WHITE PAPER

RF Architecture Choices for Next-Generation Handset Designs

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Executive Summary

The smartphone market has diversified into multiple categories with differing design goals and priorities, which require different approaches to RF front end (RFFE) integration. Flagship phones are premium devices designed for super-regional or global use. They require a highly integrated RFFE architecture such as Qorvo's RF Fusion™, which integrates all major transmit and receive functionality, including support for all major frequency bands and global carrier aggregation deployments. This approach maximizes performance and space savings, and helps manufacturers achieve global coverage with only a few variations (SKUs) on a single design. Mid-tier regional handsets, in contrast, have very different RFFE requirements. Manufacturers seek to minimize handset cost by including only the RF components needed for specific regional bands, yet they need to rapidly adapt handset designs for different regions and customers. This requires an RFFE architecture that enables design flexibility, such as Qorvo's RF Flex™. RF Flex integrates core RF components, such as power amplifiers and switches that are common to multiple regional variants of a handset; manufacturers can then quickly produce models for specific regions and operators simply by adding the appropriate filters.

Introduction

The Challenges of Carrier Aggregation

Today, advanced packaging techniques make it possible to combine multiple RFFE components into integrated modules that help smartphone manufacturers accelerate the design and manufacture of new handsets. However, not all smartphones have the same RFFE integration requirements; the smartphone market has diversified into several categories with differing design goals and priorities. This raises the question: what is the right level of RFFE integration and the best integration approach for each category of smartphone?

Today, two of the key smartphone categories are flagship phones designed for super-regional or global use, and mid-tier and entry-level handsets for regional use. These two categories have distinctly different design priorities, price points and development timelines.

Flagship phones are premium, high-performance designs that are typically launched and marketed worldwide, retailing at a price of $500 or more. Though relatively few flagship phones exist, they account for a large proportion of worldwide handset revenue, and their number is growing.

Flagship phones are designed to enable global use with only a few variations (SKUs) on a single design. Each SKU includes substantial RF content to support multiple networks and international use, typically supporting 6 modes and 15+ LTE bands. To provide the fastest data rates, today's flagship phones also include Category 6+ modems, and support downlink and uplink carrier aggregation (CA).

For manufacturers of flagship phones, limiting the number of SKUs offers the key benefit of reducing complexity in manufacturing and inventory management. Flagship phones have relatively long product cycles: the RF design requirements for flagship phones are typically fixed 12-18 months before product release.

Mid-tier and entry-level regional handsets, in contrast, are designed for regional use with some roaming capabilities. Many models exist, from many manufacturers, and handsets retail for less than $500. This highly competitive market segment accounts for the largest proportion of global volume and is growing faster than other segments as price-sensitive consumers transition from 2G and 3G phones to 4G LTE handsets, especially in markets such as China.

Because mid-tier phones are designed for regional use, manufacturers seek to minimize handset cost by including only the RF components needed for specific regional bands. A typical mid-tier phone supports 5 modes and 5-8 LTE bands, and incorporates a Category 4+ modem; some models offer limited CA support, primarily for downlink CA.

Volatile market requirements, especially in China, lead to very short development timelines and the need for great design flexibility. For example, some phones are specifically designed to meet the needs of a single mobile network operator. The operator may select a contract manufacturer only 2-6 months before the handset's target release date. Because phone manufacturers don't know in advance who their customers will be, they must be able to quickly adapt their handset designs to different networks and regions.

