Keysight

Solutions for LTE-Advanced Manufacturing Test

Understanding the Requirements for LTE-Advanced Carrier Aggregation Manufacturing Test

Application Note

KEYSIGHT TECHNOLOGIES

Introduction

Overview

Carrier aggregation (CA), introduced in the 3GPP Release 10 standard, is an important new feature of LTE-Advanced. Carrier aggregation enables the combining of multiple LTE carriers into a larger, singlechannel bandwidth to increase data rates and throughput. For operators with limited or fragmented spectrum allocations, carrier aggregation is a way to keep pace with the growing data demands on their networks.

A goal of LTE-Advanced is to preserve backward compatibility with earlier LTE releases. For that reason, CA in LTE-Advanced is based on the carriers first defined for 3 GPP Release 8. This allows existing LTE devices to continue operating properly but enables new devices to support the higher data throughput that CA makes possible. The LTE carriers defined in Release 8 are called component carriers (CCs). Component carriers can use any of the 3GPP-defined LTE bandwidths—1.4, 3, 5, 10, 15, or 20 MHz—and up to five CCs can be combined for a theoretical maximum of 100 MHz of bandwidth.

Since most LTE-FDD operators today lack the spectrum to support the widest channels, they are expected to use the 5 or 10 MHz bandwidths for carrier aggregation. In LTE-Advanced systems based on frequency division duplex (FDD), the number of CCs aggregated in the uplink must always be less than or equal to the number of aggregated downlink CCs. The carrier bandwidths can vary—for example, a 5 MHz carrier can be combined with a 10 MHz carrier—as this scenario is most likely to be fielded by operators.

In systems based on time division duplex (TDD), both the downlink and uplink share the same channel. As defined in Release 10, the number of aggregated CCs in a TDD system and the bandwidth of each CC must be the same for the downlink and the uplink. This definition changes in 3GPP Release 11, which introduces TDD support for different uplink and downlink configurations in each frequency band.

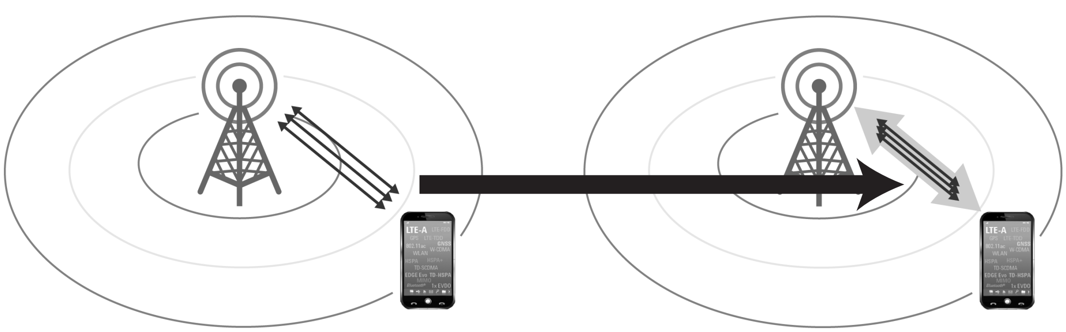

Figure 1. A simplified view of carrier aggregation. Multiple LTE carriers are combined into a larger, single-channel bandwidth to increase data rates and throughput and to make best use of available spectrum.

Two types of carrier aggregation are defined for LTE-Advanced in Release 10: intra-band carrier aggregation and inter-band carrier aggregation. With intra-band CA, aggregated CCs occupy channels within a single LTE frequency band. These channels may be contiguous (adjacent), non-contiguous, or both if more than three CCs are used (Figure 2).

Some chipsets support this feature using only a single receiver. With inter-band CA, the CCs are located in different frequency bands (Figure 3), and thus two or more receivers are needed. While this type of CA is more expensive, it is the most likely implementation for operators because blocks of spectrum are more available to them in different frequency bands.

LTE-Advanced networks can support carrier aggregation in just the downlink or in both the downlink and the uplink. Initial deployments are implementing CA in the downlink only, where internet packet-data traffic is typically heavier.

