Keysight Technologies
Understanding LTE-Advanced Base Station Transmitter RF Conformance Testing

Application Note
Introduction

LTE-Advanced is an evolutionary step forward in the continuing development of LTE. Specified as part of the 3GPP Release 10 standard, it was designed to deliver higher capacity with an increased peak data rate of 1 Gbps for the downlink and 500 Mbps for the uplink, higher spectral efficiency, an increased number of simultaneously active subscribers, and improved performance at cell edges. To achieve these capabilities, LTE-Advanced relies on a number of technologies, such as carrier aggregation (CA) and higher-order MIMO, that introduce unique challenges in the design and test of evolved Node B (eNB) or base station and user equipment (UE) devices.

This application note focuses on one of the challenges: characterizing LTE-Advanced base station transmitters using the 3GPP RF conformance tests, which have been updated with additional requirements to address CA. It examines the new and modified requirements in 3GPP Release 10 and beyond, pertaining to CA, and proposes solutions to address these measurement requirements, from early R&D through to design validation and manufacturing.

Eying LTE-Advanced: 3GPP Release 10 and Beyond

First introduced in 3GPP Release 10, LTE-Advanced builds on top of LTE parameters and even maintains some of its basic structures. However, it also incorporates new features consisting of enhancements to LTE Release 8/9, as well as newer emerging technologies and features captured in LTE Release 10 and beyond. Three of the key LTE-Advanced technologies that were enhancements to LTE Release 8/9, include:

- Carrier aggregation (CA), which enables a transmission bandwidth extension to support deployment bandwidths of up to 100 MHz.
- Enhanced multiple antenna transmission with support for 8 spatial streams and antennas in the downlink (8x8 MIMO) and up to 4 spatial streams and antennas in the uplink (4x4 MIMO). By comparison, 3GPP Release 8 supported only 4 spatial streams in the downlink and contained no support for single-user MIMO.
- Enhanced uplink multiple access where clustering of user data and simultaneous control and data transmission is supported.

In addition to these enhancements, newer technologies in 3GPP Release 10 and beyond include coordinated multipoint transmission and reception (CoMP), relaying or multi-hop transmission, LTE self-optimizing networks (SON), and support for heterogeneous networks. Heterogeneous networks—network topologies that utilize a mix of macro, pico, femto and relay base stations—are designed to enable flexible, low-cost deployments, and provide a uniform broadband experience to users anywhere in the networks using a combination of the new 256-QAM modulation scheme and CA.
Carrier Aggregation: A Deeper Dive

CA is not only one of the most important features in LTE-Advanced, it is also one of its earliest deployed technologies. CA is the mechanism by which LTE-Advanced is able to achieve the wider transmission bandwidths needed to meet higher data rates. Using CA, in addition to MIMO technology, LTE-Advanced can deliver the peak data rates specified in the 4G standard—1 Gbps in the downlink and 500 Mbps in the uplink.

CA works by aggregating two or more (up to 5) LTE component carriers (CCs), each of which can have a maximum bandwidth of 20 MHz and maintains backwards compatibility with LTE Release 8/9. The CCs can be aggregated in both contiguous and non-contiguous configurations according to the following three scenarios (Figure 1):

- Single band or intra-band contiguous CA with up to five 20 MHz CCs. While not a likely scenario, given today’s frequency allocations, it is the least challenging of the three configurations in terms of hardware implementation.
- Single band or intra-band non-contiguous CA, which involves the non-contiguous allocation of CCs in the same frequency band. In this scenario, the middle carriers are loaded with other users or network sharing is considered.
- Multi-band or inter-band non-contiguous CA, which involves the non-contiguous allocation of CCs in different frequency bands. While it is considered the most realistic scenario of all three configurations—especially when utilized for a Frequency Division Duplex (FDD) topology—it does have a number of drawbacks. For example, its use increases the complexity of the RF front-end in UE. Additionally, the antenna size, power amplifier, and filters, among other things, might not be compatible between the different radio bands. With intra-band non-contiguous CA, RF requirements apply per band.

