Carrier Aggregation Fundamentals

For Dummies

A Wiley Brand

Learn to:
• Understand carrier aggregation
• Recognize the types of carrier aggregation
• Envision the evolution and global deployment of carrier aggregation

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About Qorvo*

Qorvo is a leading provider of core technologies and radio frequency (RF) solutions for mobile, infrastructure and defense/aerospace applications. Qorvo offers the industry’s most comprehensive portfolio of RF products and technologies, and its more than 7,000 employees worldwide are dedicated to delivering solutions for everything that connects the world.

Qorvo operates design, sales, and manufacturing facilities throughout Asia, Europe, and North America. Its primary design and manufacturing facilities are located in North Carolina, Oregon, Texas, and Florida, and its primary assembly and test facilities are in China, Costa Rica, and Texas. Qorvo’s world-class manufacturing facilities are ISO9001-, ISO 14001-, and ISO/TS 16949-certified. The company’s Richardson, Texas, facility is a U.S. Department of Defense-accredited “Trusted Source” (Category 1A) for gallium arsenide (GaAs), gallium nitride (GaN) and bulk acoustic wave (BAW) technologies, products, and services. Qorvo’s design and manufacturing expertise encompasses all major applicable semiconductor process technologies, and Qorvo is a preferred supplier to the leading companies serving the mobile device, infrastructure, and defense/aerospace markets.

all around you
Carrier Aggregation Fundamentals

by Larry Miller

Qorvo Special Edition
Introduction

Mobile operators must continuously pursue cost-effective and efficient solutions to meet the high data demand requirements of their subscribers. Limited spectrum allocations and non-contiguous spectrum blocks continue to pose challenges for mobile operators supporting large data uploads and downloads across their networks. With the increase in video and social media content, the challenges have increased exponentially.

Carrier Aggregation (CA) is a solution that many mobile operators worldwide have begun adopting to address these challenges in the mobile ecosystem.

About This Book

This excellent book briefly explains carrier aggregation technology (Chapter 1), examines deployment strategies (Chapter 2), explores a few dynamics and challenges (Chapter 3), and extols the benefits of carrier aggregation (Chapter 4)!

Foolish Assumptions

It’s been said that most assumptions have outlived their uselessness, but I’ll assume a few things nonetheless!

I assume you’re a sales manager or an engineer working in the mobile carrier industry, and you’re therefore somewhat technical. I also assume you have an interest in carrier aggregation technology and how it can be used to benefit your organization.

If these assumptions describe you, this book is for you! If neither of these assumptions describes you, keep reading anyway. It’s a great book, and when you finish reading it you’ll know a few things about carrier aggregation technology!
Icons Used in This Book

Throughout this book, I occasionally use special icons to call attention to important information. Here's what to expect:

**Remember**

This icon points out information that you should commit to your non-volatile memory, your gray matter, or your noggin' — along with anniversaries and birthdays!

**Technical Stuff**

You won’t find a map of the human genome here, but if you seek to attain the seventh level of NERD-vana, perk up! This icon explains the jargon beneath the jargon!

**Tip**

Thank you for reading, hope you enjoy the book, please take care of your writers! Seriously, this icon points out helpful suggestions and useful nuggets of information.

**Warning!**

This icon points out the stuff your mother warned you about. Okay, probably not. But you should take heed nonetheless — you may just save yourself some time and frustration!

Beyond the Book

There’s only so much I can cover in 24 short pages, so if you find yourself at the end of this book thinking, “Gosh, this was an amazing book, where can I learn more?” just go to www.qorvo.com.

Where to Go from Here

Chapter 1 might be a good place to start! But if you see a particular topic that piques your interest, feel free to jump ahead to that chapter. Each chapter is written to stand on its own, so you can start reading anywhere and skip around to your heart’s content! Read this book in any order that suits you (though I don’t recommend upside down or backward).
Chapter 1

Understanding Carrier Aggregation (CA) Technology

In This Chapter

▶ Understanding what CA is and why it’s needed
▶ Recognizing CA benefits
▶ Exploring CA data rate evolution

In this chapter, you learn the basics of carrier aggregation (CA), including coverage benefits and the evolution of data rates.

