FROM PASSIVE DIPLEXERS TO ACTIVE MULTIPLEXERS

Whitepaper

Abstract

LTE-A networks' carrier aggregation feature is essential in providing high data rates for the future networks. When diplexers using fixed passive filters are no longer adequate to provide the required tunability, flexibility, and performance level to enable carrier aggregation (CA), it is necessary to seek an active multiplexer as a future-proof solution for the ever increasing capacity demands.

May 25, 2016

Yanhua Deng PhD

inquire@bascomhunter.com

Introduction

Carrier Aggregation (CA) was first introduced in LTE-Advanced in 3rd Generation Partnership Project (3GPP) Release 10, and since then has been deployed in various networks around the world[1-3]. The importance of CA is that it provides high data rates by leveraging wide bandwidth with multiple component carriers across multiple bands. This feature relies heavily on effective filtering and diplexer to ensure cross-isolation between bands.

A diplexer, which uses the simplest form of multiplexing, separates the transmit signal from the receive signal based on different frequency ranges. This is traditionally implemented with two filters at high and low frequency ranges. However, with carrier aggregation, where the frequency band has to be flexible and the bandwidth varies, multiple passive devices are not the most efficient solution. The current situation demands innovative technology, system architecture, and algorithms to provide the targeted performance metric.

Carrier Aggregation in LTE-Advanced

LTE-Advanced standards include a number of key features to enable networks supporting 3Gbps of downlink data speed and 1.5Gbps of uplink data speed. These features include carrier aggregation, higher order multiple input multiple output (MIMO) antennas, heterogeneous networks (HetNet) and relay nodes, Coordinated Multipoint (CoMP) transmission, and enhanced inter-cell interference coordination (eICIC)[4].

CA is one of the most distinct features in LTE-Advanced. In order to achieve the high data rates, it is necessary to increase the transmission bandwidths over those that can be supported by a single carrier or channel. While the spectrum usage efficiency has been improved, one single channel simply cannot provide the required data rates that are being headlined for LTE-Advanced. Carrier or channel aggregation allows expansion of effective bandwidth delivered to a user terminal through concurrent utilization of radio resources across multiple carriers. Multiple component carriers are aggregated to form a larger overall transmission bandwidth. Specifically, up to five component carriers can be aggregated and transmitted simultaneously to support transmission bandwidths as wide as 100 MHz.

Spectrum availability is a key challenge in providing wider bandwidths. Spectrum is a valuable commodity that has been carved up over many decades. It takes time to re-assign spectrum from one use to another. Accordingly, as sections of the spectrum fall out of use, they are re-assigned. Spectrum is therefore highly fragmented. Often, in a network, only small bands of spectrum are available. In some cases these bands are smaller than 10 MHz. To attain the wider bandwidth, CA adopts the flexibility of utilizing fragmented spectrum. CA enables multiple contiguous or non-contiguous small bands to be transmitted simultaneously to achieve the required bandwidth.

There are a few ways in which carriers can be aggregated[5]:

- Intra-band: This form of carrier aggregation uses a single band. There are two main formats for this type of carrier aggregation. In the first case, the easiest form of LTE carrier aggregation to implement, the Intra-band contiguous carriers are aggregated. Here the carriers are adjacent to each other. The second case, non-contiguous intra-band carrier aggregation, is somewhat more complicated than the instance where adjacent carriers are used. The multi-carrier signal can no longer be treated as a single signal; rather, two transceivers are required. This adds significant complexity, particularly to the UE where size, power and cost are prime considerations.

- Inter-band: This form of carrier aggregation uses different bands. This type of CA will be of particular use because of the fragmentation of smaller bands. This implementation is much more challenging to implement without impacting cost, performance and power. With the use of multiple transceivers, the requirements to reduce intermodulation and cross modulation may cause added complexities.

