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3G/4G Multimode Cellular Front End Challenges

Part 1: Spectrum and Regulatory Issues

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Key Concepts Discussed:

- Carrier spectrum is shaping cellular front end requirements.
- 3G band combination forecast for handsets and data cards is presented.
- Multimode, multi-band complexity will require innovation in front ends to meet performance and cost targets.

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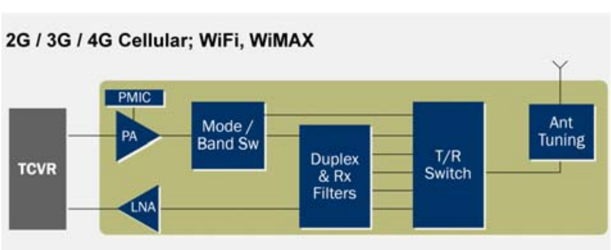
Introduction

As consumers, we are used to the continual productivity enhancements derived from ever increasing computer like handsets at our disposal. For those of us lucky enough to have in-depth industry knowledge, we know full well the complexity of a system that can deliver near desk-like performance in the palm of your hand. Still, it helps to step back now and again to consider how such an intricate system actually works in order to appreciate the arduous nature of developing these state-of-the-art mobile devices. Much like the awe we experience watching a jumbo jet take off—we may know how the basic interaction of forces occur, enabling the jet to break the sound barrier or cruise at an altitude of 30,000 feet, yet we're still fascinated with how well it all works and how seamless designers have made it appear.

Similar to the jet analogy, engineers may know how these complex handsets, and the highly integrated systems they contain, function, but that knowledge doesn't preclude us from feeling a sense of awe when watching someone use their handset to check email, download a video, or take a picture. There are also many parallels to the technical achievements and boundaries being pushed in the crop of current third-generation (3G) and future fourth-generation (4G) multimode phones under development. In this series, we'll examine some of the drivers that are pushing designers to seek new and groundbreaking solutions for a key system in these mobile devices—the RF front end.

"RF front end" has become the industry-standard term for the radio frequency components functionally located between the wireless transceiver and the antenna, required to both transmit and receive the radio signal. More specifically, the entire cellular front end system is comprised of power and low noise amplifiers; filtering, such as receive filters and duplexers; RF switches, including antenna, mode and bypass; the antenna, and the interface to the transceiver and baseband.

Figure 1. RF Front End



Market Forces Propelling Multimode Handset Development

Communication has evolved quickly in the last two to three decades. Consumers expect and demand ubiquitous "communication" throughout their mobile world. The industry has developed multiple solutions to satisfy this need for high-quality communications.

No longer is simple "on-the-go" voice communication, which is delivered mainly through 2G handsets, acceptable. Consumers expect frequent access to a variety of data-intensive information, such as corporate databases, email, multimedia messaging, real-time financial information, and social networking, regardless of where they may be or what time of the day it is. You can see this theme of "a world where everyone is connected to each other, to information and to entertainment, in all places, at all times" reflected in company advertising, taglines, and mission statements. This captures the true essence of the wireless industry's main challenge over the next few years—to deliver a compelling ecosystem capable of a ubiquitous voice and data connection anywhere in the world. And, rightly so, this is the promise of the new 3G and future 4G networks—to deliver a better consumer experience with more accessibility and usability of the data content, which is both being generated and delivered.

Carrier Expectations Impacting Front End Development

In order for original equipment manufacturers (OEMs) to satisfy these strong consumer requirements they must implement multimode systems which contribute toward a holistic handset solution. To gain a better sense of how comprehensively marketplace demands have affected 3G/4G multimode front end systems, one has to consider several key factors, including

- Carrier spectrum necessitating multi-band requirements
- Handset complexity driving development resource requirements and other costs
- Technical issues specific to front end development
- Impact of particular system architecture choices on the handset battery life

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How Carrier Spectrum Is Shaping Multi-band Requirements

Next-generation multimode phones are designed to support up to 16 different frequency bands and more than 20 different band combinations. As the number of bands and band combinations grow, frequency flexibility at the platform level has increased in importance as a critical parameter for 3G handset development. This is a far cry from the single global frequency originally envisioned for 3G.

