WHITE PAPER

Addressing Carrier Aggregation Challenges Using Multiplexer Solutions

Executive Summary

Mobile network operators worldwide are deploying carrier aggregation (CA), which enables them to provide faster data services by bonding two or more blocks of spectrum into a wider channel. With CA, mobile devices communicate on multiple LTE bands simultaneously, but this creates a challenge: how to avoid interference between the bands (cross-isolation) while minimizing insertion loss to maintain good reception and battery life. Multiplexers provide an elegant solution – and in many cases, the only practical solution – for CA combinations that use closely spaced bands. Multiplexers integrate all the filters required for multiple aggregated bands, providing isolation between and within bands while allowing them to connect to the antenna at the same time. Carefully matched bulk acoustic wave (BAW) and temperature compensated-surface acoustic wave (TC-SAW) filters are essential to meet system requirements. Multiplexers will become increasingly important as operators aggregate three or more bands. Additional benefits of multiplexers include space savings, simplified design and reduced cost.

Introduction

The Challenges of Carrier Aggregation

Worldwide demand for faster mobile data services is driving mobile network providers to rapidly deploy CA, a key feature of 4G LTE-Advanced that enables operators to provide higher data rates by bonding two or more blocks of spectrum into a wider channel.

Figure 1 illustrates the global momentum of CA deployments, with 88 LTE-Advanced systems in 45 countries commercially launched by July 2015 and another 22 in development. Current deployments are based on specifications (3GPP Release 10/11/12) that allow the combination of up to five blocks of spectrum called component carriers (CCs), each between 1.4 and 20 MHz wide and with a maximum of 100 MHz of aggregated bandwidth.

CA requires specific categories of modem in communicating devices, such as Category 4 (20 MHz aggregated bandwidth, 150 Mbps) and Category 6 (40 MHz, 300 Mbps).

Most early CA deployments combined only two CCs. But many network operators will quickly add combinations of three or more bands as they seek to offer still faster data services and maximize utilization of fragmented spectrum allocations. In general, three or more CCs are required to provide more than 40 MHz bandwidth and deliver speeds greater than around 300 Mbps. Operators in Korea and other countries are already aggregating three CCs; four-CC aggregations are expected in 2016, with five-CC aggregations in 2017 and six-CC aggregations likely by 2018. Looking further into the future, 3GPP is working on specifications that are expected to support as many as 32 CCs, with much faster data rates.

As shown in Figure 2, operators can aggregate CCs in different LTE bands (inter-band CA) or within the same band (intra-band); CCs may be contiguous (occupying adjacent spectrum) or non-contiguous.

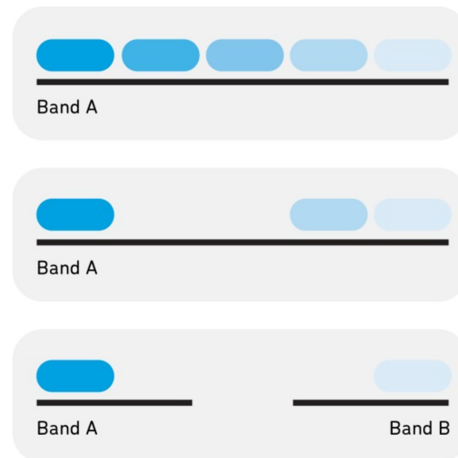

Figure 2. Options for aggregating CCs.

Top: intra-band contiguous.
Middle: intra-band non-contiguous.
Bottom: inter-band non-contiguous.