Figure 1. CA aggregates up to 5 LTE CCs using one of the three scenarios detailed in this image.
Challenges Ahead: Updated RF Requirements

When LTE-Advanced was initially introduced, the RF requirements for CA were only defined for three sets of frequency bands: two for the intra-band contiguous scenario and one for the inter-band scenario. 3GPP Release 11 extended the number of bands to 5 intra-band contiguous and 21 inter-band non-contiguous. It also added RF requirements to the intra-band non-contiguous scenario with 2 bands. 3GPP Release 12 added even more complexity through the introduction of new bands: 12 intra-band contiguous, 8 intra-band non-contiguous and 57 inter-band non-contiguous. And, whereas RF requirements in 3GPP Release 10 and 11 were limited to two CCs, 3GPP Release 12 adds 3 CC RF requirements, as well as aggregation of FDD and TDD bands.

Another challenge stems from the new cumulative ACLR (CACLR) and SEM (C-SEM) requirements for intra-band non-contiguous allocations. In the intra-band non-contiguous case, the base station transmits and receives over an RF bandwidth that is split in two (or more) separate sub-blocks with a sub-block gap in between. A sub-block is defined as one contiguous allocated block of spectrum for transmission and reception by the same base station. The new CACLR and C-SEM requirements target the gap between aggregated sub-blocks and are defined in 3GPP Release 11.

Addressing these new challenges, as well as those inherited from previous versions of the LTE standard, remain critical to the successful development and deployment of LTE-Advanced devices.
RF Transmitter Measurements for LTE-Advanced Base Stations

The 3GPP TS 36.141 standard has one key goal—to determine the performance of the base station or evolved Node B (eNB) physical layer’s receiver (Rx) and transmitter (Tx). The tests specified in Section 6 of the standard measure the characteristics of the transmitter. Table 1 provides a detailed list of the measurements required for eNB transmitter RF conformance test. Also specified in the table are the Evolved Universal Terrestrial Radio Access (E-UTRA) test models (E-TM) used for each measurement. These models specify how the physical channels must be set up to perform the various transmitter tests.

Table 1. This table lists the various transmitter tests and corresponding E-TMs used for each test, along with a reference to the measurements performed in Keysight’s X-Series signal analyzers. Keysight’s X-Series measurement application, which runs on the signal analyzers, can be used to perform all of the transmitter tests under CA configuration.

<table>
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<th>TS 36.141 paragraph #</th>
<th>Transmitter characteristics</th>
<th>E-TM used</th>
<th>Measurements on LTE-Advanced app. (N9080B/82B)</th>
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<td>6.2</td>
<td>Base station output power</td>
<td>E-TM 1.1</td>
<td>Channel power</td>
</tr>
<tr>
<td>6.3</td>
<td>Output power dynamics</td>
<td>E-TM 2; 3.1; 3.2; 3.3</td>
<td>Modulation analysis</td>
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<tr>
<td>6.4</td>
<td>Transmit On/Off power (TDD only)</td>
<td>E-TM 1.1</td>
<td>TDD only</td>
</tr>
<tr>
<td>6.4.1</td>
<td>Transmitter Off power</td>
<td>E-TM 1.1</td>
<td>Tx On/Off power</td>
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<td>6.5</td>
<td>Transmitted signal quality</td>
<td>E-TM 2; 2a; 3.1; 3.1a; 3.2; 3.3</td>
<td>Modulation analysis</td>
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<tr>
<td>6.5.1</td>
<td>Frequency error</td>
<td>E-TM 2; 2a; 3.1; 3.1a; 3.2; 3.3</td>
<td>Modulation analysis</td>
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<tr>
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<td>Error vector magnitude (EVM)</td>
<td>E-TM 1.1</td>
<td>Modulation analysis</td>
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<td>Time alignment error (TAE)</td>
<td>E-TM 1.1</td>
<td>Modulation analysis</td>
</tr>
<tr>
<td>6.5.4</td>
<td>DL RS power</td>
<td>E-TM 1.1</td>
<td>Modulation analysis</td>
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<td>6.6</td>
<td>Unwanted emissions</td>
<td>E-TM 1.1</td>
<td>Occupied BW</td>
</tr>
<tr>
<td>6.6.1</td>
<td>Occupied bandwidth</td>
<td>E-TM 1.1</td>
<td>ACP</td>
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<td>Adjacent channel leakage power (ACLR)</td>
<td>E-TM 1.1; 1.2</td>
<td>ACP</td>
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<td>E-TM 1.1; 1.2</td>
<td>ACP</td>
</tr>
<tr>
<td>6.6.3</td>
<td>Operating band unwanted emissions (SEM)</td>
<td>E-TM 1.1; 1.2</td>
<td>SEM</td>
</tr>
<tr>
<td>6.6.3</td>
<td>Cumulative mask for SEM - new in Rel 11</td>
<td>E-TM 1.1; 1.2</td>
<td>SEM</td>
</tr>
<tr>
<td>6.6.4</td>
<td>Transmitter spurious emissions</td>
<td>E-TM 1.1</td>
<td>Spurious emissions</td>
</tr>
<tr>
<td>6.7</td>
<td>Transmitter intermodulation</td>
<td>E-TM 1.1</td>
<td>ACP, SEM, spurious</td>
</tr>
</tbody>
</table>