Frequency Spectrum and Regulation Issues

The motivation and benefits of a single, harmonized, global communication spectrum was one of the primary goals of the International Telecommunication Union (ITU) as they headed into the UN-sponsored global telecommunication meetings in 1992. The World Administrative Radio Conference 1992 (WARC-92 band 1920-1980 MHz, 2110-2170 MHz UL/DL) was intended to offer a single band plan that could be used both in GSM-based 3G technologies (3GPP WCDMA) and CDMA-based 3G technologies (3GPP2 CDMA-2000). It was hoped that a single worldwide frequency would accelerate the adoption of new technology as well as reduce implementation and deployment costs. Services such as global roaming and the inherent economies of scale were to prevail. Competing technologies and a lack of clear and available spectrum worldwide, due to previous frequency allocation in some countries, caused some significant changes in spectrum policy. The resulting compromises allowed for as much commonality in frequencies as could be agreed upon, however as time goes on, a single worldwide frequency appears to be unlikely.

International Mobile Telecommunications-2000 (IMT-2000), as the global standard came to be known, added additional bands as designated in "Table 1: These frequencies were the result of IMT-2000 from Pre-WRC-07." on page 3. The main bands for IMT 2000 (3G) at devices operate in two major spectrum ranges (806-960 MHz and 1.7-2.2 GHz). Current WCDMA deployments can be found in 2100, 1900, 1800, 1700, 900, and 850 MHz bands throughout the world.

At the ITU World Radiocommunication Conference 2007 (WRC-07), the members addressed radio spectrum for upcoming 4G systems also known as IMT-Advanced. The new spectrum is spread across five additional bands in portions of the 400 to 700 MHz and 2.3, 2.5, and 3.5 GHz bands 4G systems and their backward compatibility to 3G will force multiple band and multiple front end products to meet the diverse requirements of regional carriers. The recommendations from WRC- 07 are included in "Table 2: These frequencies were added for 4G services from WRC-07." on page 3.

The harmonization in effect after the World Radio Telecommunication meeting in 2000 resulted in the new 3G spectrum in 700-900 MHz and 2600 MHz as well as modifications to the existing UMTS spectrum. This led to some regional specialization of band combinations, whereby phones would need to be customized to the frequency spectrum allocated for specific geographical regions, typically by covering one or two of these frequency bands.

Table 1: These frequencies were the result of IMT-2000 from Pre-WRC-07.

Frequency Band	Bandwidth (MHz)
806-960 MHz	154
1710-1885 MHz	175
1885-2025 MHz	140
2110-2200 MHz	90
2500-2690 MHz	190

Table 2: These frequencies were added for 4G services from WRC-07.

Frequency Band	Bandwidth (MHz)
450-470 MHZ	20
790-862 MHz ITU Reg. 1	72
698-806 MHz ITU Reg. 2	108
698-806 MHz ITU Reg. 3	108
2300-2400 MHz	100
3400-3600 MHz	200

The bands below 1 GHz are a cost-effective way to provide IMT services in sparsely populated regions in developed and undeveloped countries. The bands above 1 GHz are preferable for providing continuous blocks of spectrum for future broadband wireless systems such as IMT advanced. Among the bands being proposed, the newly identified 3.4 to 3.6 GHz band could prove to be the most attractive for implementing IMT bands in the future

Below is a list of frequencies allocated globally for both frequency duplexed (FDD paired spectrum) and time division duplexed (TDD) based systems. In the case of FDD systems, there is a clear goal to support frequencies in a region and also allow for global roaming. Close inspection reveals potential for multi-band variants based on geographical considerations.