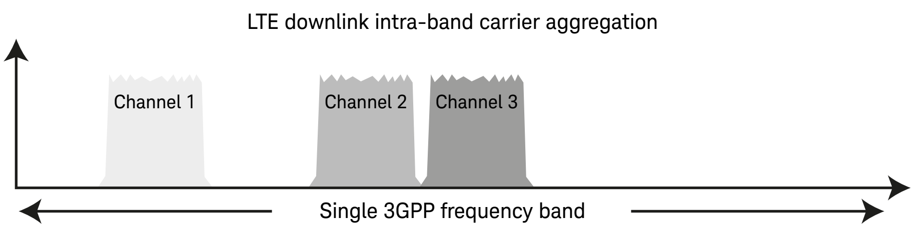

Figure 2. Intra-band carrier aggregation with contiguous and non-contiguous channels.

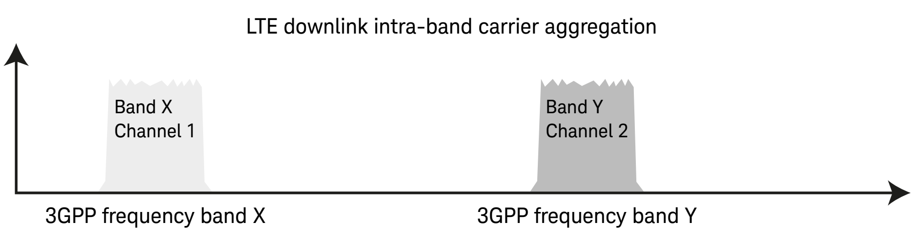

Figure 3. Inter-band carrier aggregation, which combines channels from different frequency bands.

Problem

Carrier aggregation brings some new challenges for manufacturers of LTE user equipment (UE) in terms of increased test time and complexity, even though CA does not add any new categories of test. Just as for other cellular devices, the manufacturing test process for CA-enabled UEs requires two stages: calibration and verification. Different test strategies are possible, as explained below.

Calibrating an intra-band CA device is similar to calibrating any LTE device at a given frequency. However, more steps may be required to cover the effects of supporting the aggregated bandwidth—for example, it may be necessary to verify a power amplifier back-off when the device is transmitting multiple CCs. To verify the intra-band CA device, some manufacturers may use multiple carriers for testing, while others will simply test using a single carrier and then perform audit checks on a sample basis using multiple carriers.

In the case of inter-band CA, every transmit and receive path must be calibrated individually. A dual-band device therefore requires two complete calibrations. This effectively doubles the required calibration time and is a potential cost issue for manufacturing. After calibration, each transmit and receive path also needs to be verified for proper operation. Depending on the capabilities of the chipset employed and the test philosophy of the manufacturer, either serial or parallel test techniques may be used for inter-band CA verification testing.

In recent years cellular device manufacturing has moved to sequence-based, non-signaling test for both calibration and verification (Figure 4). Using sequenced techniques has dramatically reduced test times in calibration. Sequenced verification tests are reducing both test times and the requirement for expensive, over-the-air signaling test equipment.

These gains are not automatic, however, as chipset providers have to build support into their chipsets for sequenced, non-signaling test and provide the drivers or complete software needed to implement these capabilities. Test equipment must be capable of advanced sequencing and single-acquisition measurements, and it must support the necessary cellular formats and features—in this case LTE-Advanced carrier aggregation.

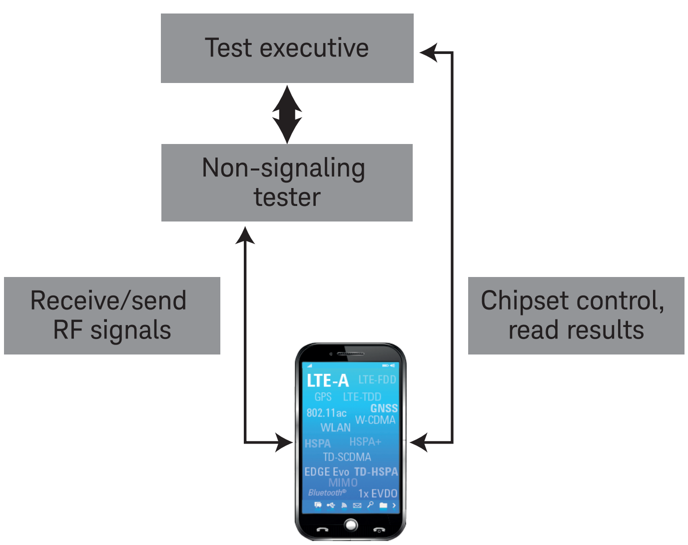

Figure 4. Setup for a non-signaling test is shown.

Test Requirements

Taking into account the capabilities in the target chipset and the capabilities of the test equipment, manufacturers of LTE-Advanced CA devices must choose an appropriate strategy for testing carrier aggregation. Tests may be performed sequentially or in parallel.

