, required by the inputs of most quadrature modulators. Usually these operational amplifiers should not provide very much gain since the baseband signal level is relatively large and even a few dB gain can saturate the modulator. In this transmitter, the input stage uses operational amplifiers of unit gain. The bandpass filter after the modulator suppresses the spurs resulting from the nonlinearity of the modulator. The transmitter works in the TDD mode, so it is important to switch off the RF amplifier and power amplifier as fast as possible when the receiving period is on, but the bypass capacitors necessary for the stability of the amplifiers always make this unpractical. To prevent the receiver from saturation or jamming by the power amplifier at the start of the receiver period, it is wise to use a RF switch, right before the RF driver amplifier together with the one before the antenna, both of which feature fast switch speed within 60 ns and thus provide enough isolation between the receiving and transmitting period quickly.

The Automatic Power Control (APC) is realized with digital attenuators, which can provide more than 60 dB attenuation control range in 0.5 dB steps. The required output power of the transmitter is 20 dBm. Considering the peak-to-average ratio of the transmitted signal, a MMIC power amplifier capable of 33 dBm output power at its 1 dB compression point is utilized. To further assure the linearity, the output IMD level is tuned and optimized when the output power is approaching 25 dBm.

Usually, special attenuation should be paid in the design of the PLL used in the direct-conversion architecture in order to avoid the LO pulling effect, which can seriously deteriorate the system performance. As briefly shown in Figure 3, the transmitter works on a carrier with an offset from the running frequency of the VCO. The offset is produced using a by 2 frequency divider fed by the VCO; the 3.45 GHz carrier is then obtained by mixing the output of the VCO with this offset. The bandpass filter is used to suppress the unwanted mixing products. The common reference clock of 10 MHz shared by the 6 × 6 MIMO system is produced either by an OCXO whose frequency can be precisely adjusted by the system AFC loop, or by the outside reference source, meanwhile bypassing the inside OCXO. This architecture is very flexible in a prototype system and capable of minimizing the frequency offset between the receiver and the transmitter, which can degrade the system performance especially when using an OFDM modulation scheme. Furthermore, the LO phase noise should be carefully optimized to achieve good system performance.[8]

CONSIDERATIONS OF BROADBAND OPERATION

In the case of broadband operation, the performance of the quadra-

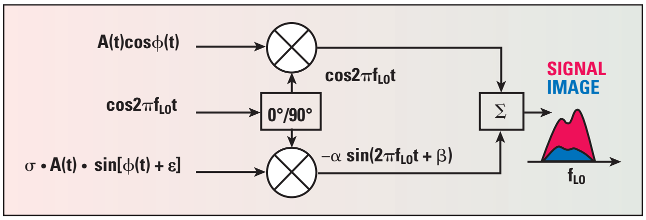

Fig. 4 Simple model representing various unbalanced components resulting in the image product.

ture modulator greatly determines the overall transmitter performance, such as the modulation accuracy indicated by EVM.[9] Compared to the narrowband case, the amplitude and phase unbalance among the differential I/Q input channels becomes more serious and thus brings about the image product, which aggravates the system performance. Furthermore, almost every quadrature modulator in the market requires a DC offset at its differential I/Q input, the unbalance of which makes the elimination of the LO feed through problem more difficult.

IMAGE PRODUCT

The mechanics resulting in the image product can be clarified using a simple model shown in ***Figure 4***. As illustrated, σ and α represent the amplitude unbalance and ε and β represent the phase unbalance. The image lies in the same frequency band as the signal, thus degrading the modulation accuracy. The lengthy development of the output signal equations can be found in the literature.[7] In the case when OFDM is utilized, the up converted signal and its image are shown in ***Figure 5***, in which the individual carrier and its image are drawn in the same color.

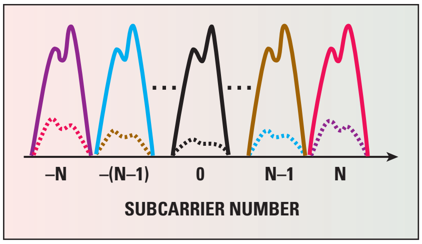

Fig. 5 Up-converted signal and its image when using OFDM.

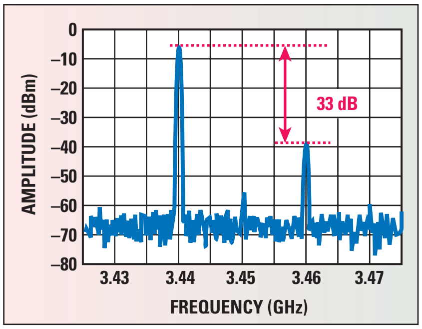

Fig. 6 The unadjusted image suppression.

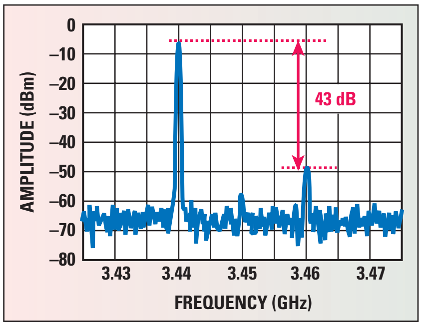

Fig. 7 The adjusted image suppression.

In reality, the amplitude and phase unbalances always exist in the differential I/Q channel, so the image product cannot be completely avoided. Of course, the unbalance of the LO path in the quadrature modulator can also result in the image product, but the influence is relatively smaller. Usually, the image product can be compensated in the baseband processing, such as adaptive adjustment of the amplitude and phase of the I/Q signal as part of the digital predistortion loop, or simply setting a fixed amplitude and phase offset.

