Measuring ACLR Performance in LTE Transmitters

Application Note

Agilent Technologies

Introduction

As wireless service providers push for more bandwidth to deliver IP services to more users, LTE has emerged as a next-generation cellular technology with great potential to enhance current deployments of 3GPP networks and to enable significant new service opportunities. However, LTE's complex, evolved architecture introduces new challenges in designing and testing network and user equipment. The commercial success of LTE will depend in part on the ability of all devices to work as specified. One of the particular challenges at the air interface will be power management during signal transmission.

In a digital communication system such as LTE, the power that leaks from a transmitted signal into adjacent channels can interfere with transmissions in the neighboring channels and impair system performance. The adjacent channel leakage-power ratio (ACLR) test verifies that system transmitters are performing within specified limits. This critical yet complex transmitter test can be made quickly and accurately using modern signal analyzers such as the Agilent X-Series (PXA/MXA/EXA) signal analyzers with LTE measurement software and signal generators such as the Agilent MXG signal generator with LTE signal creation software.

Challenges of LTE transmitter design

LTE product development is underway, and RF engineers are tackling the many design and measurement challenges this complex technology presents. LTE requires support for six channel bandwidths (from 1.4 to 20 MHz), different transmission schemes for the downlink and the uplink (OFDMA and SC-FDMA), two transmission modes (FDD and TDD), and multiple antenna techniques (MIMO spatial multiplexing, diversity, beamsteering). As a result of LTE's flexible transmission schemes, the physical channel configuration has a large impact on RF performance—much greater than in current CDMA-based systems. With performance targets set exceptionally high for LTE, engineers have to make careful design tradeoffs to cover each critical part of the radio transmitter chain.

One important aspect of transmitter design is the need to minimize unwanted emissions. Because LTE will be deployed in the same frequency bands as W-CDMA and other legacy cellular technologies, the 3GPP specifications regulate emissions to minimize interference and ensure compatibility between the different radio systems. The primary concern is control of spurious emissions, which can occur at any frequency. In this respect LTE is similar to other radio systems. However, new challenges arise at the band edges, where the transmitted signal must comply with rigorous power leakage requirements. With LTE supporting channel bandwidths up to 20 MHz, and with many bands too narrow to support more than a few channels, a large proportion of the LTE channels will be at the edge of the band.

Controlling transmitter performance at the edge of the band requires a design with filtering to attenuate out-of-band emissions without affecting in-channel performance. Factors such as cost, power efficiencies, physical size, and location in the transmitter block diagram are also important considerations. Ultimately the LTE transmitter must meet all specified limits for unwanted emissions, including limits on the amount of power that leaks into adjacent channels, as defined by ACLR.

ACLR test requirements

ACLR is a key transmitter characteristic included in the LTE RF transmitter conformance tests (Table 1). These tests verify that minimum requirements are being met in the base station (eNB) and user equipment (UE). Most of the LTE conformance tests for out-of-band emissions are similar in scope and purpose to those for W-CDMA and should look familiar. However, while W-CDMA specifies a root-raised cosine (RRC) filter for making transmitter measurements, no equivalent filter is defined for LTE. Thus different filter implementations can be used for LTE transmitter testing to optimize either in-channel performance, resulting in improved error vector magnitude, or out-of-channel performance, resulting in better adjacent channel power characteristics.

Table 1. Conformance tests for RF transmitters (from 3GPP TS 36.141 [1] and 36.521-1 [2])

Base station RF transmitter characteristics tests	
36.141 subclause	Test case
6.2	Base station output power
6.3.1	Resource element (RE) power control dynamic range
6.3.2	Total power dynamic range
6.4.1	Transmitter OFF power
6.4.2	Transmitter transient period
6.5.1	Frequency error
6.5.2	Error vector magnitude (EVM)
6.5.3	Time alignment between transmitter branches
6.5.4	Downlink reference signal power
6.6.1	Occupied bandwidth
6.6.2	Adjacent channel leakage power ratio (ACLR)
6.6.3	Operating band unwanted emissions
6.6.4	Transmitter spurious emissions
6.7	Transmitter intermodulation