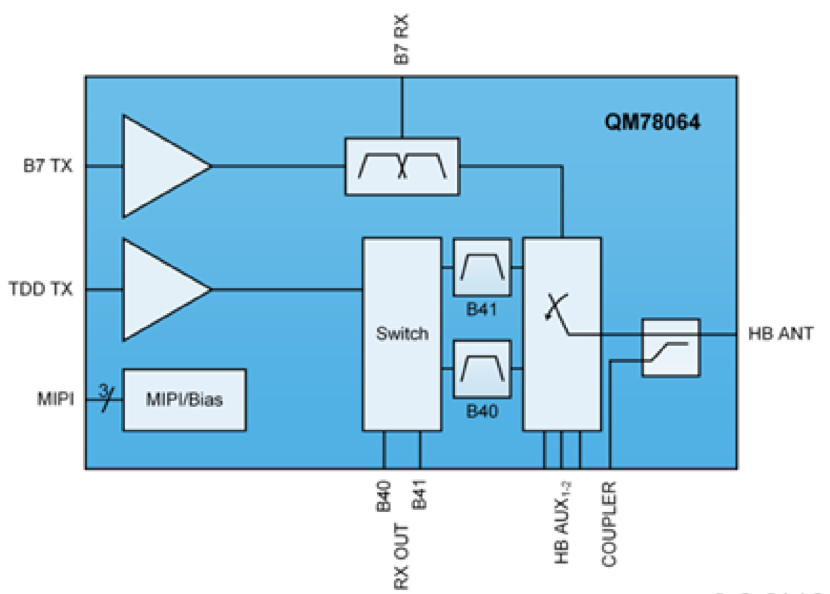
While some manufacturers focus on domestic sales, others are striving to expand into overseas markets. Manufacturers that are seeking to increase exports are starting to include a greater number of LTE bands into their mid-tier handsets to reduce the engineering work required to develop models for new markets.

In this white paper, we discuss the differing RFFE integration requirements of these two major smartphone categories – flagship and mid-tier phones – and provide examples of RFFE architectures designed for each.

RFFE integration for flagship phones

Flagship phones require and justify a very high level of RFFE integration. Manufacturers seek to attract consumers to these premium devices by squeezing the highest levels of functionality and performance into attractive, ultra-slim handsets. The RFFE must integrate a large number of bands to support super-regional or global use, as well as multiple uplink and downlink CA combinations for performance. Another factor driving RFFE integration is the limited space available for the RFFE within the handset, as manufacturers seek to maximize the space allocated to batteries and to include multiple antennas to improve performance.

Figure 1. Qorvo RF Fusion QM78064 high-band module.



Because the RF requirements of flagship phones are usually determined at least a year in advance, RFFE designers can focus on integrating the maximum functionality into front-end modules with limited concerns that the requirements will change during the module's design cycle.

An example of an RFFE architecture designed for flagship phones is Qorvo's RF Fusion, which incorporates all major transmit and receive functionality, including support for major frequency bands, into three compact modules covering the high-band, mid-band, and low-band regions of the spectrum. The architecture is also designed to integrate support for the rapid deployment of CA in markets worldwide. Each module integrates power amplifiers (PAs), switches, and filters. By using advanced wafer-level packaging, RF Fusion achieves about a 30-35% space savings over discrete components.

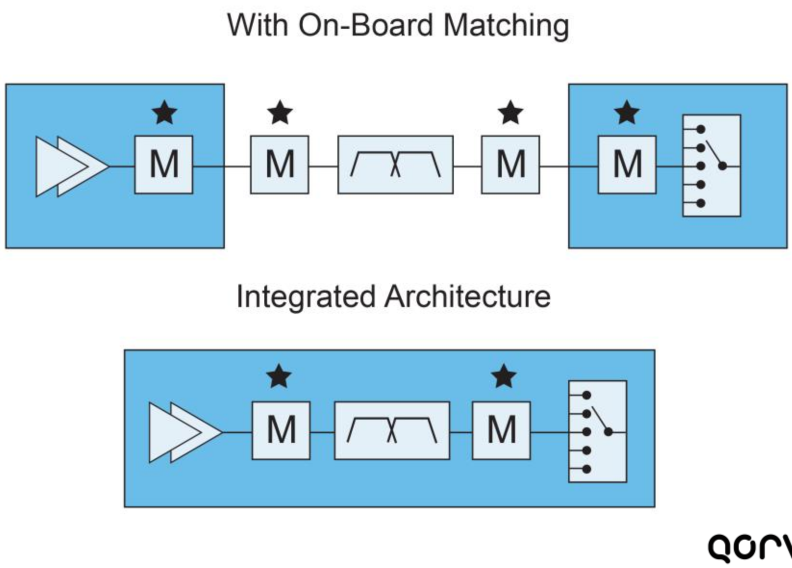
Figure 1 shows the RF Fusion QM78064 high-band module, which supports both FDD-LTE (with an integrated Band 7 duplexer) and TDD-LTE (Bands 40 and 41), and includes a wideband B41 LowDrift™ BAW filter enabling 20 MHz + 20 MHz uplink CA. The module also includes an antenna switch and supports both envelope tracking (ET) and average power tracking (APT) to minimize energy consumption.