Scoping Out CA

Today, more than 2.6 billion smartphone subscriptions exist worldwide. The total number of mobile subscriptions — which also includes mobile broadband, mobile PCs, tablets, routers and, increasingly, Internet of Things (IoT) devices — is 7.2 billion. That’s almost one mobile subscription for every man, woman, and child on the planet! And by 2020, that number is expected to grow to more than 9 billion (mobile subscriptions, not people — there will be only 7.7 billion people)!

Fortunately, all of those mobile subscribers just want to talk to their friends and family, right? If only it were that easy! The truth is, mobile data traffic far exceeds voice traffic.
According to the June 2015 Ericsson Mobility Report, in the first quarter of 2015, total monthly mobile voice traffic was only approximately 250 petabytes, while total mobile monthly data traffic was approximately 3,500 petabytes! And while web browsing on mobile devices now exceeds that on PCs in many countries, it accounts for only 10 percent of data traffic. Video accounts for approximately 45 percent of mobile data traffic, and Ericsson predicts that will increase to 60 percent by 2020. Thus, it’s no wonder we’re no longer asking “Can you hear me now?” Today, the question is “How much data do I get with that plan?”

Mobile carriers and manufacturers are struggling to address these mobile data traffic challenges with current technologies. It’s simply a problem of supply and demand. Mobile operators

- Have segmented spectrum in multiple bands and regions
- Need more capacity and faster data speeds to meet user demand

One of the answers for addressing the challenge of mobile data traffic is LTE-Advanced carrier aggregation (CA). CA is a technique used to combine multiple Long-Term Evolution (LTE) component carriers (CCs) across the available spectrum to

- Support wider bandwidth signals
- Increase data rates
- Improve network performance

Each aggregated component carrier is referred to as a CC.

**Recognizing Coverage Benefits**

Carrier aggregation allows increased data rates and improved network performance in the uplink, downlink, or both. It also enables aggregation of frequency-division duplexing (FDD) and time-division duplexing (TDD), as well as licensed and unlicensed carrier spectrum.

In FDD communication links, separate frequency bands are used to transmit and receive. In TDD communication links, uplink is separated from downlink by allocating different time slots in the same frequency band.
As of today, up to five CCs can be allocated for 100 MHz of bandwidth per user, as shown in Figure 1-1. However, 3rd Generation Partnership Program (3GPP) Release 13 will extend support for up to 32 CCs.

![Carrier aggregation diagram]

**Figure 1-1:** CA combines multiple LTE carrier signals to increase data rates and improve network performance.

Mobile carriers can use CA to increase performance on their networks, as shown in Figure 1-2.

![Carrier aggregation performance diagram]

**Figure 1-2:** CA technology boosts carrier performance.

For example:

- AT&T’s median download speed in Chicago increased from 10.69 Mbps to 15.18 Mbps when AT&T started using CA there.
- Sprint plans to use CA to combine two 2.5 GHz TDD-LTE channels. The plan combines resource blocks of spectrum to produce more capacity, and may more than double peak download speeds.
The building block of LTE is a physical resource block (PRB or RB). A scheduling algorithm handles all of the allocation of LTE RBs. One RB is 0.5 milliseconds and contains 12 subcarriers for each orthogonal frequency-domain multiplexing (OFDM) symbol in the frequency domain.

Other carriers will join this trend as demand for LTE rises and demand for 3G falls. Carriers will use CA technology to combine spectrum in low-, mid-, and high-band frequencies to boost speed and capacity.

CA enables carriers to gain capacity and network efficiency while providing an optimized user experience. A user previously experiencing slow downlinks or uplinks should seamlessly experience increased data speeds and optimized bit rates.