In the RF scenario, to alleviate the performance degradation caused by the image product, attention should be paid to the PCB layout process where the differential I/Q channels should be identical in their physical layout. In the tuning process, the level of the image product can be evaluated from the image to signal ratio, which can be measured using a spectrum analyzer. The unadjusted single tone output with its image product is shown in ***Figure 6***. Then, capacitors on the order of several pF can be shunted to ground from the signal traces of the differential I/Q channels. The working of the capacitors results from their non-ideal parameters, which can be modeled as a complex impedance; the magnitude and phase of the baseband signal can then be slightly tuned. After carefully tuning, an image to signal ratio or image suppression below -35 dBc can be achieved throughout the working band. The improved image suppression is shown in ***Figure 7***.

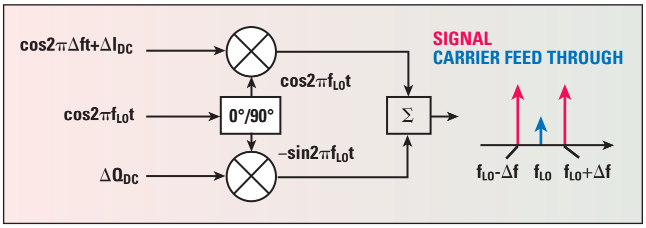

Fig. 8 Simple illustration of the carrier feed-through problem.

CARRIER FEED THROUGH

The carrier feed through results not only from the DC offset unbalance among the I/Q differential inputs, but also from the LO leakage of the quadrature modulator. Usually the LO leakage is not a concern because it is very small in a MMIC quadrature modulator. The mechanics behind the carrier feed-through problem due to DC offset unbalance is illustrated in ***Figure 8***. If a two-tone output is desired, the baseband I/Q signal can then be expressed by the following, with their corresponding DC offset:

$$\text{I channel signal: } I(t) = \cos 2\pi\Delta f t + \Delta I_{DC} \tag{1}$$

$$\text{Q channel signal: } Q(t) = \Delta Q_{DC} \tag{2}$$

Output signal:

$$O(t) = (\cos 2\pi\Delta f t + \Delta I_{DC})\cdot\cos 2\pi f_{L0} t - \Delta Q_{DC}\cdot\sin 2\pi f_{L0} t$$

$$= \frac{1}{2}\left[\cos 2\pi(f_{L0}+\Delta f)t + \cos 2\pi(f_{L0}-\Delta f)t\right]$$

$$\underline{+A\cos(2\pi f_{L0} t + \theta)} \tag{3}$$

$$A = \sqrt{\Delta I_{DC}^2 + \Delta Q_{DC}^2} \quad ; \qquad \theta = \tan^{-1}(\Delta Q_{DC} / \Delta I_{DC})$$

According to the above equations, the component underlined in Equation 3 is the carrier feed-through product. The input DC offset levels can be slightly adjusted around the recommended common mode voltage required by the quadrature modulator to greatly reduce the carrier feed-through level. The circuit realizing the tuning function is shown in ***Figure 9***. After iterative adjustment of the DC offset of the I/Q differential input, the carrier feed through to signal ratio or carrier suppression below -50 dB is easily achieved. The tuning result is shown in ***Figure 10***.

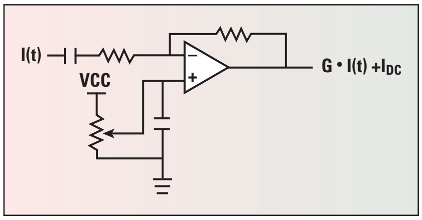

Fig. 9 Circuit realizing the tuning of the DC offset level using an operational amplifier.

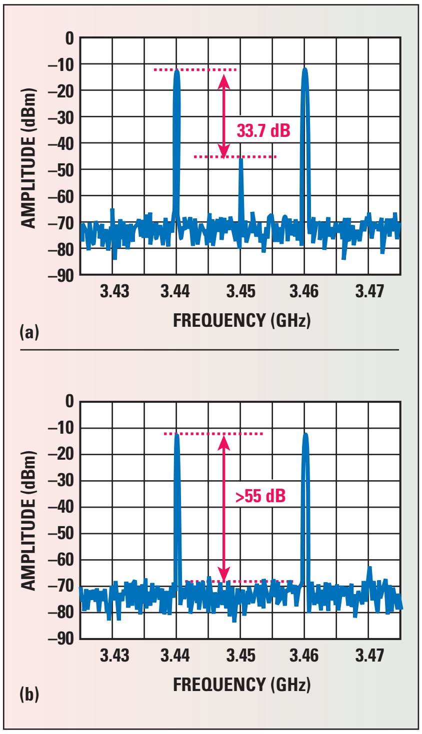

Fig. 10 The unadjusted carrier feed through (a) and the adjusted carrier feed through (b).

MEASUREMENT RESULTS

The transmitter reported in this article is integrated together with the receiver into one single PCB board. The whole 6 × 6 MIMO system consists of six such transceiver modules as well as one control board, which acts as an interface to the baseband serial control signals, and one power supply board providing the DC-DC conversion from 48 to 6 V used by the transceiver. The 6 × 6 MIMO system equipped with six transceiver modules is illustrated in ***Figure 11***.

The transmitter is tested with analog I/Q inputs from a vector signal generator. During the test process, it is convenient to divide the transmitter into three parts: modulator, driver and power amplifier, which can be tuned and tested individually. In the modulator test, the performance that is cared about is the modulation accuracy indicated by EVM. The LO phase noise should first be optimized by adjusting the setting of the synthesizer and the loop filter. After adjustments of the unbalance level mentioned before, the modulation accuracy can then be guaranteed. The resulting LO phase noise figure and the EVM of different modulation type are listed in ***Table 1***, together with the image to carrier ratio and carrier feed through level. Due to the limited capability of the laboratory instruments, the maximum signal bandwidth that can be analyzed is 20 MHz.