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Table 3: 3GPP Rel 8 FDD Band Designations

			Spectrum Available					
			Roaming Attractive					
Band Designator	Uplink - UE Transmit (MHz)	Downlink - UE Receive (MHz)	NA	LA	EMEA	ASIA	Oceania	Japan
Band 1	1920 - 1980	2110 - 2170						
Band 2	1850 - 1910	1930 - 1990						
Band 3	1710 - 1785	1805 - 1880						
Band 4	1710 - 1755	2110 - 2155						
Band 5	824 - 849	869 - 894						
Band 6	830 - 840	875 - 885						
Band 7	2500 - 2570	2620 - 2690						
Band 8	880 - 915	925 - 960						
Band 9	1749.9 - 1784.9	1844.9 - 1879.9						
Band 10	1710 - 1770	2110 - 2170						

In the case of TDD 3GPP systems, it is still too early in the development phase to predict likely combinations. Bands 38 and 40 do seem to garner the most attention of the TDD deployments based on China policy.

Table 4: 3GPP Rel 8 TDD Band Designations

Band Designator	Uplink - UE Transmit (MHz)	Downlink - UE Receive (MHz)
Band 33	1900-1920	1900-1920
Band 34	2010-2025	2010-2025
Band 35	1850-1910	1850-1910
Band 36	1930-1990	1930-1990
Band 37	1910-1930	1910-1930
Band 38	2570-2620	2570-2620
Band 39	1880-1920	1880-1920
Band 40	2300-2400	2300-2400

Band 38 & 40 receiving most attention, roaming issues TBD

"Table 3: 3GPP Rel 8 FDD Band Designations" on page 4 and "Table 4: 3GPP Rel 8 TDD Band Designations" on page 4 depict the most recent update to the possible bands in use for the 3GPP Release 8 specification. Each of the bands is geared towards coverage in a specific geography.

If we think about the increasingly desirable characteristic of global roaming, it is evident that the complexity required from the front end to be able to deal with all these frequencies and bands is accelerating at a fast clip.

Mobile data networks must satisfy both local regulatory and physical transmission requirements. Industry observers have noted the recent popularity of government-sanctioned auctions of frequency spectrum, usually for stipulated usage. Recent examples are AWS and vacated TV bands in the United States and Europe. U.S. spectrum was auctioned off in 2007 for $19.6 billion. Similar auctions are set to start in Europe for the 790-862 MHz bands, albeit with a delay in implementation, within a year's time. Spectrum auctions have delivered billions of dollars back to government agencies and created strong motivation by global carriers to see a return on their investment.

It should be apparent that whatever solutions we bring to the market, the ability to be able to customize and adapt the front end for a particular combination of frequencies will be a worthwhile investment due to the complexities involved.

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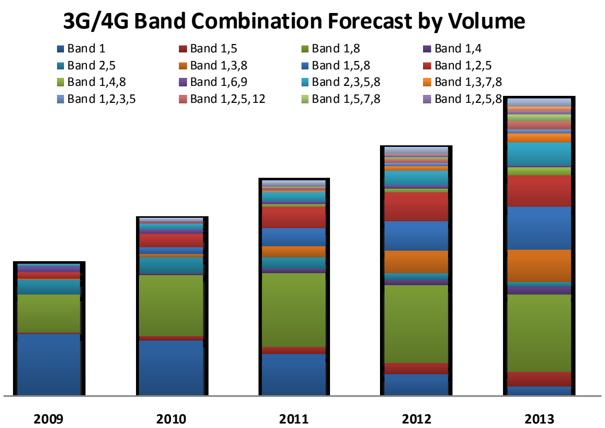
"3G/4G Band Combination Forecast by Volume" on page 5 is one view of possible band combinations required in mobile devices and embedded modems. Different analysis may come to different weightings for regional splits, but the daunting number of band combinations should not be lost.

