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3G/4G Multimode Cellular Front End Challenges

Part 2: Architecture Discussion

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Key Concepts Discussed:

- Multiple architecture options available to fill different design needs for 3G/4G cellular front ends.
- Mode-specific architectures optimized for performance.
- Converged multi-mode architectures optimized for smallest size, lowest cost of implementation, and flexible band scalable platforms.

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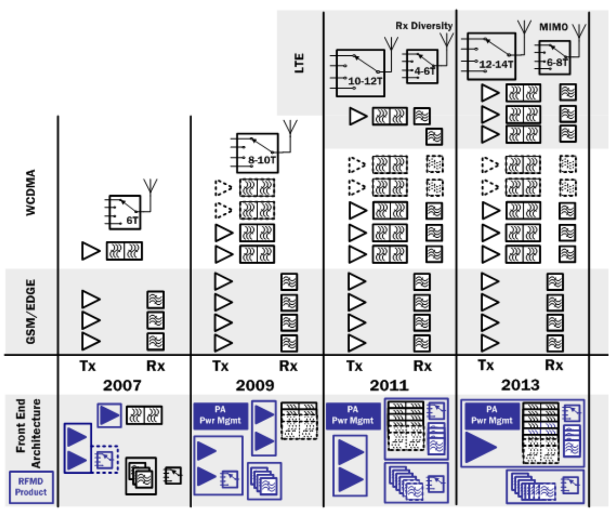
Introduction

In Part 1 of our series we looked at the challenges and factors of the front end for 3G multimode handsets that were mostly externally driven. Our focus was on regulatory issues concerning frequency spectrum and market drivers that impacted future front end requirements. In this second installment, we'll examine the multiple architectures available to accomplish multimode front ends, and we will summarize the trade-offs of each individual approach.

In this section our goal is to examine the different front end architecture options and discuss the pros and cons of each approach. To do so will draw upon the Part 1 white paper that looked at the number of band combinations and how that impacts the front end architecture.

Recall in Part 1 that we explored what a typical multi-band handset may look like. Our market analysis and feedback indicate that phones and data cards will be capable of handling between two and five UMTS bands as well as being backward-compatible to 2G systems. One view of what that might look like conceptually can be seen in the drawing below (Figure 1). These band combinations will change depending on the carrier, roaming agreements in place, and region of the world.

Figure 1. 3G/4G RF Front End Evolution



The front end architecture does generally mimic the transformation of the multimode chipsets. Just as we have witnessed the evolution of single-function radios to multifunction radios, that trend will reach fruition in the front end development cycle as well. We start out with a review of current discrete front end architectures, move toward multimode, multiband architectures, and lastly showing the future developmental models of a converged multimode, multi-standard front end. Our review will examine the benefits of deploying each type of architecture.

What Do We Mean by Mode-Specific and Converged Multimode?

3G multimode (3G MM) handsets are becoming the norm for carriers that are introducing new 3G services throughout their network coverage areas. One key requirement is that these carriers offer backward compatibility to their existing 2G networks. So not only must handsets be capable of transmitting and receiving 3G or UMTS signals, they must also be capable of transmitting and receiving 2G signals, whether that be a CDMA- or GSM-based service. This requirement is driving the need for multimode handsets to have the ability to operate in either 3G (WCDMA, HSPA+) or in 2G (GSM/EDGE or CDMA) operational modes.

3G MM is used to define a radio that transmits and receives multiple air standards. Mostly for our discussion, this will imply GSM/EDGE + UMTS capability in a single handset. In our discussions we will use the term mode-specific (MS) to imply power amplifier chains that are optimized for the single air standard; for example, GSM/EDGE or UMTS. Mode-specific means that there will be a separate amplifier path, or a separate power amplifier (PA), to complete the functionality of 3G MM handset.