UE transmitter test cases	
36.521-1 subclause	Test case
6.2.2	UE maximum output power
6.2.3	Maximum power reduction (MPR)
6.2.4	Additional maximum power reduction (A-MPR)
6.2.5	Configured UE transmitted output power
6.3.2	Minimum output power
6.3.3	Transmit OFF power
6.3.4.1	General ON/OFF time mask
6.3.4.2	PRACH and SRS time mask
6.3.5.1	Power control absolute power tolerance
6.3.5.2	Power control relative power tolerance
6.3.5.3	Aggregate power control tolerance
6.5.1	Frequency error
6.5.2.1	Error vector magnitude (EVM)
6.5.2.2	IQ-component
6.5.2.3	In-band emissions for non-allocated RB
6.5.2.4	Spectrum flatness
6.6.1	Occupied bandwidth
6.6.2.1	Spectrum emission mask
6.6.2.2	Additional spectrum emission mask
6.6.2.3	Adjacent channel leakage power ratio (ACLR)
6.6.3.1	Transmitter spurious emissions
6.6.3.2	Spurious emission band UE co-existence
6.6.3.3	Additional spurious emissions
6.7	Transmitter intermodulation

Given the extensive number of complex transmitter configurations that can be used to test transmitter performance, LTE specifies a series of downlink signal configurations known as E-UTRA test models (E-TM) for testing the eNB. These test models are grouped into three classes: E-TM1, E-TM2, and E-TM3. The first and third classes are further subdivided into E-TM1.1, E-TM1.2, E-TM3.1, E-TM3.2, and E-TM3.3 (Table 2). Note that the "E" in E-UTRA stands for "enhanced" and designates LTE UMTS terrestrial radio access, whereas UTRA without the "E" refers to W-CDMA.

ACLR test requirements
(continued)

For UE testing, transmitter tests are carried out using the reference measurement channels (RMC) specified for eNB receiver testing. The ACLR requirement for the UE is not as stringent as it is for the eNB, so our focus will be on the latter.

Table 2. E-UTRA test models (from 3GPP TS 36.141 [1])

E-TM	Notes	Test case
E-TM1.1	Maximum power tests	Output power, occupied bandwidth, ACLR, operating band unwanted emissions, transmitter spurious emissions, transmitter intermodulation, reference signal absolute accuracy
E-TM1.2	Includes power boosting and de-boosting	ACLR, operating band unwanted emissions
E-TM2	Minimum power tests	Total power dynamic range (lower OFDM symbol power limit at min power, EVM of single 64QAM PRB allocation (at min power), frequency error (at min power)
E-TM3.1	Power tests	Total power dynamic range (upper OFDM symbol power limit at max power with all 64QAM PRBs allocated), frequency error, EVM for 64QAM (at max power)
E-TM3.2	Includes power boosting and de-boosting	Frequency error, EVM for 16QAM
E-TM3.3	Includes power boosting and de-boosting	Frequency error, EVM for QPSK

The 3GPP specifications for LTE define ACLR as the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency. Minimum ACLR conformance requirements for the eNB are given for two scenarios: for adjacent E-UTRA (LTE) channel carriers of the same bandwidth, E-UTRA$_{ACLR1}$, and for the UTRA (W-CDMA) adjacent and alternate channel carriers, UTRA$_{ACLR1}$ and UTRA$_{ACLR2}$, respectively.

Different limits and measurement filters are specified for E-UTRA and UTRA adjacent channels, and are provided for both paired spectrum (FDD) operation and unpaired spectrum (TDD) operation. The E-UTRA channels are measured using a square measurement filter, while UTRA channels are measured using an RRC filter with a roll-off factor of = 0.22 and a bandwidth equal to the chip rate, which is 3.84 MHz in the example of paired spectrum operation shown in Figure 1.