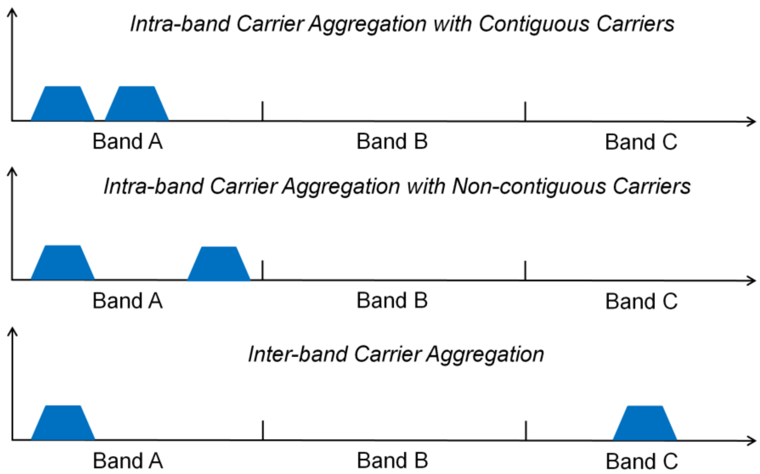
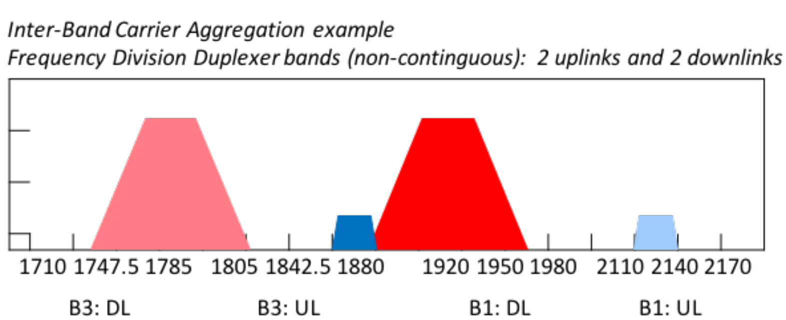


Figure 1. Illustration of three types of carrier aggregation in LTE-Advanced.

With CA, it is inevitable that for some scenarios there will be self-interference when carrier bands are close together. One such widely used CA combination is B1 and B3. For the example of inter-band aggregation with two uplinks and two downlinks, the strong downlink signal from B1 can easily saturation the weak uplink at B3, as illustrated in figure 2(a).

The problem of inter-band CA is further complicated when the carrier aggregation is done with bands that are separated by bands that may be transmitting when the CA bands are receiving or vice versa. In this case, traditional band pass filters cannot be used. This type of interference is shown in figure 2(b). For the intra-band carrier example, when one carrier is used for uplink and three used for downlink, this leads to co-channel interference between the uplink and one downlink carrier.



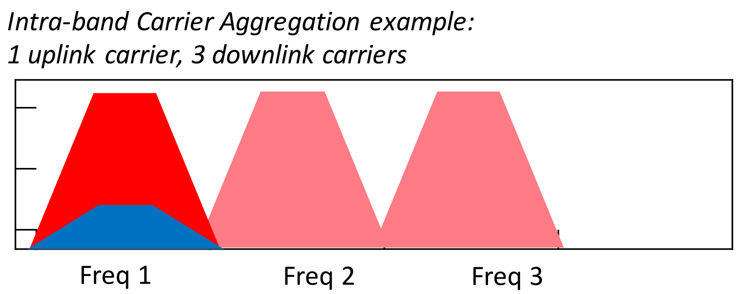


Figure 2. (a) Example of CA for B1+B3 with potential interference. (b) Co-channel interference for uplink and downlink carriers.

Diplexers/Duplexers

In CA, providing adequate filtering for different aggregated component carriers with different bandwidths is challenging[6-7].

The diplexer is an essential component for the RF front-end circuits at both the base station and user equipment (UE). At the base station, a typical RF front-end includes a 2-way hybrid combiner with isolators, duplex filters, and a power amplifier at the Tx and an integrated amplifier at the Rx. Since there is a high power requirement, ranging from ~30 – 60 dBm, the filter technology used in the diplexer is usually cavity based[8]. At the UE side, the size requirement is much more stringent. Surface or bulk acoustic wave based filters are implemented for their small footprint and high isolation[9]. One example of the filtering characteristic of the diplexer based on cavity filter is shown in figure 3, with ~40dB/25MHz performance at the frequency transition region.

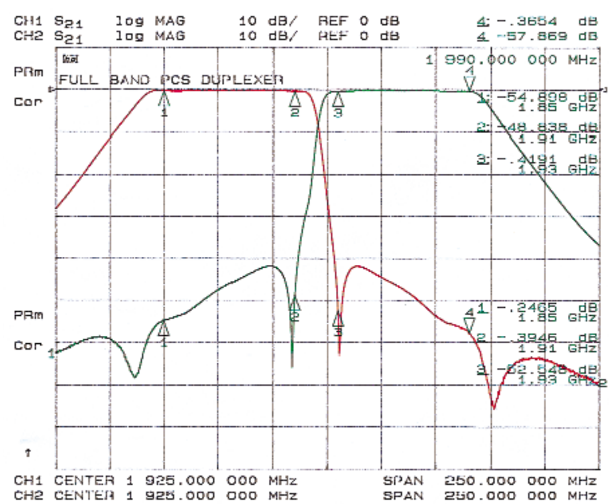


Figure 3. Performance spec of a typical diplexer[8].