Mode-Specific

Mode-specific implementation of a 3G multimode transmit section is shown in Figure 2. Note that there is an amplifier chain for the 3G (WCDMA) signal and a separate amplifier chain for the 2G portion (GSM/EDGE). The front end system must take care of all the signal conditioning and signal routing requirements for multiple radio interfaces. UMTS (FDD) systems are frequency duplexed and must be capable of transmitting and receiving simultaneously; therefore, they require the use of frequency duplexers in the front end. The diagram below contains a simple single-band case; in another section we will review the more practical case of multiple bands.

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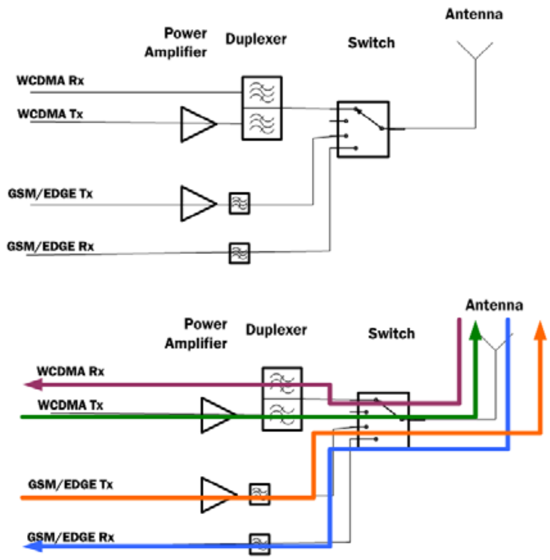
In this diagram we look at the MS case where our GSM and UMTS PAs are separate. The GSM PAs are routed through transmit filters into an antenna switch. The antenna switch selects the signal path for either transmit (Tx) or receive (Rx) signals. On the UMTS side, the signal path from the PA then goes to any frequency duplexer and through the antenna switch for the transmit path. On the receive path, the signal is routed through the receive (Rx) side of the duplex and then onto the radio transceiver input.

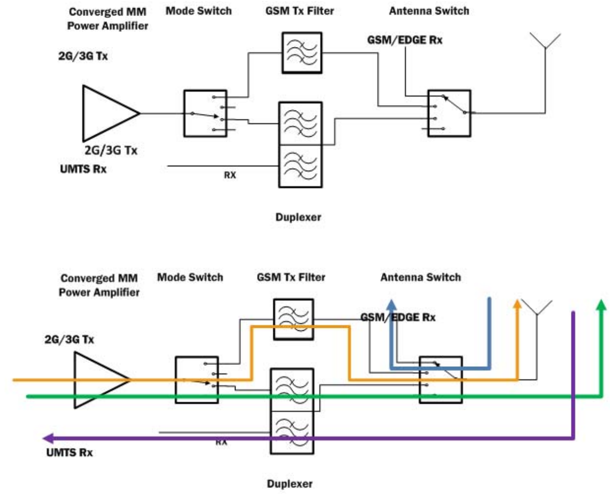
Figure 2. Mode-Specific Architecture of a 3G Multimode Transmitter



Converged Multimode

One architecture option available for future handsets will be the converged multimode (MM) PA. The converged PA will be capable of handling all air standards whether they require linear or saturated. The converged multimode concept is pictured in Figure 3. The key difference is that the amplifier is designed to handle both 2G and 3G modulation, and thereby reduces the number of amplifiers needed in a 3G MM system. In the diagram below, note that both the 2G (GSM/EDGE) and 3G (UMTS,HSPA+) are transmitted through the same path.

Figure 3. Converged Implementation of 3G Multimode Transmitter



The table below is an overview of the 3G MM architectures that will be discussed in this paper. Keeping with our mode-specific and converged nomenclature, a brief outline is as follows:

Mode-Specific	discrete implementation	Separate components for each functional block
	power amplifier duplexer (PAD) option for WCDMA	Partition where a PA + duplexer is designed in a single package- complete Tx functionality for a single band for UMTS
	hybrid mode-specific implementation for multimode	Similar to discrete implementation, but mode-specific PAs are packaged together in single module
Converged Multimode	single chain multi-standard	Single path amplifier capable of transmitting all modulations