Sequential CA testing requires no special test modes in the device chipset other than the ability to switch between the various component carriers, receivers, or transceivers (intra-band, inter-band, and uplink/downlink or both). With sequential test, the paths are tested one at a time employing the same method used to test a standard LTE device. Parallel CA test requires that both the target device and test equipment support configuration and testing of multiple component carriers, receivers, or transceivers at the same time. Clearly parallel test can yield significant time savings but comes with greatly increased complexity and cost.

For intra-band carrier aggregation, the component carriers can be tested either sequentially or in parallel. If the target chipset supports downlink intra-band CA only, then a vector signal generator (VSG) is sufficient for testing. For sequential testing of intra-band CA, the target chipset must be able to turn on the component carriers one at a time. The test setup requires a VSG and vector signal analyzer (VSA) capable of handling a single LTE carrier with the target bandwidth. The VSG and VSA are switched sequentially to test each CC.

Parallel testing of intra-band CA is faster but requires more support in the chipset test mode and more capable test equipment. The target chipset must be able to activate all receivers or transceivers simultaneously. The test equipment must have a VSG with modulation bandwidth wide enough to handle all the component carriers. It must also have a VSA with enough bandwidth to capture all the CCs and with the ability to demodulate and analyze each of the captured CCs.

For inter-band CA testing, the sequential technique offers many benefits. First, it is relatively simple to implement since the test mode in the target chipset has only to support testing on one transceiver path at a time (Figure 5). A single command in the chipset can be used to select the active transceiver path. Thus the same test plan developed for existing LTE devices can be reused with only the addition of the new command. The test sequence is then replicated for each transceiver path. Sequential testing in this case does not require highly complex and expensive test equipment. However, the test time increases 100% for each additional transceiver path to be tested. In the case of downlink-only CA, it is likely that the device supports a second receiver for diversity or MIMO capability. The secondary receiver path may already have been verified and so will require little additional CA testing.

Test Requirements (continued)

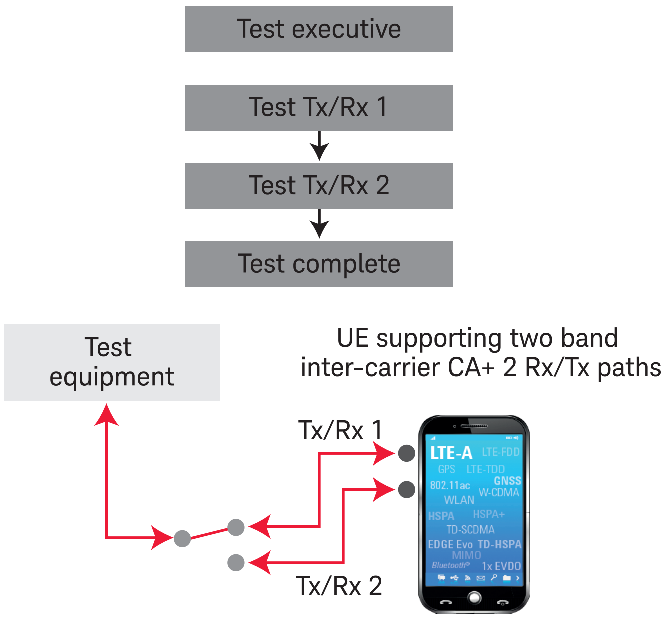

Figure 5. The sequential technique is relatively simple to implement for inter-band CA testing since the test mode in the target chipset has only to support testing on one transceiver path at a time.

Test times can be greatly affected by the measurement technique used to verify the receiver path. Today, most chipsets use some form of a single-ended bit error ratio (BER) test in which the test equipment transmits a known data pattern on the downlink and the target device then determines its receive path error rate. These tests require the capture of a relatively large number of data packets to assure reliable measurement results.

The single-ended BER measurement can dominate the overall verification test time of the device. For a device that supports intra-band CA, using this measurement technique can double the test time for each additional receiver path tested. The market trend, however, is to implement much faster measurement techniques for receiver performance evaluation. Typically some sort of signal-to-noise ratio measurement is performed by the target device (chipset) on a carrier wave (CW) signal applied to the downlink. Because these measurements can be made very quickly, they eliminate the long receiver test times and make the sequential test approach more competitive.