In many systems, diplexers and duplexers are used interchangeably. For our discussion, we are specifying duplexers as a component that enables bidirectional signal propagation, where the transmit and receive signal can share the same antenna and can be at the same or very close frequency bands. A circulator is a simple duplexer. On the other hand, a diplexer separates signals with filtering, where transmit and receive signals are in different frequency bands and typically with relatively large offset. A diplexer for a single antenna implementation can consist of two filters at different frequency bands and a circulator.

Passive Diplexer Bands for CA

The key parameter that determines the performance of a diplexer is the ratio between the isolation bandwidth and the filtering bandwidth[7]. For CA, this ratio can vary from 1 for intra-band aggregation to >100 for inter-band aggregation. An example of the diplexer performance is shown in figure 4. In order to be fully adaptable for CA, the diplexer has to be flexible in these aspects:

- *Center frequency* – Different component carriers are at different center frequencies.
- *Channel spacing* – Contiguous inter-band, non-contiguous inter-band, and intra-band schemes have drastically different channel spacing.
- *Bandwidth* – Carrier bandwidth can vary in 1.4, 3, 5, 10, 15, 20 MHz.
- *Number of carriers aggregated* – Carrier bandwidth class A-F varies from 1 to 5 carrier components.
- *Different selectivity requirements for uplink and downlink* – Downlink reception needs to maximize rejection of the transmitted signals to protect the receiver, while uplink transmission requires low insertion loss to maximize efficiency.

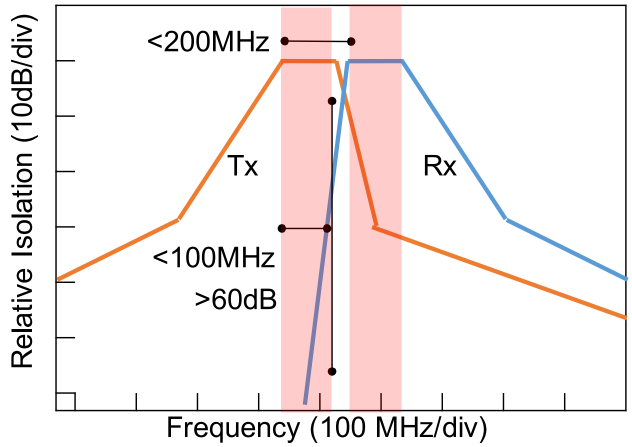


Figure 4. Performance of a diplexer enabling carrier aggregation.

Currently, there are two approaches to enable CA. The first one is implementing an array of carefully matched filters with switches to enable a number of pre-defined CA schemes. There are a variety of diplexer/multiplexer products available with fixed aggregation schemes.

The filter arrays are accessible and can be cost effective, but as the number of bands increase, the complexity and size of the filter are also becoming prohibitive. Qorvo provides an example of this solution. The array can be designed using multiple passive surface and bulk acoustic wave (BAW/SAW) filters to generate multiplexers by integrating all the filters into a single filter bank component. This requires carefully matched filters. A multiplexer configuration, with distinct filters for uplink and downlink transmission, is shown in figure 5. The figure also shows with switches, multiple filter banks can be implemented to support multiple CA schemes for transceivers covering different frequency ranges.

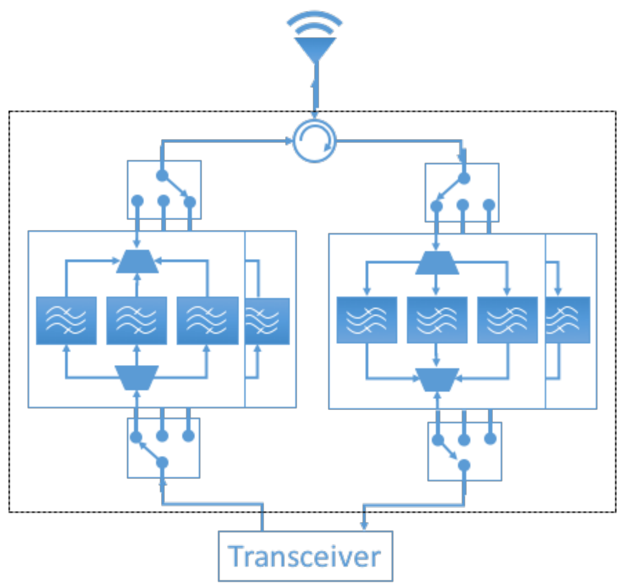


Figure 5. Multiple filter bank as a RF-front-end for CA.

A second approach to CA is using tunable filters. Making tunable high performance acoustic filters is the “holy grail” of filter research[10]. There are a few difficulties involved in making tunable diplexers. A diplexer with high Q resonators typically is not tunable. Typical filters with high Q such as SAW/BAW filtering devices are essentially quartz crystals, having a series of parallel resonant elements close together, where the crystals are not tunable. On the other hand, tunable devices such as varactors have much lower Qs and usually do not provide enough performance.