A conventional S-parameter test is carried out in the testing of the driver and power amplifier. After careful tuning, the gain fluctuation is kept below 0.5 dB in each stage. An additional IMD test is also carried out to evaluate the nonlinearity of the power amplifier when the output level of 25 dBm is achieved. The results are listed in ***Table 2***.

After individually testing of the different stages, the whole link is connected and tested. The overall performance, indicated by the EVM when the output level achieves the specified 20 dBm, is listed in ***Table 3***.

With help from the Agilent Open Laboratory in Beijing, China, the transmitter was tested with a baseband signal of 80 MHz modulation bandwidth, which was the maximum digital modulation bandwidth available from Agilent at that time. The results are shown in ***Figure 12***. The channel 1 OFDM error summary is shown in ***Table 4***.

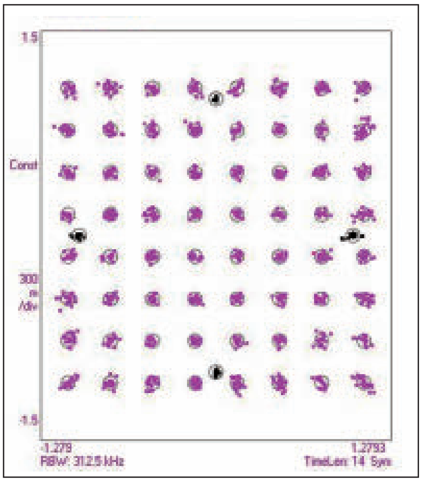

Fig. 12 Constellation diagram.

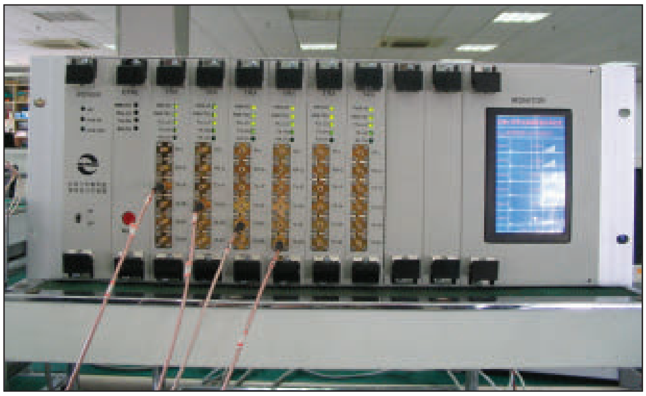

Fig. 11 The 6 × 6 MIMO RF transceiver.

TABLE I
MEASUREMENT RESULTS OF THE MODULATOR

LO phase noise:	-82 dBc/Hz@1 kHz;-95 dBc/Hz@10 kHz		
	-120 dBc/Hz@10 kHz;-139 dBc/Hz@1 MHz		
EVM & SNR			
Modulation Type (20 MHz)	***EVM (%)***	***SNR (dB)***	***Carrier Suppression***
QPSK	1.5-1.8	35	-50 dB
QAM16	1.1-1.2	35	***Image Suppression***
QAM64	1.0-1.1	35	-42 dB

TABLE II
MEASUREMENT RESULTS OF THE DRIVER AND POWER AMPLIFIER

Driver Part		***Power Amplifier Part***		
Gain (dB)	Return Loss (dB)	Gain (dB)	Return Loss (dB)	IMD3
Max: 6.8	Input: ≤15	Max: 20.2	Input: ≤17	@Pout= 25 dBm
Ripple: 0.2	Output: ≤20	Ripple: 0.5	Output: ≤27	45 dBc

TABLE III

OVERALL SYSTEM PERFORMANCE AT THE SPECIFIED OUTPUT POWER

Modulation Type (20 MHz)	EVM (%)	SNR (dB)
QPSK	1.3-1.6	36
QAM16	1.0-1.3	35
QAM64	1.0-1.1	35

TABLE IV

ERROR SUMMARY

	Ch 1	Ch 2	Avg	Units
EVM	-29.353	—	-29.353	dB
EVM Peak	-19.505	—	-19.505	dB
Pilot EVM	-31.047	—	-31.047	dB
Data EVM	-29.276	—	-29.276	dB
Freq Err	—	—	80.690	Hz
Sym Clk Err	—	—	-0.44206	ppm
CPE	—	—	0.43687	%rms
IQ Offset	-20.361	—	-20.361	dB
IQ Quad Err	-0.74561	—	-0.74561	deg
IQ Gain Imb	-0.06951	—	-0.06951	dB
Cross Pwr	—	—	—	
Sync Corr	0.92890	—	0.92890	

CONCLUSION

The implementation of a broadband direct-conversion transmitter is reported. The considerations of system architecture are discussed in detail and the issues regarding the broadband working are illustrated. The transmitter was integrated in a 6 × 6 MIMO wireless prototype system capable of data rates up to 1 Gbps in a low mobility scenario. ■

ACKNOWLEDGMENT

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[Continued from pg. 10]

still further behind at around 250 ms. Latency is a useful measure of the all-important round-trip speed that is vital to the user appeal of real-time, interactive applications. Think of multi-player gaming and media-rich social networking for an idea of just some of the applications that will be enhanced by LTE-Advanced. ***Table 1*** shows the performance characteristics for each technology.