The parallel method of inter-band CA testing is much more complex. The test mode in the target chipset must be able to activate all the transceiver paths in the device at the same time (Figure 6). The test equipment must be duplicated for each transceiver path being tested in parallel, which makes this approach more complex and expensive. The benefit of parallel testing, however, is that the time required to test multiple transceivers in an inter-band CA device is the same as for a single transceiver device. Since the number of new radio systems in chipsets continues to increase, the pressure to reduce test time may trigger a move to the parallel technique.

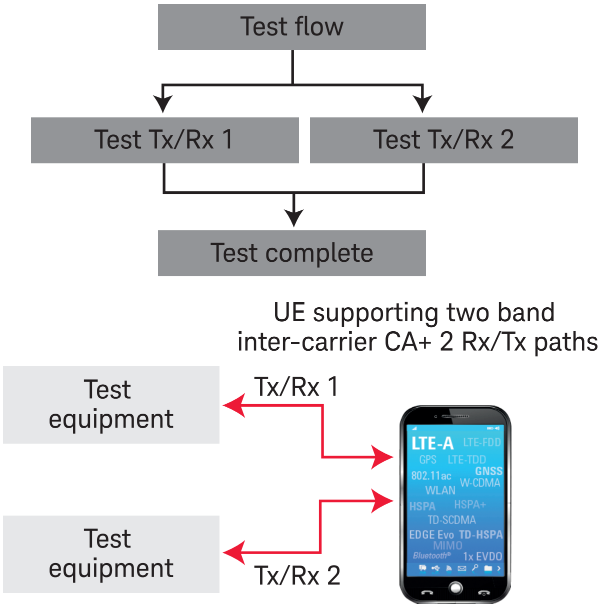

Figure 6. The parallel method of inter-band CA testing is more complex but can reduce test times significantly. because multiple devices can be tested in the same amount of time that it takes to test a single device.

Solution

The Keysight Technologies, Inc. E6640A EXM Wireless Test Set is designed for high throughput device calibration and non-signaling-based verification testing of LTE-Advanced and other cellular and wireless LAN devices. The EXM supports the requirements of carrier aggregation testing by integrating up to four complete test sets in a single, compact chassis (Figure 7). Each test set (called a TRX) contains a complete VSG, VSA, and RF input/output (RFIO) with frequency coverage up to 6 GHz and bandwidths up to 160 MHz.

The EXM test set is compatible with the Keysight EXT manufacturing test set, using the same command structure and building on the EXT's wide range of supported measurements. Additionally, the EXM offers faster measurements, increased ARB and analyzer capture memory, more sequencing steps, and enhanced sequencing capabilities. A high performance quad-core controller enables full performance, even when the EXM is equipped with the maximum four TRXs.

Each TRX in the EXM has its own 4-port RFIO section that makes it easier to test CA-enabled LTE-Advanced devices (Figure 8). Two full-duplex RFIO ports connect directly to full-duplex devices and support simultaneous downlink and uplink testing. Two user-configurable half-duplex ports can be set to either input or output functions. The internal VSG and VSA can be switched to any of these four ports, which allows multiple devices with multiple antenna ports to be connected without external switching. Rugged type-N connectors are used for all RF connections and BNC connectors for trigger connections, making the EXM test set ready to handle the rigors of manufacturing.

Figure 7. The EXM supports the requirements of LTE-Advanced carrier aggregation testing with up to four complete test sets in a single, compact chassis.

Figure 8. Each TRX in the EXM has its own 4-port RFIO section including two full-duplex ports and two user-configurable half-duplex ports.

How To Test Intra-Band CA

For downlink intra-band carrier aggregation testing, the EXM supports a VSG arbitrary waveform bandwidth of 160 MHz. The Keysight N7625B Signal Studio software can be used to create LTE-Advanced waveforms with up to five component carriers. Since only bands above 3400 MHz have bandwidths greater than 160 MHz, the EXM can cover nearly all LTE carrier aggregation bands completely with a single arbitrary waveform. With its 160 MHz bandwidth, the EXM supports contiguous and non-contiguous intra-band CA for up to five 20 MHz carriers.

For uplink intra-band CA testing the EXM also supports an RF analysis bandwidth of up to 160 MHz (Figure 9). An EXM test set equipped with a single TRX can be connected to two LTE-Advanced devices that support either downlink-only or downlink and uplink intra-band CA at the same time (Figure 10). RFIO 1 is connected to one device's main LTE antenna port and RF3 I/O is connected to the device's GPS input antenna port. RFIO 2 is connected to the second device's main LTE antenna port and RF4 I/O is connected to the GPS input antenna port.