- New test requirements introduced for carrier aggregation
- These tests are performed under carrier aggregation/multi-carrier operation
- These tests remain to be performed under single carrier configuration - can also be performed in CA/MC

While the transmitter tests for LTE-Advanced are essentially the same as those for LTE, a few new tests have been introduced because of CA and to take into consideration other factors like unwanted emissions and modifications to support wider transmission bandwidth that results with CA. All new CA-related tests are highlighted in orange in Table 1. Tests highlighted in black are existing LTE tests performed under CA/multi-carrier active conditions. Existing LTE tests for EVM and frequency error still apply per CC. Other tests, such as for unwanted emissions, are adjusted to fit the wider aggregated channel bandwidth of LTE-Advanced.

Tests highlighted in purple are not required to be performed under CA/multi-carrier active conditions. These tests remain the same as those specified in LTE Release B/9, although some base station manufacturers may want to test under CA conditions just to ensure a more realistic scenario and to provide test efficiency by eliminating test repetition for each individual carrier. In this application note, we discuss only those tests which have been affected as a result of CA and higher order modulation.
Transmitter Test Categories

In general, LTE-Advanced eNB transmitter tests are classified in three categories: power, signal quality and out-of-channel measurements. Power measurements include channel power and occupied bandwidth. With the channel power measurement, the purpose is to verify the accuracy of the maximum output power, across the frequency range, under normal and extreme conditions, for all transmitters in the base station. Extreme conditions are defined as special states in terms of the temperature, vibration, power supply, etc. Base station transmitter output power must be set accurately to avoid interference experienced by neighboring cells using the same channel, as well as from unwanted emissions outside of the transmission band.

With signal quality tests, also known as demodulation measurements, the purpose is to verify that the quality of the transmitted signal fulfills certain requirements. These tests include EVM, frequency error, timing alignment error (TAE), and downlink RS power. Out-of-channel tests include such things as ACPR and SEM.

E-UTRA Test Configurations

The 3GPP standard defines general E-UTRA test configurations (ETCs) for both contiguous and non-contiguous base station spectrum operation. ETCs 1 and 2 are used for contiguous spectrum operation, while ETC 3 is used for the non-contiguous spectrum operation.

Of all the possible RF configurations, involving number of carriers and bandwidths, the manufacturer declares those, that are supported by the eNodeB. The test configurations are constructed, depending upon the parameters declared by the manufacturer for the supported RF configurations. The number of possibilities of carriers and bandwidths is indeed numerous, and this makes the set-up very complicated. In the following example, an ETC1 configuration is created using 5 carriers each of 5 MHz bandwidth.

Example:
Maximum supported RF BW in the BS = 25 MHz,
Narrowest supported LTE carrier by BS = 5 MHz

![Diagram](image)

Figure 2: In this example, ETC1 is used to test a base station that supports contiguous CA. The RF bandwidth supported by the base station is 25 MHz (max) and the narrowest LTE carrier supported is 5 MHz.

Nominal channel spacing for CA =

\[
\left[ \frac{BW_{channel(1)} + BW_{channel(2)} - 0.1BW_{channel(1)} - BW_{channel(2)}}{0.6} \right]^{0.3}
\]
New Carrier Aggregation Measurements

The 3GPP TS 36.141 standard specifies three new eNB transmitter tests, which are now required because of CA. These tests include: time alignment error (TAE), CACLR and C-SEM.