Trade-offs in 3G Multimode Front Ends

A defining feature of a successful solution is how well it meets the program's goals or targets. Depending on the end application, one typically sees these boundary conditions or constraints specified in one of two ways. On one end of the spectrum is the requirement for optimal performance. In 3G MM phones, that usually translates into a requirement for the lowest overall current consumption of the front end, thereby extending talk time and battery life. At the other end of the performance spectrum the focus is on obtaining the smallest size and at the lowest cost of implementation. In real life this of course is a continual spectrum and each individual front

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end architecture option balances its own set of pros and cons between these two conflicting goals.

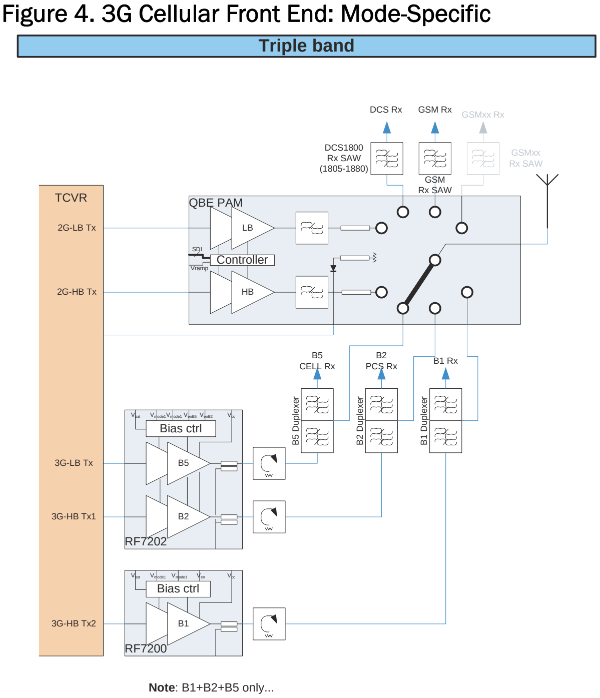
Analogous to one's use of a specific screwdriver or a Swiss Army knife, the trick is in matching the right tool for the right front end requirement. As this paper will seek to demonstrate, the reason there are multiple options in 3G MM front end solutions is that there is no single architecture tool that meets all requirements.

Discussion of 3G Multimode Front End Solution

The front end system must take care of all the signal conditioning and signal routing requirements for multiple radio interfaces. UMTS (FDD) systems must be capable of transmitting and receiving simultaneously, therefore requiring the use of frequency duplexers in the front end. Figure 4 illustrates a simple single-band case.

This diagram demonstrates the mode-specific case where the GSM and UMTS PAs are separate. The GSM PAs are routed through transmit filters into an antenna switch. The antenna switch selects the signal path for either transmit or receive signals. On the UMTS side, the signal path from the PA then goes to any frequency duplexer and through the antenna switch.

Figure 4. 3G Cellular Front End: Mode-Specific



Mode-Specific Architecture—Discrete

A majority of the 3G handsets and data cards built today use some versions of mode-specific transmit solution. In a typical configuration there is a separate GSM/EDGE PA and a separate WCDMA PA. While there are multiple ways to partition the front end functions, at the core there is a PA optimized for each air standard as well as the necessary switching and filtering to combine these imports at the antenna. In the discrete approach it is the engineer's task to carefully match and ensure proper RF performance over wide variations in temperature, battery voltage, and operating frequency.

The advantage of a mode-specific approach is that the solution is flexible enough to suit the specific requirement of each phone model. Additionally, performance metrics, such as current consumption, linearity requirements, and output powers, can be tailored at the individual phone model level. That way there is little-to-no-overhead in the solution; you pay exactly for what you need.

Some disadvantages to the mode-specific approach are the engineering resources required to customize each individual end application. This generates growing development costs that are not only due to engineering design but also to custom printed circuit board (PCB) design and development for what may only be small component changes. Additional costs to debug this solution cannot be ignored.