This configuration allows sequential pingpong testing of the two devices including the alternate receive-only paths, which are the GPS receiver paths in this example.

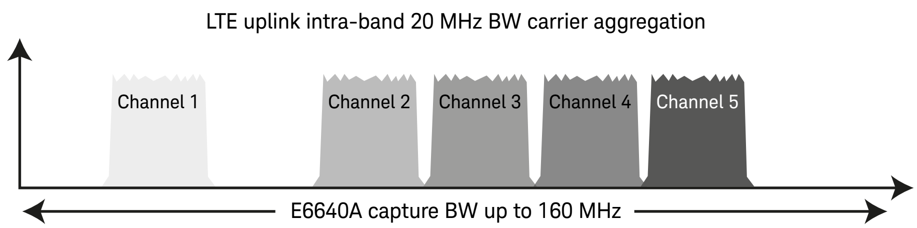

Figure 9. The EXM supports up to five contiguous and non-contiguous LTE carriers for CA testing.

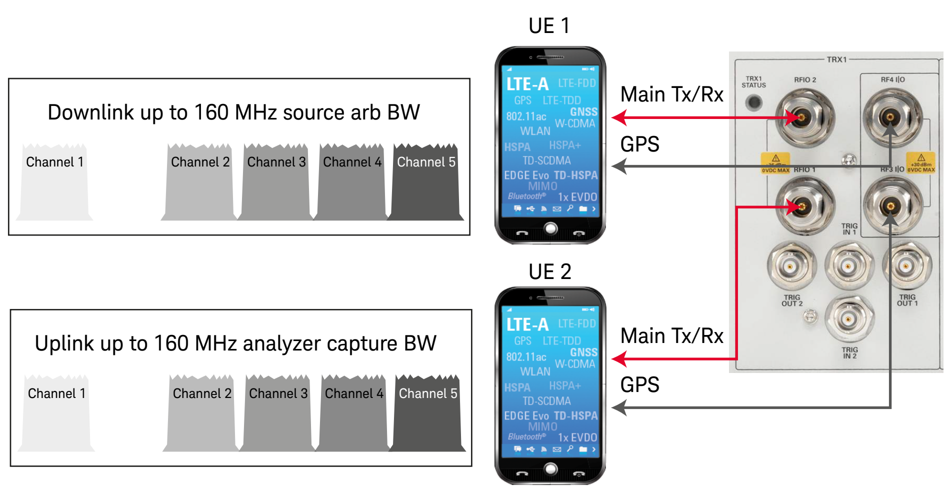

Figure 10. Each TRX in the EXM has its own 4-port RFIO section including two full-duplex ports and two user-configurable half-duplex ports.

How To Test Intra-Band CA

For this test configuration the VSG creates the intra-band downlink signal that is applied to each device's main LTE input while the VSA captures the uplink intra-band CA signal transmitted from the device (if the device supports uplink intra-band CA). The VSG also creates a GPS waveform for testing the device's GPS path. While one device is being tested, the second device is being connected to the TRX. Switching in the TRX's RFIO controls the sequential testing of the first device's main LTE antenna path and GPS receiver path and the transition to the second device. This setup allow the connection time of the second device to be hidden during the test time of the first device once the production flow starts.

By replicating the test configuration shown in Figure 10, an EXM equipped with a full complement of four TRXs can connect eight LTE-Advanced devices supporting intra-band downlink and uplink CA simultaneously and test four of them in parallel using a sequential test methodology (Figure 11).

In this test configuration, the RFIO capabilities of each TRX are used to test a receive-only path in one device—here, the GPS receiver path—in addition to the main LTE antenna port. As that device is being tested, a second device is connected to the TRX. All four TRXs are executing this test procedure in parallel.

Once again, the switching in each TRX's RFIO allows sequential testing of the main LTE antenna path and the GPS receiver path for one device and then allows switching to a second device. Thus the connection time of each device is hidden during the test time of the previous device once the production flow starts. A very high density of test is achieved with this configuration enabling high throughput in minimal space.