TAE test

TAE is a signal quality test added in 3GPP Release 10. It was originally specified in Release 8/9 of the standard; however, it focused only on MIMO and transmit diversity. TAE measures the largest timing difference (error) between any two signals, and is only applicable for base stations transmitting from multiple antennas via transmit diversity, MIMO, CA, or some combinations of these three. During real-world operation, frames of the LTE/LTE-Advanced signals present at the base station transmitter antenna ports are not perfectly aligned in time. In order for the user equipment (UE) to properly receive the transmitted signals from the multiple antennas, they must arrive at the UE at the same time, or timing offset must be kept at a minimum (Table 2).

<table>
<thead>
<tr>
<th>Transmission type</th>
<th>Maximum allowed error (includes 25 ns TT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIMO or Tx diversity</td>
<td>90 ns</td>
</tr>
<tr>
<td>Intra-band contiguous CA</td>
<td>155 ns</td>
</tr>
<tr>
<td>Intra-band non-contiguous CA</td>
<td>285 ns</td>
</tr>
<tr>
<td>Inter-band CA</td>
<td>285 ns</td>
</tr>
</tbody>
</table>

Note: CA configuration applies to both with or without MIMO/Tx. Diversity

Table 2. The maximum allowed timing error differs depending on transmission type (e.g., MIMO versus CA).
CACLR Test

CACLR is a measure of the amount of interference in an adjacent frequency channel. It measures the power that leaks into nearby radio channels and thus, estimates how much a neighboring radio receiver is affected by out-of-band emissions from the transmitter.

For LTE-Advanced with contiguous CCs, the ACLR configuration is similar to that of the multi-carrier ACLR. The ACLR requirement is defined for CCs on the edges of the aggregated channel bandwidth (Figure 3). Note that ACLR requirements assume both E-UTRA (LTE) adjacent carriers and UTRA (W-CDMA) adjacent carriers (Table 3).

Table 3. Just like LTE, LTE-Advanced has ACLR requirements for adjacent LTE channels as well as adjacent UMTS (W-CDMA) channels, and the limits/requirements remain the same as LTE Release 8/9. This relative limit is the same for all base station classes.

<table>
<thead>
<tr>
<th>Offset frequency</th>
<th>Adjacent channel carrier</th>
<th>Filter &amp; filter BW of adjacent channel</th>
<th>ACLR limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWChannel</td>
<td>E-UTRA of same BW</td>
<td>Square (BW&lt;sub&gt;Config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>2 × BWChannel</td>
<td>E-UTRA of same BW</td>
<td>Square (BW&lt;sub&gt;Config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>BWChannel/2 + 2.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RRC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>BWChannel/2 + 2.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RRC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
</tbody>
</table>

Note: BW<sub>Channel</sub> & BW<sub>Config</sub> are channel BW and transmission BW of LTE carrier. Ex. for LTE with 5 MHz channel BW, the transmission BW is 4.5 MHz.

Figure 3. Here, the offset frequency is from the center of the edge carrier to the center of the adjacent carrier.

For LTE-Advanced with non-contiguous CCs in the same frequency band (intra-band non-contiguous allocation), 3GPP Release 11 has added a new requirement similar to that of the multi-standard radio (MSR) specification. When dealing with non-contiguous CA, the spectrum in the sub-block gap can be used by a different operator. Consequently, the RF requirement in the gap is based on co-existence for un-coordinated operation. However, depending on the width of the sub-block gap, the leakage from carriers from both sides of the gap can overlap. The new CACLR requirement accounts for contributions from carriers on both sides of the gap in the limit.
A graphical view of CACLR is shown in Figure 4. Note that within the sub-block gap, it is possible to have both Normal ACLR and CACLR, depending on the width of the gap. With Normal ACLR, only one of the carriers (either left or right CC) contributes to the ACLR limit in the sub-block gap. With CACLR, both carriers contribute to the ACLR limit.

The offsets inside the sub-block gap are called inner offsets. If the sub-block gap is ≥ 20 MHz, all inner offsets are Normal. If the gap is between 15 and 20 MHz, the 1st adjacent is Normal and the 2nd adjacent is cumulative. For gaps less than 15 MHz, either one or both offsets are cumulative. Because the sub-block gap starts from the inner edge of the channel bandwidth and not the center of the channel bandwidth, the sub-block gap width is independent of the CCs’ channel bandwidth.
Images of Normal ACLR and CACLR are shown in Figure 5, respectively. In the case of Normal ACLR, the 3GPP standard specifies two different scenarios. For FDD systems, the standard assumes W-CDMA (UMTS) is transmitted inside the sub-block gap, while for TDD systems, the standard assumes a 5-MHz LTE-TDD carrier is transmitted. When measuring inner offsets, the right filter type (e.g., a 3.84 Mcps RRC filter for FDD or a square filter for TDD) must be used.