Figure 2. 3G/4G Band Combination Forecast by Volume



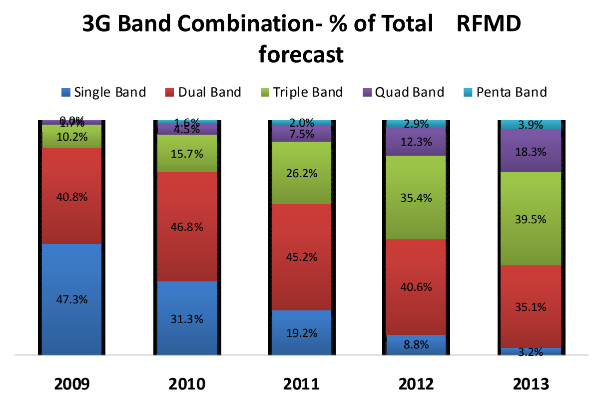
Drivers for Additional, Lower Frequency Bands—Spectrum Re-farming

One trend that is also affecting the radio front end is the growing desire by carriers to reuse (and re farm) currently available GSM frequencies, so that it can be allowed to propagate UMTS signals. One of the rationales behind this is the ability to optimize connectivity depending upon the population density and physical layout of the coverage area of interest. In highly congested, urban scenarios, higher frequencies could become more popular as they can be more spectrally efficient for high data rate applications. Alternatively, in less dense environments, operators may prefer to take advantage of the benefits of lower frequencies (700-900 MHz) that, in this case, enable a far greater coverage area for each base station as compared with its higher frequency compliment. In fact, this is the rationale for the interest in re-farming existing GSM-allocated frequencies (850 and 900 MHz). If operators are allowed to convert from GSM to WCDMA service in these lower frequency bands, there are estimates showing up to 60 percent cost reductions while increasing coverage by two-to-four times that for 2100 MHz.

Practical Implications of Spectrum Policy on Front End Developments

One can infer from the complex nature of this background on carrier spectrum all that there will be many different varieties of cellular front ends required for the complete cellular system to work in a handset, whereby information sent on different frequencies are required to be transmitted and received from a single radio source. In fact, RFMD® internal projections, based on deployment rates and industry conversations, indicate a likely scenario where the number of WCDMA bands in handsets will be as many as five by 2010, with the rate of expansion for band combinations depicted in "3G Band Combination as a Percentage of RFMD Forecast Total Handsets and Data Cards" on page 5.

Figure 3. 3G Band Combination as a Percentage of RFMD Forecast Total Handsets and Data Cards



The dichotomy of the 3G is that the diverse frequency allocations worldwide have been a significant departure from the original intent of the standard. Hopefully you can gain an appreciation for the technical challenge laid out when we look at requirements coming in to support carrier smartphone deployments across the globe. This leads to the first of many challenges for front end suppliers—developing filtering and switching solutions for each of the bands. To date, spectrum homogenization has not been realized in either 3G or 4G front ends. To add further perspective to this issue, "3G Band Combination as a Percentage of Total Industry Annual Shipments" on page 6 demonstrates the number of band combinations forecasted for the next five years. Since several of these bands will be used in combination for even the simplest 3G handset or data card, solutions must be developed in such a way as to allow suppliers to scale their offerings to accommodate the multiple bands.

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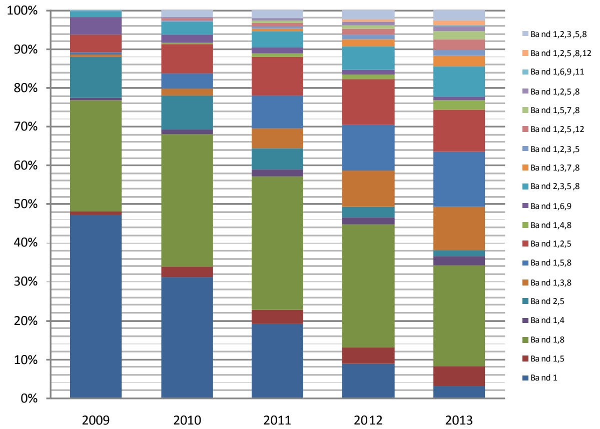
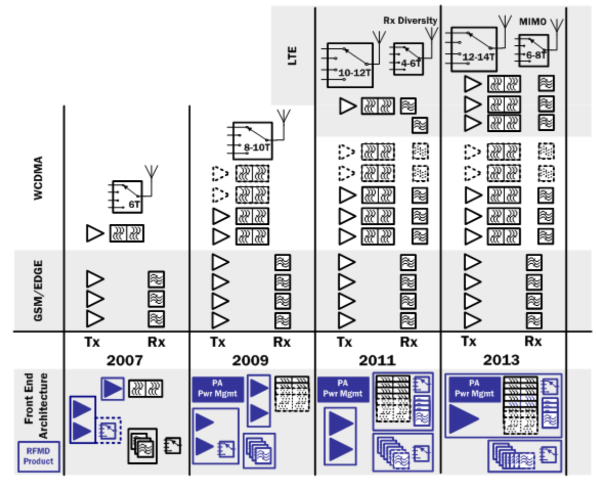
Figure 4. 3G Band Combination as a Percentage of Total Industry Annual Shipments