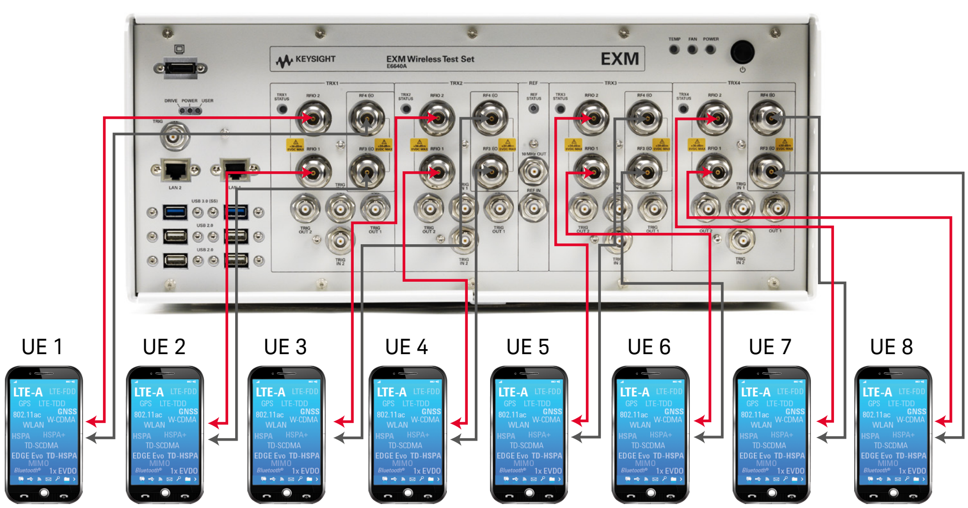

Figure 11. An EXM equipped with four TRXs can connect eight LTE-Advanced devices and test the downlink/uplink CA capability in four of them in parallel using sequential test methodology.

How To Test Intra-Band CA

Using a single TRX, two devices supporting downlink-only inter-band carrier aggregation can be tested sequentially (Figure 12). The internal RFIO switching capabilities of the EXM reduce the complexity of the external fixture for this scenario. This setup enables ping-pong testing so that the load time of the second device is hidden during the test time of the first.

During the test procedure (Figure 12), the first device is tested on both the downlink and the uplink using RFIO 2. The VSG output is then switched to the second band and channel, and routed to the device's second receive path using the RF4 I/O port. During this time, a second device is being connected to the TRX's RFIO 1 and RF3 I/O ports, thus hiding the load time within the first device's test time. Once the test is completed on the first device, the VSG (changed back to the first band and channel) and the VSA are switched to RFIO 1. The VSG output is then switched to the second band and channel and routed to the device's second receive path using the RF3 I/O port. Another device can be connected during the second device's test time and the pattern repeated.

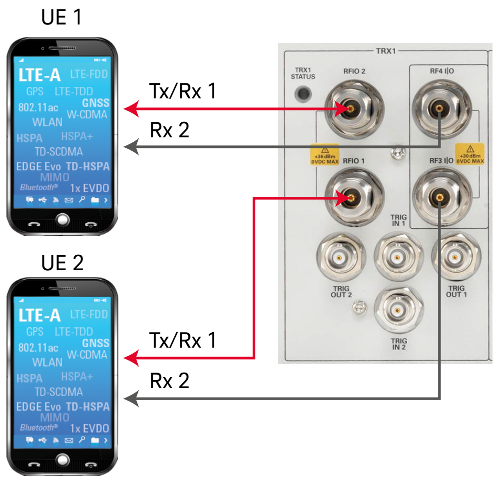

Figure 12. For inter-band CA testing, a single TRX can connect to two devices and test them sequentially, thereby reducing the complexity of external fixturing required for the test.

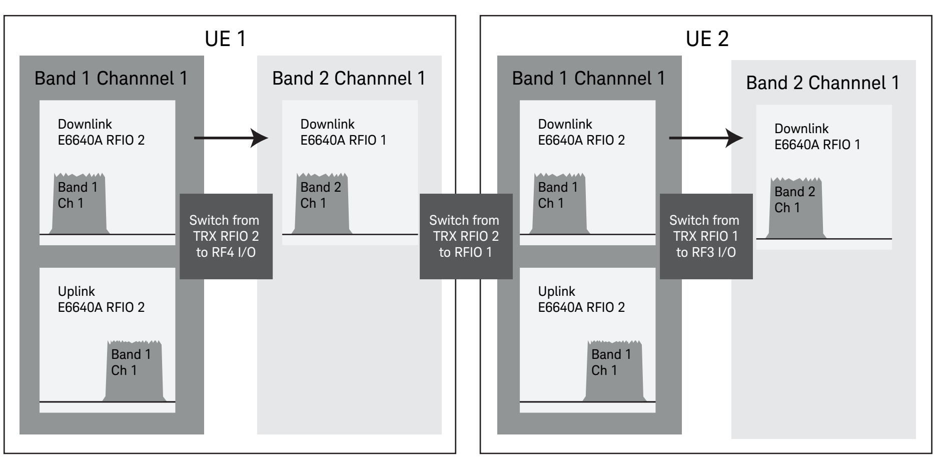

Figure 13. This setup allows ping-pong testing of inter-band carrier aggregation.