Transition to Active Multiplexer

An active analog canceller, instead of using only filters, is an innovative solution that can provide the flexibility required for CA. Since the transmit signal is much stronger than the receiving signal, with a dynamic range as high as 100dB, it is imperative to provide high isolation of the transmit signal at the receiving port.

An active analog canceller can provide a high level of isolation between the UL and DL paths. Figure 6 shows how the canceller enables multiplexing. In this illustration, at point 1, two carriers are aggregated in the UL. At point 2, the strong UL signal can easily leak through the circulator and degrade the DL signal. Since the UL signal can be more than 100dB stronger than the DL signal, often, this leakage can be stronger than the actual received signal. Therefore, even if the UL and DL are at different frequency banks, it is possible for the UL to cause DL signal distortion. At point 3, the canceller taps the DL signal and use it as a reference. Using the reference signal, the canceller can actively suppress the leakage. At point 4, after the canceller, both out-band and in-band leakages are eliminated.

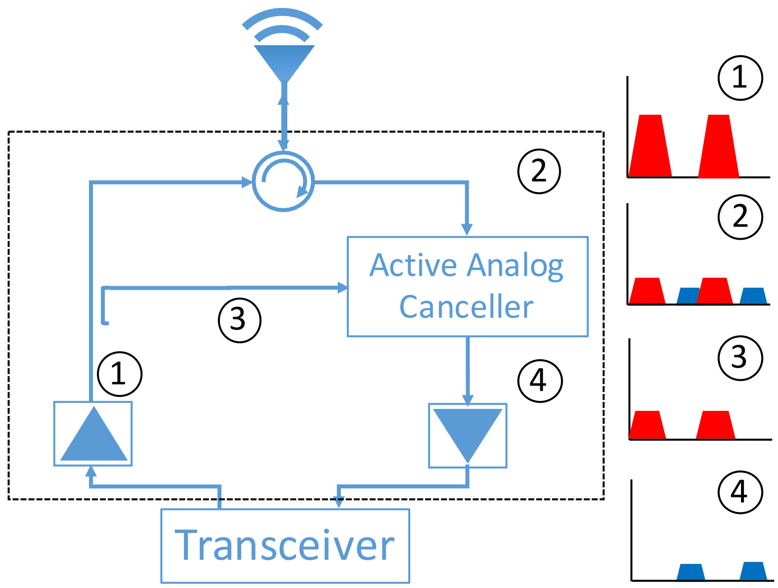


Figure 6. Multiplexer with active analog canceller.

This approach provides multi-fold advantages. As illustrated, the canceller is agnostic to the frequency bands of the UL and DL. This implies that with a single active cancelling function, the front-end can satisfy the multiple band configuration and provide the required performance in terms of the number of bands, high isolation level, and independence to bandwidth variations. The active analog canceller can either provide additive improvement to the isolation performance of the diplexer, or can relax the performance of the filter such that other filter technologies can be used to achieve tunability.

This adaptive approach potentially opens up many new applications. By consolidating many discrete filter banks and simplifying the front-end's circuits and control, this approach also leads to long term cost reduction. In addition, a system implementing this approach can be adjusted quickly to new carrier aggregation schemes or to new standards or protocols. From this perspective, an active analog canceller is future proofing the system to new frequency bands and new bandwidth requirements.

Conclusion

Carrier Aggregation is an important feature in the current and future communications systems. It is going to be widely implemented as the capacity demands continue to increase. Therefore, an adaptive solution is essential to follow the new trend.

Bascom Hunter's approach to interference mitigation is based on a photonic-based high-resolution wideband interference cancellation system. It is adaptive, compact, and capable of removing high-power interference in band or in close proximity to the signal of interest. The technology has been tested and validated with results showing over two orders of magnitude greater performance than existing products. Bascom Hunter's technology offers several key advantages over current technology, including greater levels of interference removal, low distortion of signal of interest, high dynamic range, insensitivity to IEM, and operation over wide bandwidth. The innovative solution can improve the network reliability and reduce costs.

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About Bascom Hunter

Over the last five years, the amount of data sent wirelessly has increased tenfold. The result is a dramatic increase in demand for wireless bandwidth—exponential growth with no foreseeable slowdown. The finite resource of available radio frequency spectrum, however, is plagued by unreliable coverage and signal interference. Today's solutions simply will not meet tomorrow's demand. Bascom Hunter's mission is to enable customers to get the most out of the RF technology revolution. We provide the leading solutions in wireless communication and security at competitive prices. Contact us today to learn how our products can help you to address coverage problems and take full advantage of wireless technologies.

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inquire@bascomhunter.com