To further complicate next-generation handset development, the evolution of the 3G standard has resulted in a relatively complex analog RF front end for these multimode, multi-band handsets. Depicted in “3G Cellular Handset Evolution” on page 6, as networks evolve, so must the devices that consumers use to access them. Handsets, therefore, have quickly moved from their humble voice-only beginnings, with a relatively straightforward radio design, to a device enabling real time, high data-rate communications through the use of multiple, complex transmit and receive paths. Technological advances, such as the use of MIMO and receive diversity in mobile devices, will enable higher mobile productivity. Handsets will act much more like multi-radio media devices by offering a continual linkage not only to cellular networks, but all IP-based networks through the use of data portals such as Wi-Fi and WiMAX. As these cellular standards evolve even further with the addition of HSPA+ and LTE, consumers will continue to see additional data-rate improvements in 3G networks. This, the ultimate goal of 4G, will enable true mobile broadband access through a portable internet connection.

Figure 5. 3G Cellular Handset Evolution



With the addition of these extra bands, modes, and associated verification, the resource requirements for next-generation platforms is much more extensive than it was for 2G cellular handsets. Multimode phones are designed to work with EDGE and WCDMA air interface standards as well as Long Term Evolution (LTE) for high-speed data and media transport applications and, perhaps, WiMAX mobile applications as well. Additionally, mobile operators require customized handsets to meet various consumer roaming needs. Hence, the handset original equipment manufacturers (OEMs), who must configure 3G handsets with multiple frequency bands and operating modes (WCDMA r99, HSDPA, HSDPA+, EDGE), are left with the daunting issue of rapid customization in order to meet both market timing and mobile operator requirements. All the while handset OEMs are seeking to integrate these advanced features and multiple band configurations into a size-reduced, platform-capable form factor. Lest we not forget the continual cost-reduction pressures these consumer devices are under, which further aggravates the dilemma of increasing content in a cost-sensitive marketplace.

To be able to support the different standards, applications, band combinations, and mobile operator requirements, handset designs must now utilize very specific power amplifiers, filters, switches, duplexers, and other RF components to implement these highly specialized multimode front end systems. Given the number and specificity of RF components required to complete the multimode front end system, in combination with the growing list of handset features, it should come as no surprise that engineers are requiring longer amounts of time to complete front end system designs. Furthermore, with this highly specialized nature of the front end system, testing and calibrating during the various phases of the handset development process have also lengthened considerably. All of these additional resources—whether they take the form of additional specialized components, additional testing, or increased engineering time—raise costs.

In our next installment, "3G/4G Multimode Handset Challenges Part 2: Architecture Discussions," we will take an in-depth look at the technology impact multi-band multimode handset requirements has on battery life, size, and consumer preference. We will also discuss the different front end architecture options and the technical issues associated with each.

Contributors

While there were many contributions from colleagues at RFMD, we wish to particularly thank Jason Yorks, Scott Yoder, Ray Arkiszewski, Ben Thomas, Robert Pipkin, and Alston Skinner for their valuable contributions to this series.

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