How To Test Intra-Band CA

If a single device supports both downlink and uplink inter-band carrier aggregation, then it can be sequentially tested with a single TRX using the RFIO 1 and RFIO 2 ports (Figure 14). The first band and channel are tested on RFIO 2 and then the VSG and VSA are switched to RFIO 1 to test the second band and channel. If the device supports any receive-only paths, then the RF3 I/O and RF4 I/O ports on the test set can be used to send the VSG to these antenna ports on the device. In this example, the RF3 I/O port is routed to the GPS antenna port of the device.

Parallel testing of LTE-Advanced devices that support inter-band carrier aggregation is possible with the EXM. Using two TRXs, both the downlink and uplink for two bands in a single device can be tested in parallel (Figure 15). The VSG and VSA of each TRX are used to create two downlink signals and to analyze both uplink transmitters in the device. In this example UE 1 is connected to the RFIO 2 ports from two TRXs with each testing the downlink and uplink in one frequency band at the same time.

Switching from RFIO 2 to the RFIO 1 ports in both TRXs allows the same test to be performed on the second device, UE 2. This ping-pong configuration allows the load time of the second device to be hidden during the test time of the first device. A receive-only path such as the GPS receiver shown here can also be connected using the half duplex ports. Two such receive-only paths can be connected and tested using a sequential switching plan for the VSG.

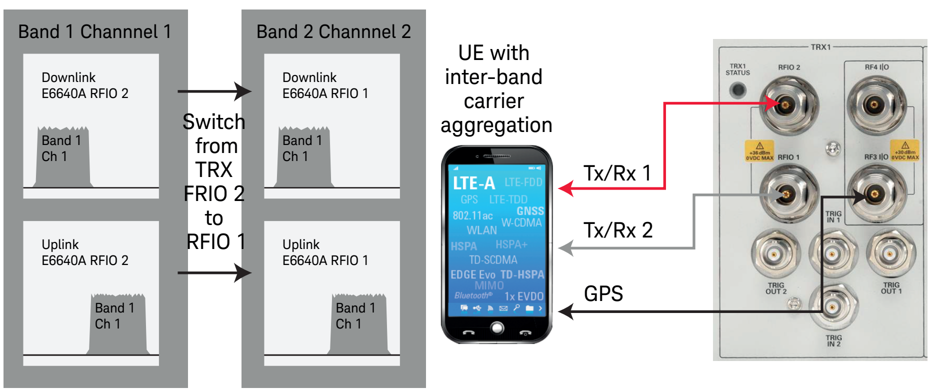

Figure 14. A single TRX can sequentially test a device that supports both downlink and uplink inter-band carrier aggregation.

How To Test Intra-Band CA

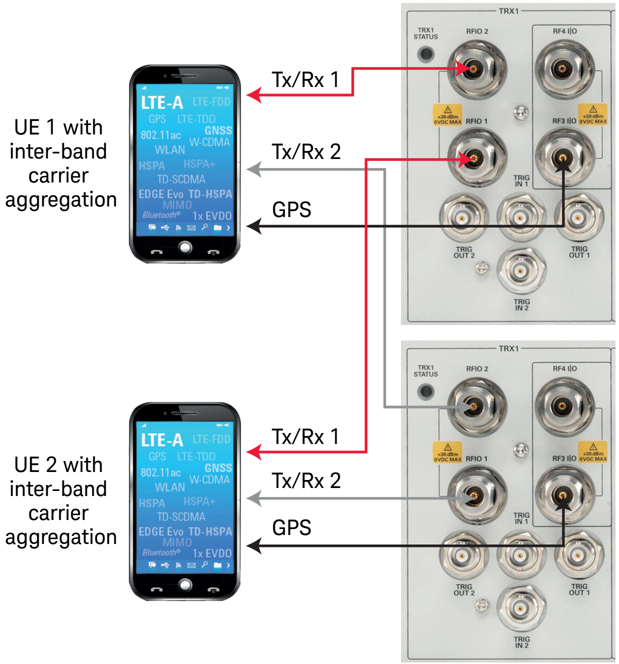

Figure 15. Using two TRXs and parallel testing, the EXM can quickly test both the downlink and the uplink for two bands in a single device.