Some of the ways to alleviate the custom development costs associated with mode-specific designs is a growing trend toward platform solutions. These platform solutions are intended to provide the flexibility required to tailor performance at the platform level, yet standardize the layout and footprint so that design reuse is maximized. The mode-specific, multi-band platforms are designed in such a way as to reduce complex matching requirements (quadrature vs. single-ended) and are therefore suitable in designs where the band requirements may change. This is especially true as the industry moves quickly into multi-band (≥2 bands) phones. One can witness the proliferation of pin-for-pin compatible dual-band PAs as evidence of this trend.

Figure 5. Mode-Specific Implementation of RF Front End

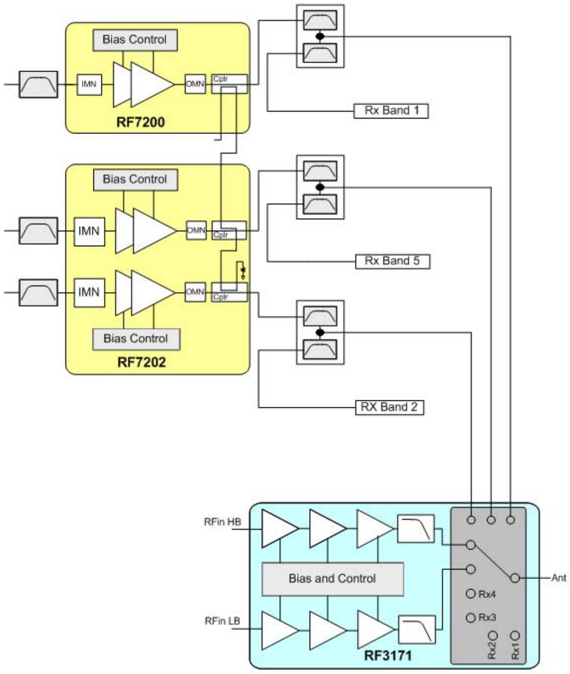


Figure 6. Mode-Specific WCDMA PA with Frequency-Flexible Front End

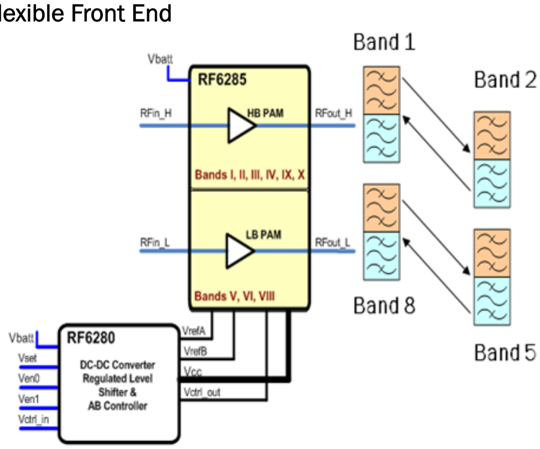


Figure 6 illustrates an approach where the transmit solution can be regionally customized by swapping out band specific duplexers, while minimizing the RF layout changes by keeping the PA the same. This is an example of platforming in the mode-specific realm.

Power Amplifier Duplexer or PAD Mode-Specific Architecture

This mode-specific architecture variant for the WCDMA transmit path describes a trend to include the WCDMA PA plus a single-band duplexer in a single package and is commonly referred to as a PAD. The PAD approach is particularly well-suited for single band UMTS applications. When the platform target has significant market volume in a single fixed frequency band, the integration of a duplexer with the PA solves many of the RF issues. The complex match between the PA and the duplexer is taken care of in the design of the PAD module. This results in simplifying the front end design. The PAD approach is beneficial from a sourcing standpoint as well since a single source supplies both the PA and duplexer for the WCDMA portion of the design. The PAD approach is also attractive for new emerging frequency bands, such as the case in LTE bolt-on applications.