This approach to RFFE integration – grouping functions into high-band, mid-band and low-band modules – offers several key advantages.

As shown in Figure 2, integration of components along each pathway increases performance by eliminating the need for on-board matching of components. This reduces matching losses for both transmit and receive by as much as 0.5 dB, which translates into lower current consumption and lower thermal load. This arrangement also ensures the most efficient use of each PA by integrating the filters for the bands within the PA's bandwidth. The improved performance of each module makes it easier to meet the manufacturer's overall performance targets for the handset.

The RF Fusion architecture also provides significant benefits for CA. This is particularly important in flagship phones, where manufacturers are rapidly adding CA support. Some aggregations that combine widely spaced bands (e.g. low-band and high-band) carry a risk of harmonic interference; a harmonic of the low band falls into the receive frequencies of the high band, potentially de-sensing the receiver. Separating these bands into different modules increases the physical isolation between them, thus reducing the possibility of harmonic interference. The architecture also helps support aggregations of closely-spaced bands and intra-band CA, because multiplexers that support specific aggregations can be incorporated into each module (the

Figure 2. By eliminating redundant on-board matching, the RF Fusion architecture reduces losses, resulting in improved performance.
Traditional architecture requires redundant matching. PAMiD architecture allows for "direct" match to filter and reduces matching loss for both Tx and Rx by as much as ~0.5dB.



RF Fusion QM78013 mid-band module includes a quadplexer enabling B1+B3 CA, for example).

The high degree of integration in RF Fusion helps manufacturers simplify and accelerate handset design and development. Manufacturers incorporate three modules from a single source instead of having to select, match and incorporate 30 or more discrete components. This increases manufacturing yield and reduces the risk of component failure. The simplified design and improved performance reduces the risk of missing the target dates for product release and carrier non-compliance.

RFFE design flexibility for regional mid-tier phones

Regional mid-tier handsets have distinctly different RFFE requirements compared to global premium handsets. Because handset price is critical in this intensely competitive market segment, manufacturers generally aim to include only the RF components that are needed for each target region or operator. Design flexibility is imperative, because manufacturers must be able to rapidly adapt handsets for different regions; they often have only a few months to develop a handset and achieve carrier compliance, and the requirements may change even during that period.

To rapidly develop handset models at minimum cost, manufacturers need to minimize the engineering effort involved with RFFE architectures so they can quickly adapt handset designs by adding the specific bands required for each region or operator. Typically, manufacturers want to use a single printed circuit board (PCB) layout that can be used to produce multiple SKUs by adding different RF components.

The requirements of these mid-tier handsets call for an RFFE integration approach that differs from the approach used for flagship handsets. Qorvo's RF Flex is an example of this approach, which offers a broad portfolio of modules designed to provide manufacturers of mid-tier smartphones with the flexibility to quickly produce different models.

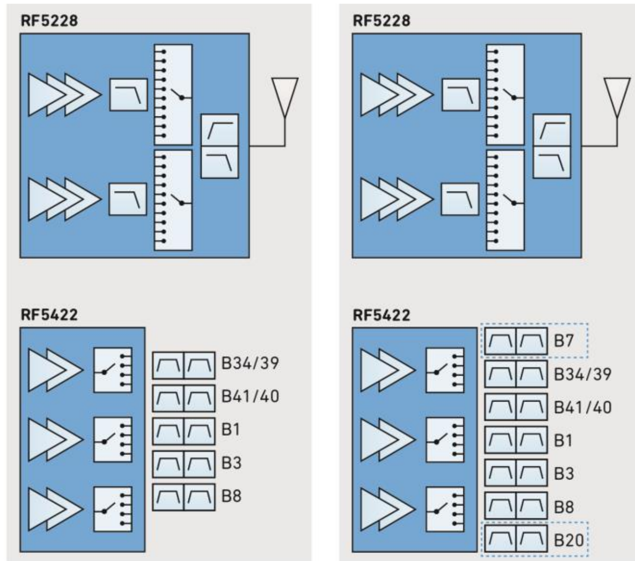
Each RF Flex module integrates core RF components that are common to multiple regional variants of a handset. Today, these components are typically PAs and switches. Manufacturers can then quickly produce regional handset variants by adding the filters required for specific operator networks and regions.