Also taking centre stage is the ability of LTE-Advanced to leverage advanced topology networks. Reflecting the ITU's vision for IMT-Advanced, Release 10 caters for seamless interworking with a jigsaw of radio access systems. Macro-, micro-, pico- and femto-cells all figure in a heterogeneous network environment, covering cell sizes from tens of kilometres to just a few meters.

As long ago as 2003, ITU-R articulated its long-term strategic vision for IMT-Advanced: a global platform to build the next generation of interactive mobile services, encompassing fast data access, unified messaging and broadband multimedia.

The ITU's formal process of identifying technology candidates for this, a new wireless generation moved forward with an invitation (issued in March 2008) for the submission of proposals for candidate radio interface technologies for the terrestrial components of IMT-Advanced.

In October 2009, the 3GPP Partners made their formal submission to the ITU, proposing LTE Release 10 and beyond—'LTE-Advanced'—as a candidate for IMT-Advanced. Of the five other technology candidates that were submitted in parallel, some were technically identical, leaving just two main candidates. Self-evaluation results in 3GPP have shown that LTE-Advanced meets—or in some cases exceeds—all requirements of ITU-R.

After the expected approval of LTE-Advanced specifications in December 2010, it is anticipated that work on Release 10 will be effectively completed by mid-2011. Following final approval of LTE-Advanced by the end of 2011, this will give vendors and operators a clear target to start building 4G networks. While estimates vary, this timeframe points to initial LTE-Advanced deployments around 2015.

As proposed by the 3GPP Partners, LTE-Advanced is the next technological iteration in a continuum of wireless standardisation at a global level that spans almost three decades.

As with GSM and W-CDMA/HSPA/LTE currently, there will be a long period of co-existence between 3G and 4G systems—maybe for two decades or more. As 2010 draws to a close, there are a growing handful of commercially deployed LTE networks based on 3GPP Release 8, with a flood of further launches expected during 2011 and 2012. These '3.9G' networks are already giving customers an early taste of the possibilities of ultra-high speed mobile broadband, and—tantalisingly—a glimpse of our true 4G future. ■

Jean-Pierre Bienaimé *was elected Chairman of the UMTS Forum in 2003. Since joining France Telecom (FT) in 1979, he has served as Advisor to the General Director of Moroccan Telecommunications in Rabat, Director of Marketing and Product Development for international business networks and services at FT, Director of Business Development and Subsidiaries at France Cables and Radios, Chief Executive Officer of Nexus International and VP International Development at France Telecom Mobile. After the purchase of Orange by FT, he was appointed VP Group Technical Support. He is currently Senior VP, Strategy and Communications at Orange Wholesale.*

BAW Innovation Helps WiFi and 4G to Happily Coexist

Channels allocated for wireless services are increasingly being crammed together on the frequency band while the price per MHz of spectrum remains quite high at auction. This is especially at issue for 4G signals, which are commonly located at frequencies adjacent to existing WiFi and Bluetooth channels and therefore suffer from mutual interference issues. As such, operators and device makers need interference mitigation solutions. One such solution arises out of an advanced filter technology known as bulk acoustic wave (BAW) that has emerged over the past few years. This article will investigate the driving forces behind the need for better filtering for 4G applications and discuss an effective hardware-based solution.

As demand for broadband services grows, the trend towards wireless is well-established. In emerging markets, such as China and India, build-out of wireline infrastructure will be too expensive, time consuming and logistically complicated. In established economies, mobility is the "killer app" that drives the growth in demand for wireless devices and applications. But wireless communications require spectrum, which is—in economic terms—a scarce resource; this has three key implications.

First, a limited supply coupled with strong demand will naturally lead to high prices. This has been evident in the billions of dollars generated at auction for the rights to these bands. For example, this year's 4G auctions in India generated $8.2 B. The popularly quoted revenue figure for the India BWA auction is $5.5 B (USD), which doesn't take into account the additional $2.7 B paid by state-run operators BSNL and MTNL. Without having to actually participate in the auction, these two firms were guaranteed spectrum at a price equivalent to the winning bid. This equated to an average of $6.2 M per MHz of spectrum, with that price per MHz per capita peaking over $1.15 in Mumbai and Delhi.

Josh Raha
TriQuint Semiconductor, Hillsboro, OR

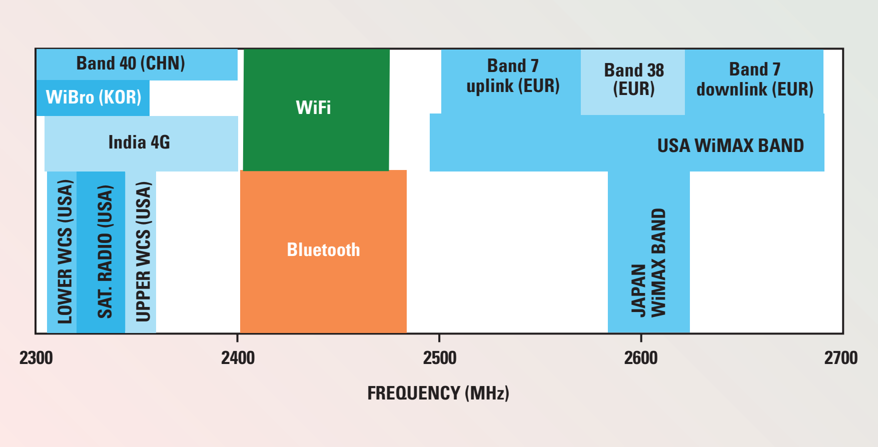


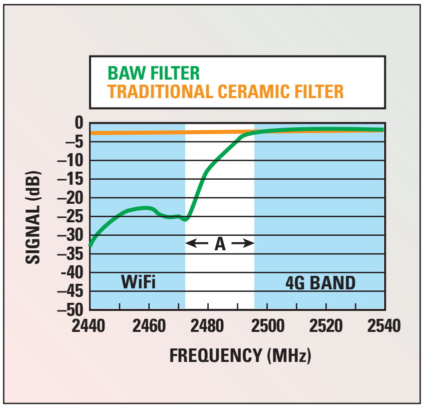
Fig. 1 Allocated frequency bands.