While the PAD is useful for bolt-on and single-band, their utility diminishes when faced with a multi-band platform requirement. As discussed in Part 1, there are requirements to cover a broad range of frequencies, denoted as Bands 1-10. With the PAD approach each individual band requires a whole new PA plus duplexer development. Along with additional development costs, some band combinations will not reach the scale required to pay for the engineering investment. From a performance aspect, a single source manufacturer may not have access to the optimum technology required for each band. For example, some bands may require SAW technology where other bands would benefit from BAW duplexers or a mix of SAW and BAW to meet the filtering needs of that particular band. This leads to trade-offs in performance being made for convenience in sourcing decisions.

In the PAD approach, the phone hardware design team does not have access or the ability to tune performance. The PAD is essentially fixed, and any requirement to adjust performance has to be routed through the manufacturer for new device.

In the cases where there are more than two bands of UMTS, the PAD approach becomes too unwieldy to be practical. The solution grows at a greater rate than the alternatives based not only on packaging overhead but also on signal routing concerns. From RFMD's standpoint, we see the PAD approach as particularly suited for single-band and emerging LTE applications that are bolted on to a pre-existing multimode solution. PADs in general are not

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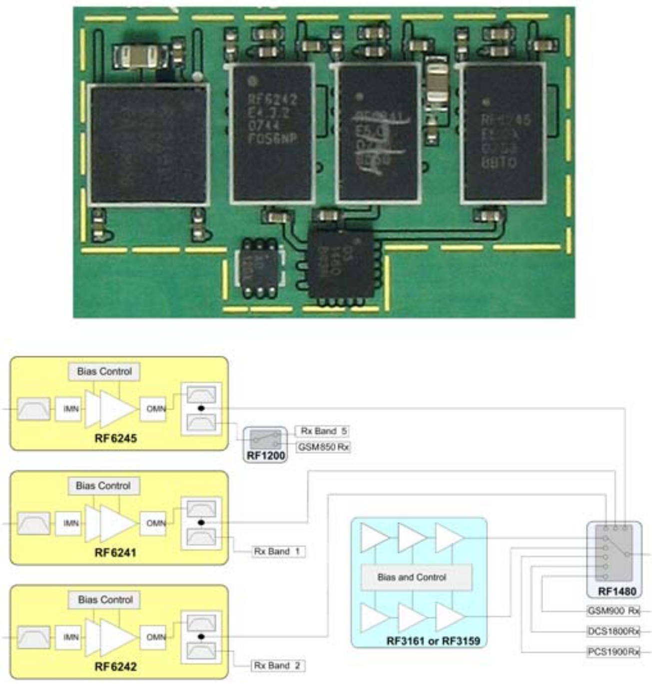
suitable for the general trend toward converged multimode solutions.

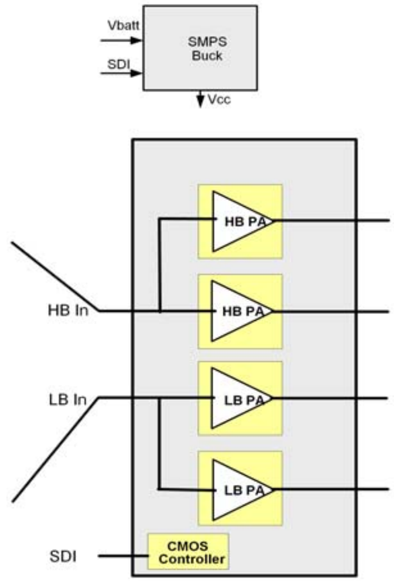
Figure 7. Mode-Specific Front End Implemented with PAD Architecture



Mode-Specific Hybrid PA Architecture

This hybrid approach represents an evolution in design and packaging that combines mode-specific 2G and 3G PAs in a single package. Hybrid mode-specific architecture overcomes the size penalty of the discrete approach yet enables any current optimized solution. A key advantage to this architecture is that the base module establishes a flexible platform on which to build multiple band combinations of the front end. As seen in the diagram below (Figure 8), the module consists of a high- and low-band PA chain that is split into mode-specific PAs. The switching, filtering, and duplexing takes place outside the PA module.