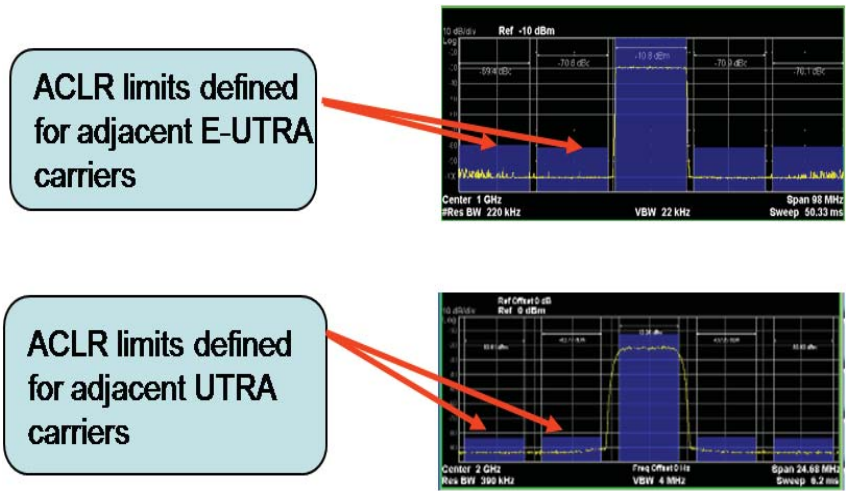


Figure 1. Measurement filters for ACLR measurements

ACLR test requirements *(continued)*

ACLR test requirements for the eNB including paired and unpaired spectrum operation are summarized in Table 3. As of the September 2009 specification release, the ACLR test cases for the UE were not fully complete. However, the UE test procedure is essentially the same as that used for the base station.

Table 3. ACLR base station conformance test requirements (from 3GPP TS 36.141 6.2 [1]). Note that the specification defines the minimum requirement plus the test tolerance (TT)).

Spectrum	Bands	Adjacent Carrier	Limits (Min req + TT) *
Paired Spectrum	Category A	E-UTRA	44.2 dB or -13 dBm/MHz
		UTRA	44.2 dB or -13 dBm/MHz
Paired Spectrum	Category B	E-UTRA	44.2 dB or -15 dBm/MHz
		UTRA	44.2 dB or -15 dBm/MHz
Unpaired spectrum	Category A	E-UTRA (LTE)	44.2 dB or -13 dBm/MHz
		1.28 Mcps UTRA	44.2 dB or -13 dBm/MHz
		3.84 Mcps UTRA	44.2 dB or -13 dBm/MHz
		7.82 Mcps UTRA	44.2 dB or -13 dBm/MHz
Unpaired spectrum	Category B	E-UTRA (LTE)	44.2 dB or -15 dBm/MHz
		1.28 Mcps UTRA	44.2 dB or -15 dBm/MHz
		3.84 Mcps UTRA	44.2 dB or -15 dBm/MHz
		7.82 Mcps UTRA	44.2 dB or -15 dBm/MHz

** Relative limits are 44.2 dB = 45 dB min requirement + 0.8 dB TT. Both Absolute and Relative limits are provided. Whichever is less stringent is to be used for the conformance requirement.*

Setting up the ACLR test

Sophisticated signal evaluation tools are available for making complex LTE measurements quickly and accurately. Power measurements including ACLR generally are made using a spectrum or signal analyzer, and the required test signals are built using a signal generator. In the following examples, Agilent's PC-based Signal Studio application connected to an MXG signal generator is used to build the standards-compliant E-TM signal required for transmitter testing. The output signal is connected to the RF input of an Agilent X-Series signal analyzer running N9080A LTE measurement application, which is used for signal analysis. This equipment setup follows the simple block diagram provided in the 3GPP LTE specifications (Figure 2). Although the measurement process described here is for FDD operation, the process for TDD operation is similar.

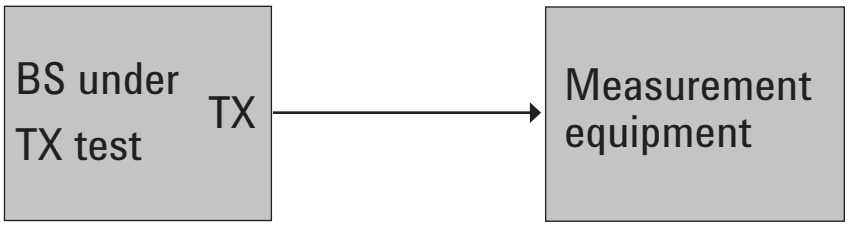


Figure 2. Measurement equipment setup (3GPP TS 36.141 [1] Annex I, Figure I.1-1)

According to the specifications, the carrier frequency must be set within a frequency band supported by the base station under test, and ACLR must be measured for frequency offsets on both sides of the channel frequency, as specified for paired or unpaired spectrum operation (Table 3). The test is performed first using a transmitted signal of type E-TM1.1, in which all of the PDSCH resource blocks have the same power, and then again using E-TM1.2, in which power boosting and deboosting are used. The E-TM1.2 configuration is useful because it simulates multiple users whose devices are operating at different power levels. This scenario results in a higher crest factor, which makes it more difficult to amplify the signal without creating additional, unwanted spectral content—i.e., ACLR.