Second, high demand for a scarce resource motivates a supplier to produce as much of that resource as possible. While it is not possible to "produce" more electromagnetic spectrum, it is possible to "refarm" existing spectrum. To that end, regulatory bodies worldwide are working to find more channels to put into use, with the assumption that interference or other considerations will be handled by the marketplace. The FCC, with the support of President Obama, has released The National Broadband Plan this year. Amongst other recommendations, the document calls for 500 MHz of new spectrum to be made available for broadband within 10 years, 300 MHz of which should be allocated for mobile use within five years. To the Broadband Plan's credit, it does recognize that interference issues are lurking, but it does not offer solutions. Meanwhile, many bands allocated for 4G data services happen to be immediately adjacent to the International ISM band, the unlicensed band that runs roughly from 2.4 to 2.5 GHz and is used worldwide for Wireless LAN and Bluetooth signals. Another example in the US is the satellite radio band, which sits right in the middle of WCS spectrum with no guard-band defined by the FCC (see ***Figure 1***). As band assignments get tighter, interference issues multiply.

Third, scarcity leads owners of a resource to use it as efficiently as possible. There are two main approaches to achieving spectral efficiency, both equally important. The first is the use of better modulation techniques, allowing an operator to pack more data into a given channel. The second is to find ways to stretch the use of purchased spectrum to its edges—to use an entire 20 MHz channel for data rather than give up 5 MHz on each side as guard-bands.

Let us take a moment to consider guard-bands. A guard-band is the slice of frequency between two channels, a sort of "no-man's-band" where both parties gradually roll off their transmission power. In some cases, guard-bands are built into the operator's license; the FCC might designate 10 MHz between channels that cannot be used. More commonly, the regulatory body tends to leave the definition of the guard-band to the operator. The requirements for out-of-channel transmissions will be set by, say, the FCC, and the license holder is free to use as much spectrum as he wants, providing he meets those rules. Guard-bands, naturally, represent wasted spectrum, and operators are intent on minimizing them.

Arising out of these implications is a clear picture: 4G operators are spending a great deal of money on channels that happen to lie very close on the frequency spectrum to interfering signals, but have no built-in guard-bands. The standards upon which 4G data services will be delivered are WiMAX, LTE and TD-LTE. These are extremely similar in terms of transmission pattern (all use the OFDMA modulation scheme); and, more importantly, there is a significant overlap in the frequencies that each will use. As



▲ *Fig. 2 Example filter performance.*

such, for the purposes of this discussion, they can be referenced collectively as "4G". While there are sub-2 GHz bands set aside for LTE (most notably, the 700 MHz "digital dividend" spectrum), a significant proportion of 4G services will be delivered in what the author calls the 4G bands: 2.3 to 2.4 and 2.5 to 2.7 GHz (see Figure 1).

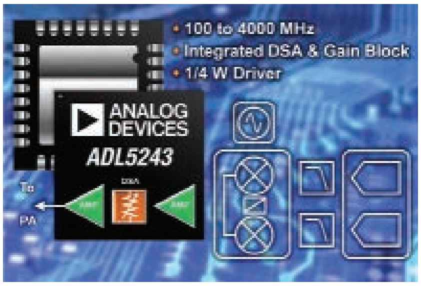
Operators find this spectrum attractive for three main reasons. First, it has relatively good RF propagation characteristics. Second, it is largely unused, meaning there are bigger chunks of consecutive spectrum available here than elsewhere in the band. Third, we are seeing some level of global harmonization, with governmental regulators in India, China, Japan, America and Europe all offering this spectrum for 4G services. Alas, nothing is perfect and there is a key drawback, discussed earlier: nestled amongst these attractive 4G bands are nasty interferers in the form of WiFi, Bluetooth and satellite radio signals.

This issue is perhaps most apparent and acute in the increasingly popular "personal hotspot" devices. These are wireless LAN access points that take a 4G signal from the service provider and convert it to WiFi in order to share the 4G connection across multiple WiFi-enabled devices. Because they transmit and receive 4G and WiFi signals at the same time, these personal hotspots have the greatest risk for mutual interference issues.

In order to address this issue while minimizing wasted spectrum in the guard-bands, operators and device makers have turned to advanced filtering technologies. A filter with a steep skirt—one that rolls off quickly from pass-band to rejection band—becomes increasingly important in cases like these (see ***Figure 2***). Surface acoustic wave (SAW) filters have traditionally served this purpose. However, as frequencies rise to the 2.3 to 2.7 GHz range, SAW performance starts to decline. BAW filters are the natural evolution of acoustic wave technology for higher frequency bands, and become extremely attractive as frequencies grow to 2.3 GHz and above.