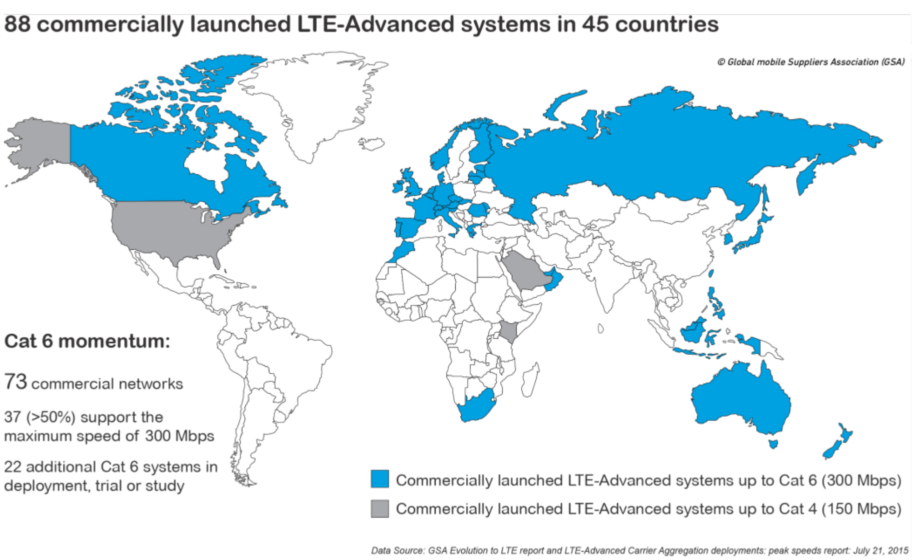

Figure 1. Global LTE-Advanced carrier aggregation deployments.

Global networks using Category 6 and Category 4 modems, which support up to 300 Mbps and 150 Mbps respectively. Source: Global mobile Suppliers Association (GSA).

RF Filtering Challenges

With CA, each device transmits and/or receives on more than one CC simultaneously. This creates new radio frequency (RF) filtering challenges for mobile devices due to the need for cross-isolation: preventing interference between CCs.

To enable simultaneous communication on multiple CCs, the device's RF front end must support multiple open, parallel transmit and receive paths between the transceiver and the antenna(s). Each pathway must be sufficiently isolated from the others. This isolation can be achieved using RF filters, and/or by allocating each aggregated band to a different antenna. Smartphone industrial form factors are constrained by several consumer-driven requirements such as height, functionality, screen size and battery life, which may make it prohibitive to add more antennas. Manufacturers therefore strive to maximize the number of bands per antenna as much as possible within the practical limits of performance.

Achieving cross-isolation using RF filters requires that filters attenuate the out-of-band signals for each CC sufficiently to avoid loading the other aggregated bands. At the same time, each filter must minimize insertion loss of the transmitted signal in order to maintain good reception and minimize power consumption.

Cross-isolation is easiest to achieve when aggregating widely separated bands, such as the aggregation of a high-frequency band (>=2300 MHz) with a low-frequency band (<=960 MHz). An example of a widely-spaced band combination is B7 + B20, which is used in several European countries. When bands are widely separated, adequate isolation may be provided by a diplexer (a simple frequency splitter). For example, a diplexer could be used to separate high-band and low-band signals and direct them along existing high-band and low-band pathways within the phone.

Cross-isolation is much more challenging when aggregating bands that are closer together, such as combinations of multiple mid-frequency (1428-2200 MHz) bands. Many of the widely used CA combinations will fall into this category: current examples include B1 + B3 and B25 + B66 (see Table 1).

Band Combination	Multiplexer	Separate Antenna	Primary Region of Use
B1 + B3	x		China, Korea, Europe
B25 + B66	x		North America
B3 + B7	x	x	Europe, Middle East & Africa
B1 + B3 + B7	x	x	Korea
B3 + B7 + B20	x	x	Europe, Middle East & Africa
B39 + B41	x		China
B1 + B3 + B8	x		Japan

Table 1. Carrier aggregation band combinations that require multiplexers.

The Value of Multiplexer Solutions

Multiplexers provide an elegant solution – and in many cases, the only practical solution – for CA combinations that use closely spaced bands. Multiplexers integrate into a single component all the transmit and receive filters for the aggregated CCs, providing the required isolation while allowing multiple CCs to connect to the antenna at the same time. The filters must be carefully co-designed and matched to achieve the required performance. Without using a multiplexer, it may be impossible to meet demanding system requirements for in-band isolation and cross-isolation, together with low insertion loss and low current consumption.

The complex performance requirements for multiplexers can be illustrated by comparing the isolation requirements when communicating on a single band (i.e. without CA) to the requirements when communicating on multiple bands (with CA).

Without CA: For communication on a single FDD-LTE band, the primary challenge is in-band isolation: preventing interference between the transmit and receive frequencies of the same band. The transmit filter must sufficiently attenuate the transmitted signal at the receive frequency output, to avoid desensitizing the receiver. In-band isolation is typically achieved by using two bandpass filters, corresponding to the transmit and receive frequencies. These filters are often combined into a single device called a duplexer.