Download a free copy of RF Filter Technologies For Dummies and RF Filter Applications For Dummies at www.qorvo.com/filters-for-dummies to learn more about frequency bands.

Exploring Data Rate Evolution

In 2013, the first commercial implementation of CA on an LTE Advanced network was announced in South Korea. CA technology has since been deployed on LTE networks in regions throughout the world, notably in the United Kingdom, North America, and China.

To support CA, mobile device manufacturers must deploy capable CA products. In LTE, user equipment (UE) categories define the capabilities of a mobile device. After the network has identified what category a mobile device supports, it knows the device capabilities and can scale the data link accordingly. These categories align with the CA bandwidths shown in Table 1-1.

Commercial LTE networks started with Category 3 and 4 devices supporting up to 100 to 150 Mbps with continuous 20MHz spectrum, as shown in Figure 1-3. In 2015, Category 9 devices produced up to 450 Mbps data rates with 60 MHz of spectrum, and up to 1 Gbps and higher data rates are expected in the near future.
Table 1-1: Aggregated Downlink Bandwidth and Data Rates for LTE User Equipment Categories

<table>
<thead>
<tr>
<th>Aggregated Downlink Bandwidth</th>
<th>Downlink Data Rate</th>
<th>Modem Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz</td>
<td>75 Mbps</td>
<td></td>
</tr>
<tr>
<td>15 MHz</td>
<td>100 Mbps</td>
<td>LTE Category 3</td>
</tr>
<tr>
<td>20 MHz</td>
<td>150 Mbps</td>
<td>LTE Category 4</td>
</tr>
<tr>
<td>25 MHz</td>
<td>185 Mbps</td>
<td></td>
</tr>
<tr>
<td>30 MHz</td>
<td>225 Mbps</td>
<td></td>
</tr>
<tr>
<td>40 MHz</td>
<td>300 Mbps</td>
<td>LTE Category 6/7</td>
</tr>
<tr>
<td>50 MHz</td>
<td>375 Mbps</td>
<td></td>
</tr>
<tr>
<td>60 MHz</td>
<td>450 Mbps</td>
<td>LTE Category 9/10</td>
</tr>
<tr>
<td>80 MHz</td>
<td>600 Mbps</td>
<td>LTE Category 11/12</td>
</tr>
</tbody>
</table>

*Assumes 64-quadrature amplitude modulation (QAM) in the downlink
*The scaling in data rate between 64 QAM and 256 QAM is a factor of 1.33 (8-bit symbol versus 6-bit symbol)
*Any bandwidth above 20 MHz requires at least two-CC CA
*Any bandwidth above 40 MHz requires at least three-CC CA
*Any bandwidth above 60 MHz requires at least four-CC CA

Figure 1-3: Data rate evolution in downlink with carrier aggregation

LTE categories define performance specifications for mobile device classes and enable base station communications at known performance levels.
In 2011, carrier aggregation was introduced in 3GPP Release 10 (see Figure 1-4), which defined the following specifications:

- Signaling to support up to five CCs
- Deployment scenarios limited to two CCs
- Maximum aggregated bandwidth of 40 MHz
- Prioritized support for intra-band contiguous and inter-band

3GPP Release 11 expanded the deployment options and capabilities of CA in 2013 as follows:

- Support for multiple time advances (required for uplink CA)
- Core requirements for intra-band non-contiguous deployments defined
- Performance requirements for new inter-band and intra-band combinations established

3GPP Release 12 (completed in 2014) included

- Core requirements for uplink CA inter-band defined
- Performance requirements for intra-band non-contiguous deployments defined
- Core analysis for three CCs in inter-band completed
- Maximum aggregated bandwidth of 50 MHz
Chapter 2
Finding Out About CA
Deployment Strategies

In This Chapter
▶ Relating FDD and TDD to CA
▶ Joining adjacent CCs in the same band
▶ Bringing separate CCs together in the same band
▶ Combining multiple CCs in different bands

In this chapter, you learn about different carrier aggregation (CA) types and deployment scenarios.