For example, TriQuint Semiconductor's BAW technology has been applied to a trio of filters specifically designed to mitigate the interference issues between the ISM and 4G bands. One filter in this family passes the ISM band while effectively rejecting signals above 2.5 GHz. One application for this part would be as a WiFi pass-band filter. Notch filters are used to knock down WiFi/BT signals and pass the 4G signals with low insertion loss both above and below the ISM band. In addition to excellent electrical performance, BAW filters can be extremely small with very low profile packaging. Filters are available in 1.3 × 1.7 mm packages with a profile of less than 0.5 mm. Clearly, this supports the long-term trends toward ever-smaller, full-featured mobile devices. BAW also exhibits excellent power handling capabilities, with WiFi notch filters typically withstanding +28 dBm (continuous wave). Used in various combinations depending on the end application, these BAW filters are good examples of how companies are simplifying RF connectivity with new hardware technology that resolves real-world problems like the interference and band adjacency issues 4G operators now face.

Demand for 4G will continue its path of explosive growth and it is conceivable that, moving forward, every scrap of spare spectrum will be prized as a vehicle for delivery of lucrative broadband data services. As useable spectrum bands continue to press together, innovative filtering solutions like BAW technology will continue to help operators make better use of their spectrum and realize more complicated and compelling consumer devices. ■



IF and RF DVGAs for Next Generation Wireless Systems

Analog Devices has introduced four new Digital Variable Gain Amplifiers (DVGA): ADL5201 and ADL5202, which are IF DVGAs; and ADL5240 and ADL5243, which are RF DVGAs. These new DVGAs will enable the design of smaller base stations with multiple carrier capabilities for next generation wireless systems such as Long Term Evolution (LTE) systems.

The ADL5201 and ADL5202 DVGAs are optimized for use in IF sampling receivers. The ADL5201 (see ***Figure 1***) is suitable for single-channel receivers while the dual-channel ADL5202 is suitable for use in main and diversity or MIMO receivers. For the most common IFs used between 70 and 300 MHz, both these devices exhibit minimum amplitude variations over frequency, allowing designers to choose an optimum IF for their design. With a gain range of 31.5 dB (-11.5 to 20 dB), these devices can be used to expand the dynamic range of high performance IF sampling receivers. In addition, a gain-control step size of 0.5 dB ensures that the full input range of the analog-to-digital converter (ADC) can be fully utilized.

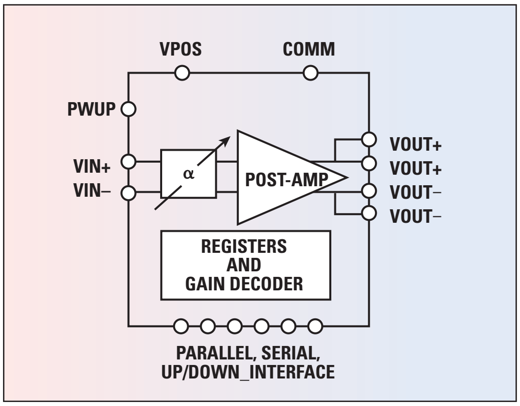


Fig. 1 ADL5201 block diagram.

The ADL5201 and ADL5202 DVGAs feature novel and flexible gain control interfaces. In addition to parallel and serial interface options, a novel up/down mode is also available. When operated in parallel mode, the 6-bit gain code can either be latched into a register or the register can be made transparent resulting in the gain following the code on the six gain control pins. In serial mode, the gain is set by clocking serial data into the devices' serial to parallel interface (SPI), which also has a read back mode. In the serial mode, there is an additional fast attack mode where rather than setting the gain to a specific level, the gain can be changed by 2, 4, 8 or 16 dB step increments or decrements. The gain can also be changed using an up/down interface. This allows the gain to be incremented up or down in steps of 0.5, 1, 2, or 4 dB. The gain control interfaces of the

[Continued on pg. 34]

Analog Devices Inc.
Norwood, MA

Mobile Communications: Company Showcase

LTE Base Station Emulator

Agilent Technologies has a new LTE Base Station Emulator designed to speed development and verification of LTE user equipment. The PXT Wireless Communications Test Set (E6621A) is a powerful, common hardware test platform that is used across the LTE development lifecycle. Agilent's PXT test set represents a significant breakthrough in testing handsets and data modems for all planned LTE deployments. The new PXT is the basis for a Signaling Conformance Test suite that will run TTCN-3 scripted test cases validated by PTCRB, the North American regulatory agency responsible for cellular device compliance. For more information, visit www.agilent.com/find/PXT.

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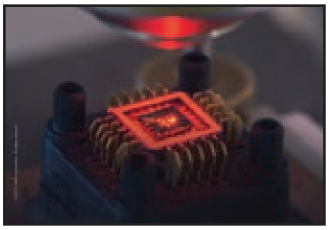

AWR Visual System Simulator 2010

AWR's Visual System Simulator™ software (VSS) is ideal for communication system design. The 2010 release introduces new capabilities that increase productivity for RF engineers, including time delay neural network (TDNN™) advanced amplifier behavioral models for capturing memory effects and a new phased-array element for radar designs. Enhancements have also been made to the VSS's RFA™ architect tool. New communication models and signal processing blocks have been added as well, including turbo decoders for 3G/4G standards. AWR Connected™ for Rohde & Schwarz's WinIQSIM2 waveform generation software integrates with VSS to ensure test & measurement source signals are identical to those within VSS. This additional module to VSS supports all communications standards and their variants. Visit www.awrcorp.com and AWR.TV to learn more about VSS as well as to download a free 30-day trial.