Inner offsets are defined from the edge of the gap to the center of the adjacent channel. Since both FDD and TDD assume a 5-MHz carrier transmitted inside sub-block gap (5 MHz W-CDMA for FDD and 5 MHz LTE for TDD), the inner offsets will always be 2.5 MHz and 7.5 MHz for the 1st and 2nd adjacent offsets.

In the case of CACLR, if the sub-block gap is between 5 MHz and 20 MHz, either one or both inner offsets will overlap and carriers on both sides of the gap will contribute to the ACLR limit. The 3GPP standard defines the CACLR requirement for this specific case.

Table 4. Shown here are the 3GPP limits for the inner offsets for FDD and TDD base station ACLR (non-contiguous).

**FDD base station ACLR non-contiguous inner offset**

<table>
<thead>
<tr>
<th>Sub-block gap size (Wgap)</th>
<th>Offset frequency (sub-block edge to inner offset center)</th>
<th>Adjacent channel carrier</th>
<th>Filter &amp; filter BW of adjacent channel</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal ACLR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wgap ≥ 15 MHz</td>
<td>2.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RCC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>Wgap ≥ 20 MHz</td>
<td>7.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RCC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>CACLR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 MHz ≤ Wgap &lt; 15 MHz</td>
<td>2.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RCC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>10 MHz ≤ Wgap &lt; 20 MHz</td>
<td>7.5 MHz</td>
<td>3.84 Mcps UTRA</td>
<td>RCC (3.84 Mcps)</td>
<td>44.2 dB</td>
</tr>
</tbody>
</table>

**TDD base station ACLR non-contiguous inner offset**

<table>
<thead>
<tr>
<th>Sub-block gap size (Wgap)</th>
<th>Offset frequency (sub-block edge to inner offset center)</th>
<th>Adjacent channel carrier</th>
<th>Filter &amp; filter BW of adjacent channel</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal ACLR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wgap ≥ 15 MHz</td>
<td>2.5 MHz</td>
<td>5 MHz E-UTRA</td>
<td>Square (BW&lt;sub&gt;config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>Wgap ≥ 20 MHz</td>
<td>7.5 MHz</td>
<td>5 MHz E-UTRA</td>
<td>Square (BW&lt;sub&gt;config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>CACLR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 MHz ≤ Wgap &lt; 15 MHz</td>
<td>2.5 MHz</td>
<td>5 MHz E-UTRA</td>
<td>Square (BW&lt;sub&gt;config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
<tr>
<td>10 MHz ≤ Wgap &lt; 20 MHz</td>
<td>7.5 MHz</td>
<td>5 MHz E-UTRA</td>
<td>Square (BW&lt;sub&gt;config&lt;/sub&gt;)</td>
<td>44.2 dB</td>
</tr>
</tbody>
</table>
Table 4 shows the 3GPP limits for the inner offsets for FDD and TDD base stations, respectively. For the FDD base station, the standard assumes a 5 MHz W-CDMA signal is transmitted inside the gap. The relative limits for the inner offsets are the same as those of the outer offsets, 44.2 dB. For the TDD base station, it is assumed that a 5 MHz LTE-TDD carrier is transmitted inside the gap. As a result, the inner adjacent channel carrier and filter and filter bandwidth parameters change. However, the relative limits for TDD (44.2 dB) are the same as those for FDD.

With regard to the 3GPP limits, there are a few important things to note. First, the ACLR and CACLR relative limits (44.2 dB) are the same for all base station classes—from macro to femto cells. However, the absolute limits are different for the different base station classes. These limits are as follows:

- Wide area Cat A base station: −13 dBm/MHz
- Wide area Cat B base station: −15 dBm/MHz
- Medium range base station: −25 dBm/MHz
- Local area base station: −32 dBm/MHz
- Home base station: −50 dBm/MHz (There is no CACLR limit defined for home base stations)

These limits differ because of the different minimum coupling loss (i.e., the minimum separation distance between the base station and UE) between the base station and UE.