Relating FDD and TDD to CA

As defined in 3GPP Release 12, CA can be deployed in both frequency-division duplexing (FDD) and time-division duplexing (TDD) frame structures. Each CC in FDD or TDD can have a bandwidth of 1.4, 3, 5, 10, 15, or 20 MHz. Thus, with five CCs at 20 MHz, a maximum bandwidth of 100 MHz can be achieved with CA.

In TDD, the bandwidth and number of CCs must be the same for both the uplink and downlink.

In FDD, downlink and uplink can be configured with a different number of CCs and different bandwidths in each (known as asymmetric configuration). However, the number of uplink CCs cannot exceed the number of downlink CCs. CA in FDD improves coverage and data rates.
3GPP defined FDD-TDD aggregation in Release 12, which allows either FDD or TDD as the primary cell. FDD-TDD aggregation can provide an attractive combination of low-band FDD for good coverage and high-band TDD with more spectrum for higher data rates.

### Joining Adjacent CCs in the Same Band

The simplest CA deployment scenario, intra-band contiguous CA, aggregates multiple adjacent CCs in a single operating band. Intra-band contiguous CA, shown in Figure 2-1, is typically used to increase capacity.

![Intra-band contiguous CA](image)

**Figure 2-1:** Intra-band contiguous CA aggregates multiple adjacent CCs in the same operating band.

Unfortunately, because of current operator frequency allocations, aggregating contiguous CCs is not always possible. However, as new spectrum bands (such as 3.5 GHz and 600 MHz) are allocated in the future, intra-band contiguous CA may become more common.

### Bringing Separate CCs Together in the Same Band

In regions where spectrum allocation is more fragmented, such as North America, intra-band non-contiguous CA, shown in Figure 2-2, is a common deployment scenario. Intra-band non-contiguous CA aggregates multiple separated CCs in a single operating band.
Combining Multiple CCs in Different Bands

Inter-band CA, shown in Figure 2-3, aggregates multiple CCs in different operating bands (the CCs aggregated in each band can be contiguous or non-contiguous).

Inter-band CA is more complex than intra-band CA because the multi-carrier signal cannot be treated as a single signal and therefore requires a more advanced transceiver in the User Equipment (UE).

Why are carriers interested in CA? Because they need to acquire and retain customers. They do this by offering customers best-in-class network performance. CA enhances the carrier network performance and ensures a high-quality user experience, most specifically in uplink and downlink data rates.

CA addresses radio link capacity and data rates, but differences arise depending on whether a carrier is using FDD-LTE or TDD-LTE.

As shown in Tables 2-1 and 2-2, FDD-LTE aggregated at 40MHz, for example, in the downlink is very different from TDD-LTE (40 MHz FDD-DL = 300 Mbps compared to TDD-DL = 224 Mbps).
Low-and high-band CA is a common configuration for carriers because many operators have valuable low-band spectrum (such as 700 MHz) that has definite coverage advantages. Pairing low-band spectrum such as 700 MHz with Advanced Wireless Service (AWS) in the 2 GHz band maximizes an operator’s spectrum assets for coverage and capacity.
In this chapter, you learn about the various downlink and uplink challenges associated with the different types of carrier aggregation (CA).

**Understanding Downlink Challenges**

Downlink CA challenges include

- Downlink sensitivity
- Harmonic generation
- Desense challenges in CA RF radio design
Downlink sensitivity

In a non-CA, single carrier FDD (frequency division duplex) scenario, an RF duplexer ensures that transmissions on the uplink do not interfere with reception on the downlink.

If you design a duplexer for each of the bands ensuring downlink bands are not affected, connecting two duplexer paths can affect the filter characteristic of both duplexers, thereby causing you to lose transmit and receive path isolation required to operate at system sensitivity.