During parallel testing of devices supporting downlink inter-band CA, the downlink signals from the TRX may need to be tightly synchronized. This requirement comes from the Release 10 standard, which specifies a single uplink timing advance value for all component carriers. This means that the base station transceivers for different carriers should be at the same location to avoid different propagation delays. The effect of this requirement from the physical layout of the network is that test equipment generating the required downlink signals must be synchronized.

The EXM supports tight synchronization between two TRXs. All synchronization occurs internally so no external connections are required. Typical performance is around 30 ns accuracy between downlink signals, which is more than sufficient for to meet the syn-chronization requirement.

A fully configured EXM with four TRXs installed can parallel-test two devices supporting dual inter-band carrier aggregation, and the EXM can connect two more such devices during test (Figure 16). Using the same configuration that was shown in Figure 15, one device is tested on two channels in two different bands through two transceivers using two TRXs. Another device can be connected during testing.

With four TRXs, two devices can be tested in parallel while each is parallel-tested in both supported bands for carrier aggregation. As before, the RFIOs in the TRXs also allow connection of up to two more receive-only paths for each device. In this example, one of the RF I/O ports is being used to test the GPS receive path in each device.

How To Test Intra-Band CA

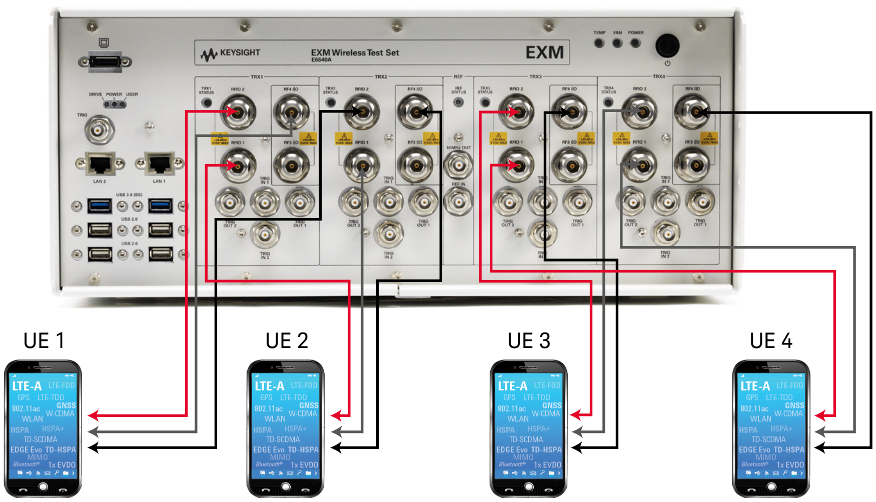

Figure 16. A fully configured EXM with four TRXs can test two inter-band CA devices in parallel while connecting to two additional devices.

Summary

The limited amount of spectrum available worldwide is leading most LTE-Advanced operators to implement inter-band carrier aggregation even though this feature increases the cost of the UE and reduces battery life. Many LTE-TDD operators have wider blocks of spectrum and may choose to implement wider (up to 20 MHz) bands of intra-band CA. In the near term, most implementations will be downlink-only as this limits the complexity of implementation and matches customer usage patterns for packet data.

Although carrier aggregation enables operators to combine available blocks of spectrum to achieve the throughput and efficiency benefits of LTE-Advanced, carrier aggregation adds to the calibration and verification effort required in the UE production process. Manufacturers will most likely adopt sequential methods of carrier aggregation testing at first since this approach reduces both the complexity of the test mode in the target device and the capability required of the test equipment. Moreover, the industry move towards faster receiver test metrics will reduce the receiver test time, helping to mitigate the additional testing required for downlink carrier aggregation support. With the inevitable increase in the complexity of cellular devices, pressure to reduce test time will continue to mount. This pressure could drive the market to implement faster but more complicated parallel testing.

To meet these new test challenges in an efficient and cost-effective manner, the Keysight E6640A EXM Wireless Test Set supports both sequential and parallel carrier aggregation test processes without the need for additional test equipment. The EXM can provide high density test capability by offering up to four complete test sets in a single package. Each test set includes a flexible four-port RFIO section that reduces complex and expensive external switching.

With four test sets in a single compact package, the EXM helps manufacturers reduce capital costs by offering a smaller test footprint and shared use of a single internal controller, timing reference, and internal power supply. Additionally, the EXM delivers the highest levels of throughput based on industry-standard measurement science developed for Keysight X-series analyzers and wireless test sets.

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