Simple, Cost-Effective Solutions for CA Measurements

Addressing the new requirements for CA in both contiguous and non-contiguous modes, demands a simple, cost-effective approach to performing eNB transmitter RF conformance tests. The Keysight LTE-Advanced measurement application—an add-on to the Keysight LTE measurement application—provides just such a solution.

Keysight’s LTE-Advanced measurement application runs on both benchtop instruments and modular products. As an example, Keysight’s benchtop X-Series signal analyzers can analyze multiple component carriers simultaneously, capabilities critical to testing carrier aggregated signals. When running on one of these analyzers, the LTE-Advanced measurement application transforms into a 3GPP standard-based RF transmitter tester able to perform fast, one-button RF conformance measurements that can help engineers design, evaluate and manufacture LTE-Advanced base station (eNB) transmitters. In addition to 3GPP RF conformance testing of base station transmitters, the measurement application can also be used for uplink RF measurements. Moreover, it can be used to perform all transmitter tests specified in 3GPP TS 36.141 section 6 under CA configuration. Specific RF conformance measurements supported include:

- FDD and TDD uplink and downlink analysis
- Aggregation of up to 5 contiguous/non-contiguous component carriers
- Clustered SC-FDMA and simultaneous PUCCH/PUSCH UL analysis

RF transmitter measurements on eNB and UE devices can be performed in time, frequency, and modulation domains. Measurement setups are simplified with automatic detection of downlink channels and signals. For eNB conformance testing, measurement is simplified by recalling E-TM presets according to the 3GPP TS 36.141 specifications.
Example: Modulation Analysis

There are three approaches to making transmitted signal quality or modulation analysis measurements: sequential carrier frequency switching, multi-measurement sequential acquisition and multi-measurement shared acquisition. All three methods are supported by Keysight's LTE-Advanced measurement application and X-Series analyzers.

Sequential carrier frequency switching is the traditional approach for measuring signal quality when dealing with CA. Here, the center frequency and parameters to each CC are switched and analyzed for each carrier, one at a time (Figure 6). While it can be performed using Keysight's LTE measurement application, the required switching of frequency/parameters increases the overall test time. Also, the result from each of the carriers gets overwritten with subsequent measurements, making it impossible to view the results of multiple CCs on the same display.

Figure 6. With sequential carrier frequency switching, the signal for each CC is configured and acquired, the waveform is captured, EVM results are calculated, and results are displayed.
Multi-measurement sequential acquisition also involves the sequential acquisition of each carrier; however, it uses advanced algorithms to eliminate the frequency/parameter switching and speed up the process (Figure 7). Here, all active carriers are configured and acquisition is done individually with a narrowband hardware front-end that is wide enough to capture the widest component carrier. But, once Carrier 1 is captured and being calculated, the capture of Carrier 2 starts and so on, reducing the total measurement time across all carriers. The results of all measured CCs can then be viewed side-by-side. The X-Series signal analyzers, with 25 MHz of bandwidth, are ideal for this approach.

Figure 7. Shown here is a LTE-Advanced EVM measurement result for 4 CCs. The measurements were performed in one measurement sequence. The measurement results of the multiple CCs can also be viewed side-by-side for ease of comparison.
For transmitter RF conformance testing, measurements are made using test models, which are repetitive waveforms. In addition, the modulation analysis test requirements are defined per carrier. Consequently, it’s not necessary to capture all carriers simultaneously. While an expensive wideband analyzer could be used to capture all carriers at once, a much more cost-effective approach is to utilize either the LTE-Advanced measurement application or 89600 VSA software running on an X-Series signal analyzer. Using these solutions, the results of up to 5 CCs can be displayed side-by-side for ease of comparison (Figure 8).

Figure 8. This measurement example shows the results of 5 CCs displayed side-by-side. Any of the traces can be changed to display any measurement results. All of the advanced demodulation traces available with the LTE measurement application are also available for LTE-Advanced measurement application (e.g., viewing EVM across symbol, subcarrier or even resource block).
With multi-measurement shared acquisition or multi-box sync, all active carriers are simultaneously captured using either a wide bandwidth analyzer or multi-channel/multi-box synchronization. Here, all active carriers are first pre-configured and then acquired as one wideband waveform sample simultaneously. The software algorithm then extracts each carrier and calculates the EVM from the same waveform sample. The X-Series signal analyzers running the LTE-Advanced measurement application can be used to implement this approach. Their main advantage is that they enable the acquisition of truly simultaneous events across carriers in device verification and troubleshooting tasks. A measurement example using these solutions is shown in Figure 9.