Figure 8. Mode-SpecificHybrid PA Front End



While not a true converged solution the hybrid architecture satisfies many of the goals required in complex 3G front ends. With the addition of a DC-DC buck converter this solution forms the basis of a multi-band, multimode platform that can be optimized for talk time in 2G and 3G modulations without compromising size relative to a discrete mode-specific PA or PAD approach. The ability to platform over multiple frequency combinations is a key driver for these more sophisticated techniques. Reference design and phone manufacturers find that the ability to adapt the specific frequency requirements outside the core module is an advantage in reducing overall development costs and time. To make a regional customized solution, a robust core with dedicated specific switch duplexer modules is all that is required to adapt phones to different geographies. Given the accelerated adoption of multi-band and roaming requirements, we believe the concept of “platforming” will increase over time.

A complete 3G front end solution using the hybrid mode-specific PA and a DC-DC buck converter will still require mode switches, duplexers, and an antenna switch. Several of the multi-band front ends can be consolidated into a relatively few number of switch duplexer modules (Bands 1, 2, 4, 5; Bands 1, 2, 5, 8). In this case, each manufacturer will have to weigh the benefits of platforming and its subsequent scale and time-to-market advantages against the overhead penalty costs sometimes required for flexibility.

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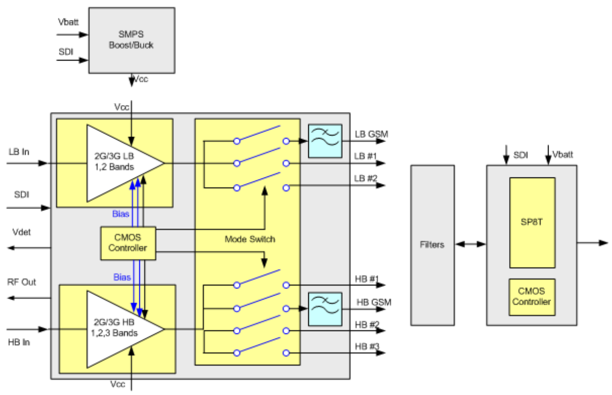
Converged Multimode PA Architectures

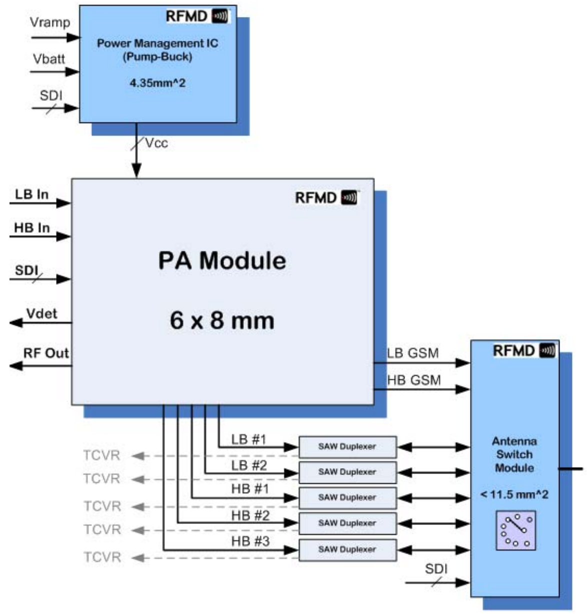
When one considers the challenges of the designing and manufacturing multi-band 3G front ends it is easy to get an appreciation for a movement toward converged front end architectures.