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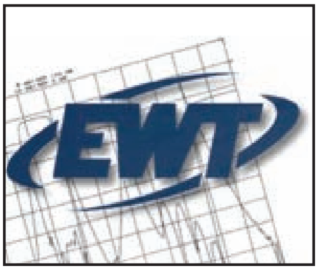

EWT: Where Performance Counts

Eastern Wireless TeleComm Inc. (EWT) specializes in custom design and manufacture of RF and microwave filters and filter-based products for mobile communications applications. The staff encompasses over 50 years of combined experience in the design, development, and high volume manufacturing of cavity and waveguide filters to 50 GHz and lumped element filters up to 10 GHz. All of the company's products are manufactured to strict guidelines set forth in its ISO-9001 compliant quality system, ensuring the highest level of product performance and reliability. Through utilization of the company's in-house machining capabilities and state-of-the-art manufacturing processes, rapid turn-around is standard. EWT can develop any cavity, lumped element, waveguide, or wireless filter to meet your needs. Visit us online to request your quote today.

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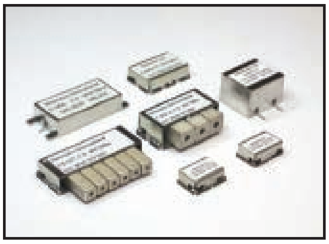
Empower RF Systems Inc.,
Inglewood, CA (310) 412-8100,
www.empowerrf.com.



Mobile Communications

NIC's mobile communication products include filters, diplexers and integrated assemblies used in the transmit-receive chain as well as for harmonic suppression. Different technologies such as LC, ceramic and cavity are used based on the specifications. Custom designs are available to support specific requirements. Features include: cavity filter designs with low insertion loss and high power handling capability; custom high Q ceramic filter designs offering high performance in a small package configuration; integrated solutions providing improved performance while significantly reducing the size and simplifying customer procurement; and standardized products to offer low cost solutions. NIC is a global manufacturer of custom RF and microwave components.

Networks International Corp.,
Overland Park, KS (913) 685-3400,
www.nickc.com.

RF CMOS Solutions

Peregrine's new PE42662 SP6T features six fully symmetric transmit ports allowing any combination of transmit/receive for 3G front-end modules in multi-band GSM/EDGE/W-CDMA handsets. The UltraCMOS™ switch delivers high linearity and exceptional harmonic performance: 2fo/3fo = -40 dBm at 35 dBm TX (900 MHz) and 33 dBm TX (1900 MHz); IIP3 of +68 dBm at 50 Ohm; low transmit insertion loss of 0.5/0.6 dB (900/1900MHz); and 38 dB/33 dB isolation (900/1900 MHz). The switch handles maximum +35 dBm input power with world-class ESD tolerance of 4000 V HBM at ANT port, and 2000 V HBM on all ports.

Peregrine Semiconductor,
San Diego, CA (858) 731-9400,
www.psemi.com.

RFMD® LNA Products

RFMD® offers a broad portfolio of LNA products ideally suited for cellular applications that demand high performance in a space-constrained environment. Products include the RF281x family of GPS LNA modules and the RF2884 broadband general-purpose LNA. The RF281x family of GPS LNA modules is based on RFMD's EpHEMT process and integrates SAW filters. These modules have been designed in very compact packages to deliver best-in-class performance, which in turn enable GPS solutions that feature reduced front-end noise and improved sensitivity. Features for the GPS LNA and general-purpose receive LNA modules include low noise figure, high gain and excellent linearity. To learn more about RFMD's wide range of LNA products, visit www.rfmd.com.

RFMD,
Greensboro, NC (336) 664-1233,
www.rfmd.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.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.

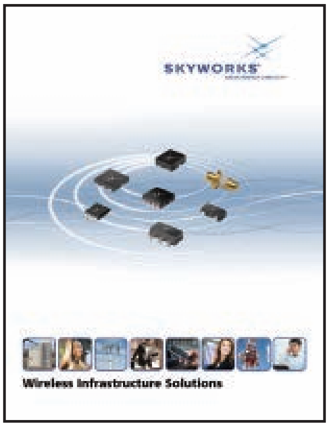
High Performance RF Components

VENDORVIEW

Are your mobile device customers demanding more talk time, faster data exchange rates and streaming video? Do they want connectivity that seamlessly switches between cellular and broadband to experience fewer delays and longer battery life? TriQuint Semiconductor designs and manufactures high-performance radio frequency solutions for communications companies building mobile devices ranging from high-end smartphones and gaming devices to ereaders and netbooks. TriQuint is the industry's only RF vendor to offer a total front-end solution that integrates the amplification, filtering and switching technology into a single solution. TriQuint's solutions minimize board space and maximum battery life. Help your customers talk, text, download video and enjoy their favorite mobile devices. Choose TriQuint for your mobile device RF.

TriQuint Semiconductor Inc.,
Hillsboro, OR (503) 615-9000,
www.triquint.com.

Wireless Infrastructure Solutions



VENDORVIEW

Skyworks' broad portfolio of RF/microwave products includes solutions for today's demanding wireless infrastructure systems including cellular base stations, WiMAX access points, land-mobile radio systems and point-to-point radio links. Skyworks offers components and subsystems from the antenna connection to the baseband output, including low noise amplifiers, power amplifiers, general-purpose amplifiers, mixers, modulators, demodulators, phase shifters, switches, attenuators, detectors, directional couplers, hybrid couplers, power splitters/combiners, ceramic filters and resonators, plus discrete control components including PIN, tuning varactor, Schottky diodes and chip attenuators.

Skyworks Solutions Inc.,
Woburn, MA (781) 376-3000, www.skyworksinc.com.

RF Probe

INGUN has announced an innovative breakthrough in modern RF probing technology with the introduction of the HFS-835 series RF Probe with integrated attenuator. It is said to be the first spring-loaded RF probe with an integrated attenuation module. The 50 Ω RF probe has a broadband frequency range of DC to 3 GHz. Front plungers and inner conductor tip-styles can be tailor-made to accommodate contacting of several different PCB land-pattern shapes as well as selected RF connector types. Applications include virtually any kind of production-line test with RF test applications, e.g. the general telecommunication market, WiFi boards, Bluetooth applications and the automotive market. It is especially suitable for test fixtures with space restrictions or to prevent shear forces to the probe due to externally connected attenuators.