Regardless of which approach is utilized for modulation analysis, an appropriate receiver filter is required for each carrier-of-interest. The filter rejects adjacent carrier power interference so that the analyzer can achieve good enough synchronization and the demodulation robustness necessary for each carrier in the multicarrier-active condition. Both Keysight’s LTE-Advanced measurement application and 89600 VSA software provide this multi-carrier filter. The filter is turned on by default in either software when in the LTE-Advanced mode.

Figure 9. In this graphic, 5 CCs have been captured in a single acquisition and displayed in simultaneous measurements, each with user selectable frequency/span setting, meas. and demod. setup and trace types.
Example: CA TAE Measurement

TAE measurement of carriers separated by a wide span or those that are in different frequency bands can be performed using single RF input hardware with a maximum bandwidth of 20 MHz (i.e., the maximum bandwidth of an LTE carrier). With 25 MHz of analysis bandwidth, the X-Series signal analyzers can make this measurement using the sequential acquisition method (Figure 10). Here, the signals are acquired with either an external frame trigger from the device under test or an internal periodic timer trigger provided by the signal analyzer. The LTE-Advanced measurement application then calculates the timing offset between the start of the frame and trigger event signal (external frame trigger or internal periodic timer trigger) for all component carriers sequentially.

TAE measurement can also be performed using wideband hardware or synchronous analyzers, such as Keysight’s 89600 VSA software and multiple X-Series signal analyzers (Figure 10).

Figure 10. Shown here is an example of a TAE measurement performed using Keysight’s LTE-Advanced measurement application. The cross-carrier summary trace under modulation analysis measurement reports TAE including Max and Min values.

A key advantage of using the X-Series signal analyzers for a signal quality measurement like TAE is simplified set up. As previously mentioned, engineers have to set up the analyzer differently for each base station tested, depending on its capability and RF bandwidth. Several LTE-Advanced features require the base station to transmit from multiple antennas (such as MIMO, Tx Diversity and CA). The measurement is essentially a reference signal (pilot) based measurement. Since reference signals are not precoded, they don’t overlap in frequency between the multiple transmit antennas, and they uniquely identify each transmitter. As a result, the output of the two transmitters can be combined using a power combiner and the measurement can be made using just a single input analyzer such as the X-Series signal analyzer.
Example: CACLR Measurement

The LTE-Advanced measurement application can be used to perform ACLR measurements, both Normal ACLR and CACLR (Figure 11). However, accurate ACLR measurement of inner offsets requires that the engineer first specify in the measurement application whether they are Normal or Cumulative based on the sub-block gap of the signal under test.

Multi-touch capability allows you to drag and scale signal by your fingers just like playing on a Pad.

Both Outer (LTE) and Inner (W-CDMA) offsets are reported

Figure 11. Results of normal and cumulative ACLR
Comprehensive LTE/LTE-Advanced RF Test Solutions

In addition to the LTE-Advanced measurement application, X-Series signal analyzers and 89600 VSA software, Keysight provides a comprehensive set of LTE/LTE-Advanced RF test solutions (Figure 12). These software and hardware solutions can be used for signal generation and signal analysis of LTE and LTE-Advanced eNB and UE devices, and support all three CA modes.

Conclusion

LTE-Advanced is the evolved version of LTE developed by 3GPP to meet or exceed the requirements of the International Telecommunication Union (ITU) for a true fourth generation radio-communication standard (IMT-Advanced). While initially specified in Release 10 of the 3GPP standard, subsequent releases continue to add features, such as CA, that introduce unique design and test challenges for engineers designing and developing LTE-Advanced eNB and UE devices. Although the base station transmitter RF tests in more recent 3GPP releases are mostly the same as those specified in the LTE Release 8/9, additional requirements have been added to address CA in contiguous and non-contiguous allocations. Keysight’s LTE-Advanced RF solutions, including the LTE-Advanced measurement application and X-Series signal analyzers, are well suited to address the challenges that arise from CA and other LTE-Advanced features, whether during early research and development or at any time through to manufacturing.
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