Figure 9. Converged Multimode PA



The complexity of 3G front ends is creating a resource burden all along the supply chain. From handset manufacturers to solution providers to component manufacturers, the complexity of these multi-band personal computing devices is causing designers to rethink how to adequately address the problem. With an elongated development time for more complex software solutions the pressure to move to a scalable platform on the front end increases daily. Efficiency in development dictates that a solution is scalable in frequency in the number of bands addressed while simultaneously reducing the overall footprint and associated costs. The natural evolutions of the mode-specific architecture to its most efficient form ends with the development of a converged transmit solution. By reducing redundant packaging and die, a converged solution can always be optimized for smaller size. Second-generation converged devices will be deployed in handsets that will be capable of transmitting up to five separate UMTS frequencies all while being backward compatible with the 2G networks. The time-to-market advantage of using a single scalable platform device at the RF core is significant not only from a sourcing standpoint but also by the reduced development time it takes to perform regional customized variants of a phone platform. The adaptability of a converged device is enhanced further by mating it with a buck boost DC-DC converter. This approach guarantees the transmit solution can adapt and be optimized for any 3G MM modulation and RF performance requirement.

Figure 10. Converged Multimode PA Platform



However, as discussed earlier, there is a downside to this flexibility. In the case of a converged device, the downside is a small penalty in increased current for the GSM side, which can be seen in the diagram of the 3G converged PA (Figure 9). Careful inspection shows the addition of a mode switch now in line with the 2G transmit path that does not exist in a mode-specific hybrid variant. It is this additional switch loss that accounts for the degradation in current. While teams are working to reduce the overall penalty, higher GSM current is the price one pays currently to gain the optimal size and cost advantage solution for 3G multi-band, multimode front ends.

Tying It All Together

So far we have reviewed the different architecture options available for cellular front ends. In the following tables and charts we will present the comparisons as a review of the pros and cons of each type.

In Table 1, we provide a relative comparison of the converged and hybrid mode-specific solutions. Depending upon the number of 3G bands that are required, there are different optimizations that can be obtained. In our observations, there is a strong desire to provide solutions that are scalable in terms of the number of bands supported. From the following chart, you can observe that both the hybrid mode-specific and converged multimode architectures bring significant advantages when looking at cost-per-band metric.

Below is a comparison table of the key metrics for 3G MM transmit solutions. Included are relative size, relative cost, key performance indicators DG09 current, suitability for multiple modulation, etc. In this table we compare the discrete approach to the hybrid and converged approach for a quad-band 2G and dual-band 3G MM system.

Case 1: Dual-Band UMTS/ Quad-Band EDGE	Mode-Specific Discrete 3G Single Band PA	Mode-Specific Hybrid 3G Multiband PA	Converged Multimode 2G/3G Multiband
Relative Cost	Lowest	+15%	+10%
Relative Size	Lowest	+30%	+15%
DG09	Highest	-12%	-10%
Max 2G I_{CC}	Mid	-10%	+5%
ECTEL 2G I_{CC}	Highest	-40%	-25%
Output Mismatch Immunity	None	3G (HB and LB)	2G and 3G (HB and LB)
PMIC	None	Yes	Yes
Modulation Optimization	GSM/WCDMA	GSM/WCDMA HSPA+/LTE	GSM/WCDMA HSPA+/LTE
Band Scalable	No	Yes	Yes

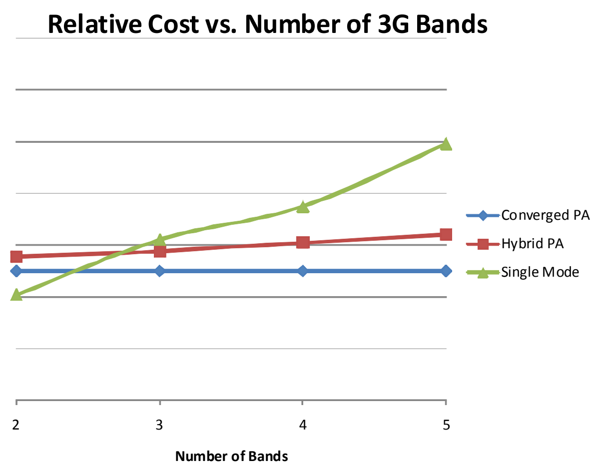
In this instance, we highlight the changes between the architectures when you add an additional 3G band requirement to cover a three-band UMTS requirement. Note that in the discrete case, more engineering effort is required to scale the solutions, and considerably less so when using hybrid or converged architectures.