Radio receiver sensitivity is the minimum receiver input power measured at the antenna connector at which a minimum throughput is achieved or the frame error rate/bit error rate (FER/BER) does not exceed the value defined for various bands under static conditions.

In some CA cases with large frequency separations between two bands (for example, mid band and low band), a separate diplexer can be added. A diplexer is inserted between the antenna and the two individual band-specific duplexers.

In CA architectures, some designers are using multiplexers and hexiplexers in place of duplexers, where applicable (which you can learn more about in Chapter 2 of Carrier Aggregation Applications For Dummies). If a multiplexer is desired, each individual filter within the device requires complex development. It isn’t as easy as placing two filters in one package with the expectation that they will work as a unified device. Designers must ensure that each band works cohesively in the multiplexer. Although a multiplexer is more challenging to develop, it simplifies the RF front-end designer’s effort and increases available PC board area. Figure 3-1 depicts a simple front end showing duplexers and diplexers.

Harmonic generation

Harmonics are generated by nonlinear components such as transceiver output stages, power amplifiers (PAs), duplexers, and switches. During component development, designers must prudently trade off various device performance criteria to help reduce harmonics and other intermodulation products generated from these devices.
A harmonic is a signal whose frequency is an integer multiple of the frequency of some reference signal.

Harmonics can cause a degradation in system sensitivity, known as desense, when the harmonic of a transmit signal falls in the receive band of a paired CA band. System desense can occur when isolation between system signal paths is insufficient. This creates a scenario where the sensitivity of the receiver is degraded because the harmonic level in that band is high enough to prevent the desired signal from being detected.

High switch isolation and filter attenuation can minimize interference from one port to another. Harmonics can interfere with another frequency band because of insufficient isolation. For example, in Figure 3-2, the low-band harmonics from Band 17 leak to the high-band signal path of Band 4, causing desense of the high-band receiver. High switch isolation and harmonic filtering are required to mitigate this situation.

**Desense challenges in RF design**

Multiband RF radio signals can interfere with each other because of insufficient filter attenuation. This means there is a higher probability of desense in CA applications if isolation or cross-isolation between the transmit and receive paths is insufficient.
Figure 3-3 depicts an RF front end with diplexers at the antennas separating the low-band and mid-band signals. The duplexer provides FDD operation on Band 17 and helps with out-of-band rejection for the receive signals.

However, some desense challenges occur in this scenario. As shown in Figure 3-2 and Figure 3-4, the third harmonic from low Band 17 transmit couples with the mid Band 4 received signal path, causing desense. Another issue that can cause desense occurs if the isolation between the primary and diversity antennas is insufficient.
If the PC board isolation is not sufficient, the Band 17 transmit path (PA output) could couple directly to the Band 4 receive path via the PC board, causing the same harmonics issue, as shown in Figure 3-5 (indicated by the dotted arrow). This problem can be mitigated by designing the PC board to meet an isolation of greater than 90 dB on these paths.

Finally, switch coupling can occur if the switch has insufficient isolation between its internal low- or mid-band switch paths, as shown in Figure 3-6. Again, harmonics can pass through these paths and cause system desense. High isolation between internal switch paths can mitigate this problem.

The recent growth in uplink and downlink CA in cellular networks has created new challenges in RF receivers related to sensitivity and desense. Optimizing components for insertion loss in the Rx (receive) paths helps maintain smartphone sensitivity, while improving Tx-Rx (transmit-receive) isolation helps mitigate desense problems.
Figure 3-5: Insufficient PC board coupling can cause harmonics challenges.

Figure 3-6: Insufficient isolation between internal low- or mid-band switch paths can cause harmonics challenges.
Addressing Intra-Band Uplink Challenges

In the China market, TDD is the main driver for UL carrier aggregation. In 2014, China Telecom and Nokia Networks announced the world’s first FDD-TDD CA device chipsets. This development uses FDD Band 3 for improving LTE coverage and TDD Band 41 for improving throughput.