Setting up the ACLR test
(continued)

In this ACLR measurement example, Signal Studio is set up to generate a standards-compliant E-TM1.2 test signal. The frequency is set to 2.11 GHz, a frequency that is in several of the major downlink operating bands specified for LTE. The output signal amplitude—an important consideration in determining ACLR performance—is set to -10 dBm. A 5 MHz channel bandwidth is selected from the range that extends from 1.4 to 20 MHz.

Figure 3 shows the eNB setup with Transport Channel selected. A graph of the resource allocation blocks for the test signal appears at the bottom. The Y axis indicates frequency or resource blocks, while the X axis indicates slots or time. The different colors correspond to different channels, with the white areas representing Channel 1 and the pink areas Channel 2. Both are downlink shared channels, of interest in this measurement. The other colors represent synchronization channels, reference signals, etc.

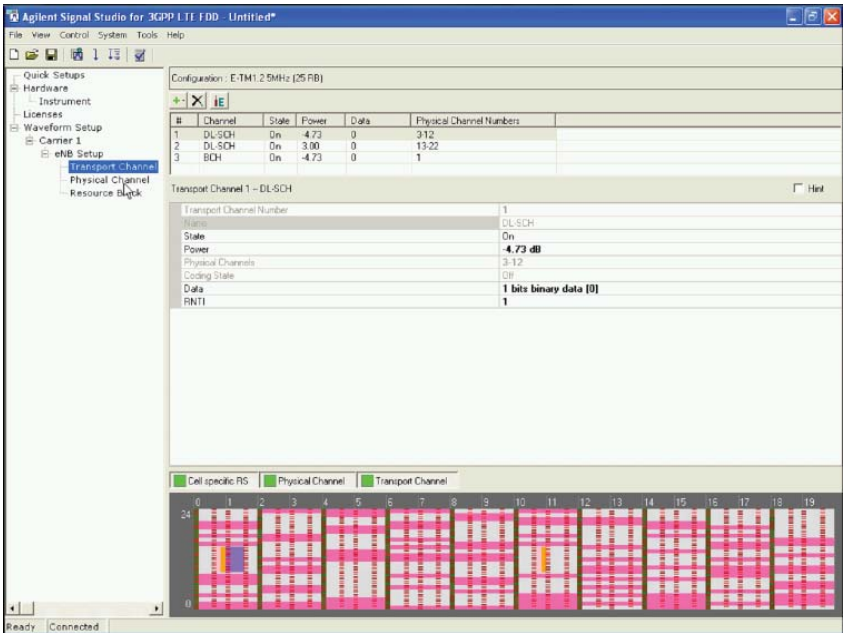


Figure 3. Resource allocation blocks (at bottom) for E-TM1.2 test signal

Selecting Channel 1 shows the output power level to be at -4.3 dB, so the channel power has been deboosted. The output power of Channel 2 has been boosted and is set at 3 dB (Figure 4). A complex array of power boosting and deboosting options can be set for the different resource blocks from resource block allocation graph. The resulting composite signal will have a higher peak-to-average ratio than a single channel in which all blocks are at the same power level. Amplifying a boosted signal such as this can be difficult, as noted earlier. Without sufficient back-off in the power amplifier, clipping may result.

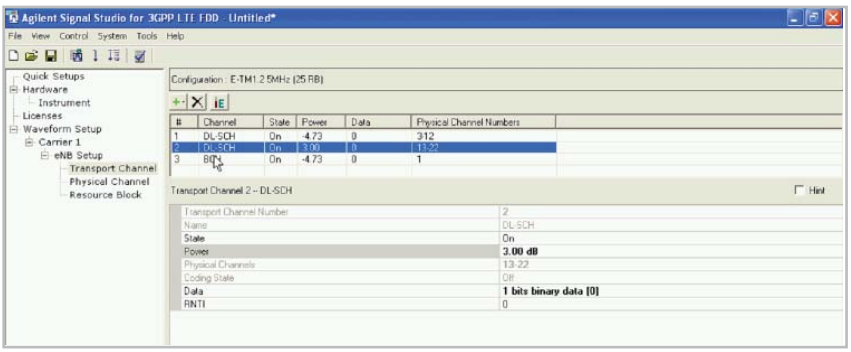


Figure 4. Boosted output power in Channel 2

Setting up the ACLR test
(continued)