Case 2: Tri-Band UMTS/ Quad-Band EDGE	Mode-Specific Discrete 3G Single Band PA	Mode-Specific Hybrid 3G Multiband PA	Converged Multimode 2G/3G Multiband
Relative Cost	Highest	-5%	-10%
Relative Size	+5%	+15%	Lowest
DG09	Highest	-7%	-6%
Max 2G I_{CC}	Mid	-10%	+5%
ECTEL 2G I_{CC}	Highest	-40%	-25%
Output Mismatch Immunity	None	3G (HB and LB)	2G and 3G (HB and LB)
PMIC	None	Yes	Yes
Modulation Optimization	GSM/WCDMA	GSM/WCDMA HSPA+/LTE	GSM/WCDMA HSPA+/LTE
Band Scalable	No	Yes	Yes

Multiple different design reviews for numerous channel partners and customers has led us to this basic conclusion. At the current time, if optimal performance is the key project goal, than a mode-specific solution would be best. If, on the other hand, size, cost, and band scalability are more important, then a converged approach is the one to choose.

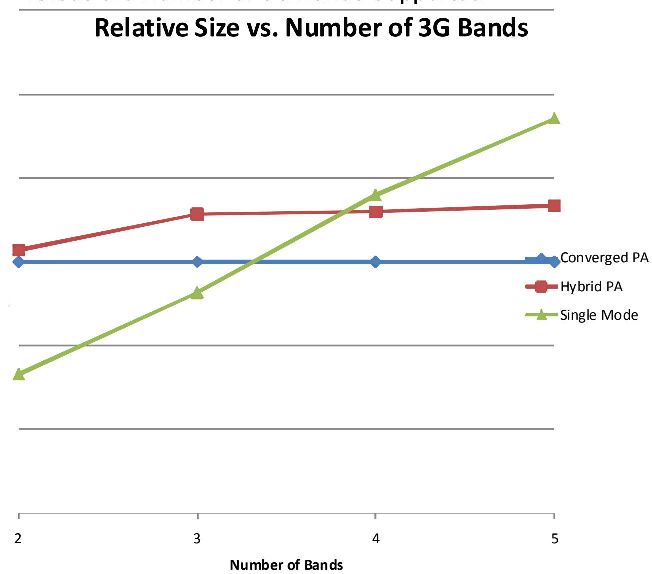
In the chart below, we provide a relative comparison of the converged and hybrid mode-specifc solutions. Depending upon the number of 3G bands that are required, there are different optimizations that can be obtained. In our observations, there is a strong desire to provide solutions that are scalable in terms of the number of bands supported. The chart shows that both the hybrid single mode and converged multimode architectures bring significant advantages when considering cost-per-band metrics.

Figure 11. Relative Cost Comparison of Differing Architectures Based on Number of 3G Bands Supported



A similar analysis can be made in terms of the actual front end solution size. Designers are constantly challenged with reducing the radio function size, and that is even more difficult when you start to add bands. From that aspect, the converged solutions and hybrid really separate from discrete mode-specific (and PAD) approaches.

Figure 12. Relative Size of Different PA Architectures versus the Number of 3G Bands Supported



Summary

In Parts 1 and 2 of our three-part white paper, we examined the challenges and factors of the front end for 3G MM handsets, with a focus on regulatory issues concerning frequency spectrum and market drivers impacting future front end requirements. In Part 2, we considered the multiple architectures available to accomplish multimode front ends and summarized the trade-offs of each individual approach. Part 3 of the series deals with the technical requirements of 3rd Generation Partnership Project (3GPP) on the PA and transmit sections collectively known as the 3G front end. Our discussion will involve design requirements for the PA, front end filtering and signal duplexing functions, and the complex switching requirement needed for a multi-band, multimode 3G handset.

Contributors

Please feel free to contact the authors with any questions at www.RFMD.com

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