Intra-band uplink is the easiest implementation of the different uplink CA types (see Chapter 2), so it is the first step for most carriers.

Maximum Power Reduction

Intra-band uplink CA signals use more bandwidth and have higher peak-to-average power ratios (PAPRs) than standard LTE signals. Also, many possible configurations of resource blocks (RBs) exist in multiple component carriers (CCs) where signals could mix and create spurious out-of-band problems. To address the new signal dynamics, 3GPP allows for different Maximum Power Reductions (MPRs) to be applied based on different configurations of RBs.

As an example, two contiguous 20 MHz CCs using all 200 RBs would be allowed to back off the maximum power by 2dB. For the same two 20MHz CCs with 50 RBs allocated in each CC — positioned so there are 100 adjacent RBs — the transmitter would have 1dB MPR. This situation occurs because the 100 adjacent RBs can’t create as many out-of-band problems as in the 200 RB scenario.

Linearity

Intra-band, uplink CA signals present mobile device designers with many challenges because they can have higher peaks, more signal bandwidth, and new RB configurations. A PA design must be tuned for very high linearity even though the signal power may be backed off. Adjacent channel leakage, intermodulation products of non-contiguous RBs, spurious emissions, noise, and sensitivity must be considered.
For example, a PA transmitting two 20 MHz CCs with 2 dB back-off requires more linearity than a 20 MHz 100 RB FDD waveform at 1 dB back-off to achieve the same Adjacent Channel Leakage Ratio (ACLR), even without considering memory effects related to the wider bandwidth.

The tradeoff of linearity comes at the expense of efficiency and thermal effects. Although discrete designs could provide some benefit, this approach comes at the expense of higher loss and longer development times.

Using optimized Qorvo front-end-module products like RF Flex, RF Fusion, and MMPA modules with best-in-class efficiency and linearity provides the performance and ease of use required for CA applications.

**Recognizing Inter-Band Uplink Challenges**

Inter-band uplink CA combines transmit signals from different bands. The maximum total power transmitted from a mobile device is not increased in these cases, so for two transmit bands, each band carries half the power of a normal transmission, or 3 dB less than a non-CA signal.

Because different PAs are used to amplify the signals in different bands, and the transmit power is reduced for each, the PA linearity isn’t an issue. Other front-end components, like switches, have to deal with high-level signals from different bands that can mix and create intermodulation products. These new signals can interfere with one of the active cellular receivers or even another receiver on the phone, like the GPS receiver. To manage these signals, switches must have very high linearity.
Ten Benefits of Carrier Aggregation

In This Chapter

- Recognizing the benefits of carrier aggregation

You know ’em, you love ’em. Here’s a list of ten great benefits of carrier aggregation, presented in classic *For Dummies* style!

- **More efficient use of spectrum:** Operators can combine fragmented smaller spectrum holdings into larger and more useful blocks, and can create aggregated bandwidths greater than those that would be possible from a single component carrier.

- **Leveraging of underutilized spectrum:** CA enables carriers to take advantage of underutilized and unlicensed spectrum, thereby extending the benefits of LTE-Advanced to these bands.

- **Increased uplink and downlink data rates:** Wider bandwidth means higher data rates.

- **Network carrier load balancing:** Enables intelligent and dynamic load balancing with real-time network load data.

- **Better network performance:** With CA, carriers provide a more reliable and stronger service with less strain on their individual networks.

- **Higher capacity:** CA doubles the data rate for users while reducing latency by approximately 50 percent.

- **Scalability:** Expanded coverage allows carriers to scale their networks rapidly.
Dynamic switching: CA enables dynamic flow switching across component carriers (CCs).

Better user experience: CA delivers a better user experience with higher peak data rates (particularly at cell edges), higher user data rates, and lower latency, as well as more capacity for “bursty” usage such as web browsing and streaming video.

Enabling of new mobile services: Delivering a better user experience opens opportunities for carriers to innovate and offer new high bandwidth/high data rate mobile services.
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