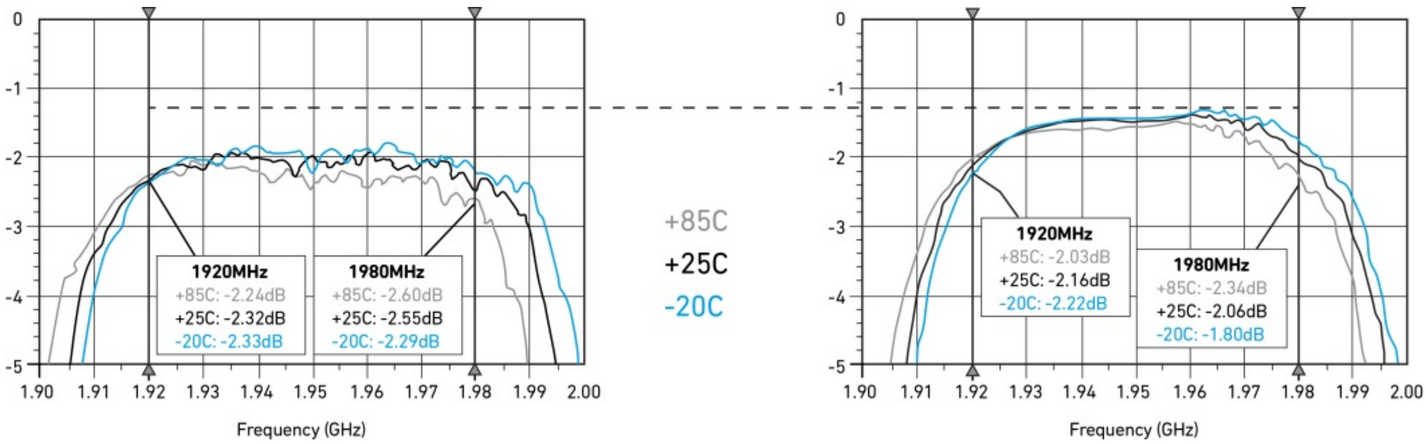

Figure 4. Performance of Qorvo® multiplexer using BAW filters (right) TC-SAW/SAW filters (left).
The BAW multiplexer delivers lower insertion loss across the B1 receive frequency range,
with less variation over temperature, resulting in improved receive sensitivity.

With CA: When using CA to communicate on multiple FDD-LTE bands, the isolation challenges become far more complex. There are many more possible interactions, because of the requirement for cross-isolation between each of the bands as well as isolation within each band. A multiplexer designed to allow aggregation of n bands must include 2n filters (one filter for each transmit frequency and one for each receive frequency), and it must ensure adequate isolation between each of the transmit and receive frequencies. The number of required isolations increases very rapidly with the number of aggregated bands. Considering all the possible interactions, there are eight isolations required in a quadplexer (used for aggregating two bands) versus two in a duplexer. For a hexaplexer (six filters for three bands), the situation is even more complex with 18 possible isolations. To achieve these isolations while meeting system requirements for low insertion loss, the filters must be designed together and carefully matched. For mid-band and higher frequencies, BAW filters are essential to provide the required combination of steep skirts to avoid interference between closely spaced bands, consistent performance over a wide temperature range and low insertion loss. Some combinations of low-frequency bands may require TC-SAW filters: an example might be B26 + B12.

A well designed multiplexer provides additional benefits to mobile device engineers because of the high level of integration. Combining multiple filters into a single component typically requires 60% less PCB space than using discrete filters; such space savings becomes increasingly important as more features and bands are packed into each generation of smartphones. The integration also reduces the overall number of components in each smartphone, which simplifies design, reduces cost and accelerates time to market for device manufacturers.