INGUN Prüfmittelbau GmbH,
Konstanz, Germany +49 7531 8105-62,
www.ingun.com.

[Continued from pg. 30]

IF DVGAs are designed to allow simple interfacing to ADCs from Analog Devices, such as the AD9643, which features over range detection. When the ADC is connected to an ADL5201 or ADL5202 up/down interface, over range detection at the ADC's output port starts decreasing the gain until the ADC is no longer in an over drive condition.

The ADL5201 and ADL5202 provide outstanding linearity, with an output third-order intercept point (OIP3) of better than +50 dBm at the high end of the gain range at IFs up to 150 MHz. Another key feature of these devices is the low power mode, which reduces the supply current by 25 percent compared to the standard operating mode. Operating in the low power mode results in a moderate drop in linearity, but the mode can be switched on and off based on dynamic conditions in the receiver. For example, under normal receive conditions the low power mode could be used with the higher linearity mode turned on only when large in band blockers are present.

The ADL5240 and ADL5243 are high-performance RF DVGAs that operate over a broad frequency range of 100 MHz to 4 GHz. The ADL5240 integrates a DSA with a broadband, fixed-gain amplifier. The amplifier is internally matched and has a broadband gain of approximately 19.5 dB. The 6-bit DSA has 31.5 dB gain-control range, 0.5 dB step size and ±0.25 dB step accuracy over the entire frequency range. The DSA attenuation can be controlled by using either a parallel or serial interface mode. The DSA and amplifier in the ADL5240 can be wired for the attenuator to drive the amplifier, for transmit applications, or for the amplifier to drive the attenuator, for receive applications. The ADL5240's +38 dBm OIP3 and 3 dB noise figure make the device attractive for both receiver and transmitter signal paths.

The ADL5243 provides an even higher level of integration. Along with a broadband amplifier and a 31.5 dB DSA, the ADL5243 includes a second amplifier. This allows the device to be configured in an amplifier-DSA-amplifier component lineup. When the three components are connected in the aforementioned configuration, they provide a cascaded gain of 29 dB when the DSA is set to minimum attenuation. The ADL5243's final stage amplifier is designed to deliver highly linear output power with OIP3 of +41 dBm and is capable of driving directly into a base station power amplifier. Like the ADL5240, the DSA attenuation in the ADL5243 can be controlled either by a parallel or serial interface mode and support 0.5 dB step size with ±0.25 dB step accuracy.

The newly introduced RF and IF DVGAs from Analog Devices provide significant integration advantages with reduced system and cost complexity and will support and enable small footprint designs for next generation wireless systems.

Analog Devices Inc.,
Wilmington, MA
(978) 658-8930,
www.analog.com.

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RFMD®

RF3482
WiFi, Low Band Front End Module

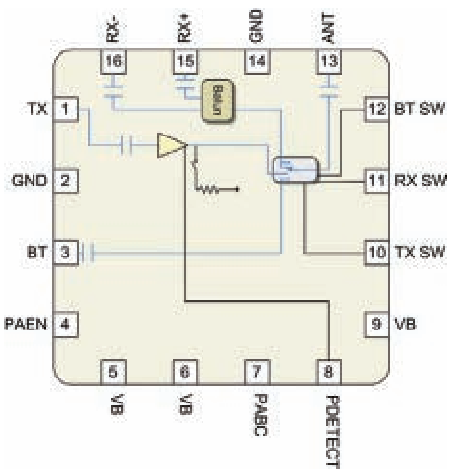
RFMD® now offers the RF3482, a single-chip, integrated front end module (FEM) developed for high-performance WiFi applications in the 2.4 to 2.5 GHz ISM band. This FEM addresses the need for aggressive size reduction for a typical 802.11b/g/n front end design and minimizes the number of components required beyond the core chipset. The RF3482 features an integrated b/g/n power amplifier, power detector, receive (Rx) balun, and some transmit (Tx) filtering. It is also capable of switching between WiFi Rx, WiFi Tx and *Bluetooth*® Rx/Tx operations. The device comes in a 3 x 3 x 0.45 mm, 16-pin package and meets or exceeds the RF front end needs of 802.11b/g/n WiFi RF systems.

SPECIFICATIONS

Part Number	Functionality	IEEE 802.11 Type	11g/n P_{OUT} (dBm)	11b P_{OUT} (dBm)	11b/g/n Gain (dB)	11g/n EVM (%)	V_{CC} (V)	11g/n Operating Current (mA)	11b Operating Current (mA)	Package (mm)
RF3482 *	PA, SP3T, Rx Balun, 2170 MHz and 2 Fo Filter	b/g/n	16.0	20.5	33.0	3.0	3.3	135	170	QFN 3.0 x 3.0

*** Power Detector Coupler**

RF3482 Block Diagram



FEATURES

- Single module radio front end
- Single voltage supply 2.7 to 5.5 V
- Integrated 2.5 GHz b/g/n amplifier, Rx balun, and Tx/Rx switch
- P_{OUT}=16 dBm, 11g, OFDM at 3.0% EVM and P_{OUT}=20.5 dBm, meeting 11b mask
- Applications include IEEE802.11b/g/n WiFi; single-chip RF front end module; 2.5 GHz ISM bands; WiFi systems; portable battery-powered equipment; optional *Bluetooth*® sharing of single antenna port

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