RF Flex provides design flexibility for manufacturers, and enables them to minimize handset cost by including only the required RF components. At the same time, this approach applies integration where it makes sense, to achieve benefits such as space savings and simplified design.

The RF Flex architecture is also scalable, which is particularly valuable to manufacturers who are seeking to expand internationally; they can design a model for domestic use and quickly add more filters to support the bands used in other countries.

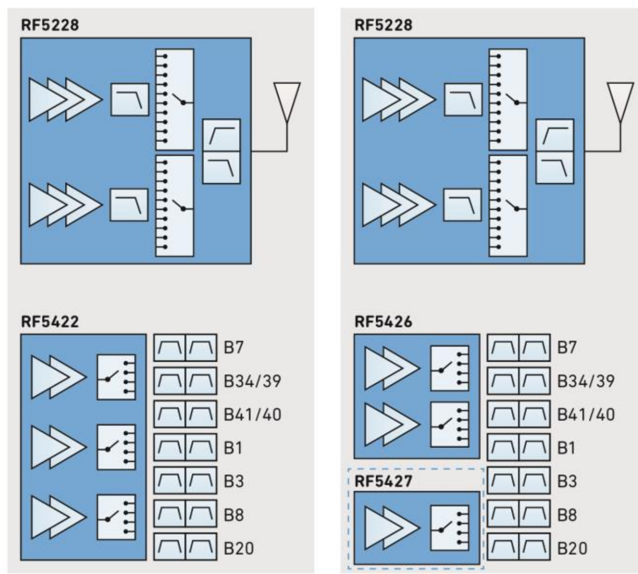
Figure 3. Scenario illustrating how the RF Flex architecture enables design flexibility.

Scenario 1 *A manufacturer designs a mid-tier handset using the RF5422 multi-band PA module and RF5228 advanced transmit module. The RF5422 provides all necessary 3G and 4G PA functionality; the RF5228 provides 2G support and antenna switching for all bands. For the China market, the manufacturer adds filters to support Bands 1, 3, 8, 34, 39, 40 and 41. The same design can then be scaled for European use by simply adding filters for Bands 7 and 20. The manufacturer uses the same PCB design for both regions, populating the PCB with filters as needed.*



Design for China market | *Scaled up for use in Europe*

Scenario 2 *The RF5422 supports up to five low-frequency bands, enough to meet the needs of many mid-tier handsets. When manufacturers need to support additional low-frequency bands, they can instead use the RF5427, a low- and very-low band module that supports up to 7 bands. The RF5427 is combined with the RF5426 mid- and high-band module to provide complete band coverage. Used together, the two modules also offer the advantage of providing additional isolation to facilitate CA combinations of high and low bands.*



Baseline Mid-Tier Handset design | *Scaled up to support LB and VLB*

Conclusion

Different approaches to RFFE integration are required to meet the distinct requirements of flagship and mid-tier phones. Highly integrated modules, like Qorvo’s RF Fusion products, maximize performance and space savings in flagship phones designed for global markets. Targeted integration of core RF functions, as in Qorvo’s RF Flex modules, allows design flexibility in mid-tier phones so that manufacturers can quickly adapt handsets for different operators and regions.

Over time, the RF content in mid-tier and flagship phones will increase as more bands and CA combinations are deployed. RF modules for both mid-tier and flagship phones will become correspondingly more integrated, while retaining the distinct characteristics required by each category.

About Qorvo

Qorvo (NASDAQ:QRVO) makes a better world possible by providing innovative RF solutions at the center of connectivity. We combine product and technology leadership, systems-level expertise and global manufacturing scale to quickly solve our customers' most complex technical challenges. Qorvo serves diverse high-growth segments of large global markets, including advanced wireless devices, wired and wireless networks and defense radar and communications. We also leverage our unique competitive strengths to advance 5G networks, cloud computing, the Internet of Things, and other emerging applications that expand the global framework interconnecting people, places and things. Visit **www.qorvo.com** to learn how we connect the world.