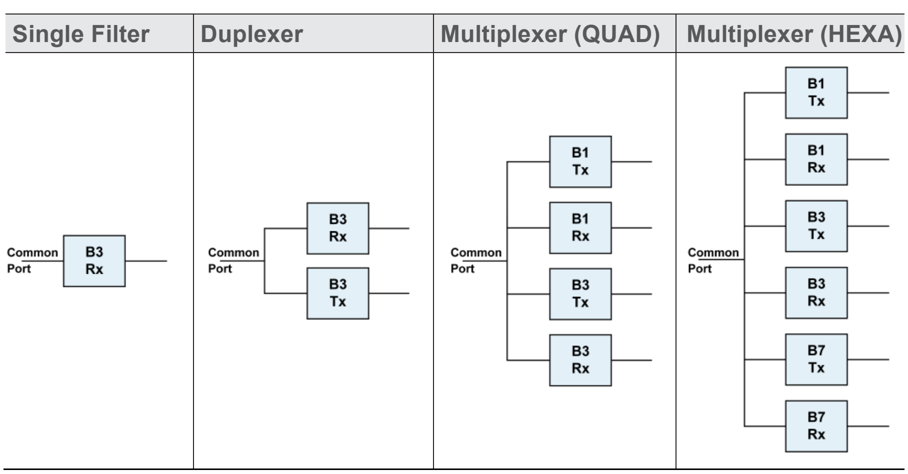

Figure 3. Comparing single filters, duplexers and multiplexers.

An example of a CA challenge that is solved by a multiplexer is the aggregation of two mid-frequency bands, B1 + B3. This band combination is used in China, the world's largest smartphone market and is supported by the Qorvo QM25005 quadplexer, which includes four bandpass filters for the B1 and B3 transmit and receive frequencies connected to a common antenna node. The multiplexer utilizes Qorvo LowDrift™ BAW filters to meet the increasingly stringent requirements related to narrow spacing on receive and transmit bands while delivering consistent performance over temperature variation.

Using carefully matched filters with BAW technology for CA B1 + B3 applications, the QM25005 achieves high isolation and low insertion loss to maximize system performance compared to competing devices using TC-SAW/SAW. As shown in Figure 4, >0.5 dB of nominal insertion loss improvement can be realized using BAW technology, which translates into better phone reception (receive insertion loss) and longer talk-time (transmit insertion loss) for consumers. The lower receive insertion loss also effectively extends base station range and coverage, which means operators require less capital investment in infrastructure.

The CA Roadmap: Future Challenges

CA deployments will continue to grow rapidly both in geographical reach and in complexity. As operators seek to offer even faster data rates using their fragmented spectrum allocations, many new combinations of three, four, five, six or even more bands are expected to come into use over the next few years. As the number of aggregated CCs increases, more parallel pathways for simultaneous transmission are required within each mobile device. There are several ways to create these parallel pathways, as shown in Figure 5:

- **More antennas:** A challenge with this approach is that the space required for additional antennas can conflict with other industrial design requirements, including the need to cram more features and support for more bands into slim handsets.
- **Frequency splitters such as diplexers:** As noted earlier, this approach is useful primarily for widely separated bands.
- **Multiplexers:** These will become increasingly important as the number of CCs increases. For example, aggregations of three or more carriers significantly increase the probability of using close-together bands and therefore are more likely to require multiplexers, including quadplexers and hexaplexers.

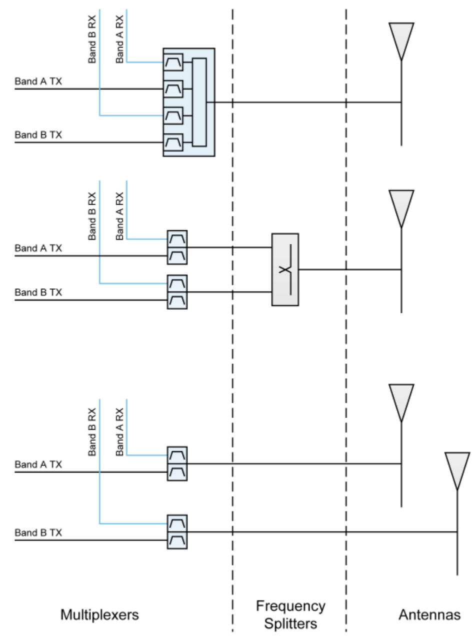

Figure 5. Alternative architectural approaches for creating parallel pathways to support carrier aggregation in handsets. Top: multiplexer; middle: diplexer; bottom: multiple antennas.

Conclusion

Carrier aggregation is a key technology for providing faster data services to meet the global demand for mobile data. However, it presents new, complex filtering challenges for RF solutions in mobile devices, especially when aggregating closely-spaced bands. Multiplexers based on carefully matched premium BAW filters can solve these challenges, and will become increasingly important as the number of aggregated CCs increases. These highly integrated products will also play a role in the broader trend toward greater integration in RF solutions; for example, Qorvo plans to progressively incorporate multiplexer technology into its RF Fusion™ line of high-performance front-end solutions.

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