The test signal is now generated using the Signal Studio software. Because Signal Studio is PC-based, it can be run from the PC-based X-Series signal analyzer. The waveform in this case is created on the desktop of the signal analyzer and then downloaded to the signal generator via LAN or GPIB. The RF output of the signal generator is connected to the RF input of the signal analyzer, where the ACLR performance is measured using swept spectrum analysis. In this example, the signal analyzer is in LTE mode with a center frequency of 2.11 GHz and the ACP measurement selected. At this point it is possible to make a quick, one-button ACLR measurement according to the LTE standard by recalling the appropriate parameters and test limits from a list of available choices in the LTE application. These choices include options for paired and unpaired spectrum, Category A or Category B limits (as defined in ITU-R SM.329), and type of carrier in the adjacent and alternate channels—E-UTRA (LTE), UTRA (W-CDMA), or TD-SCDMA.

Recall that for FDD operation, LTE defines two different methods of making ACLR measurements. In Figure 5, the upper graph shows the case in which E-UTRA (LTE) is used at the center and offset frequencies. The lower graph shows LTE at the center frequency and UTRA (W-CDMA) at the adjacent and alternate offsets.

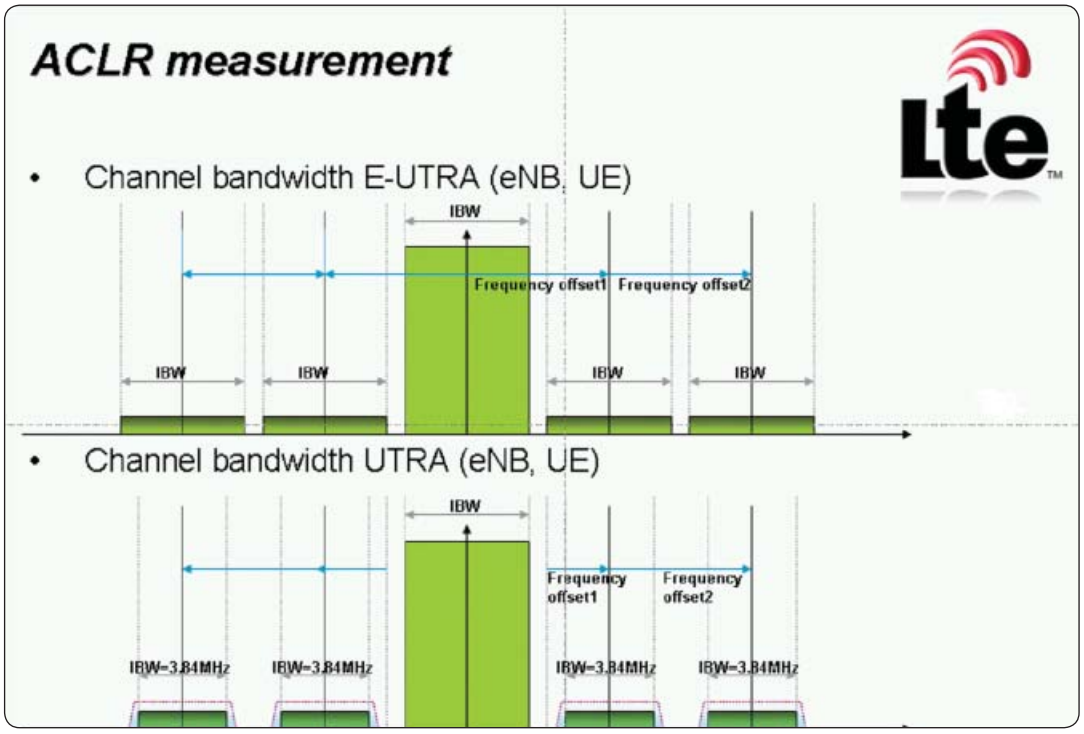


Figure 5. Two specified methods of ACLR measurement

Setting up the ACLR test
(continued)

In Figure 6 the measurement result shows the E-UTRA adjacent and alternate offset channels. For this measurement a 5 MHz carrier is selected; however, the measurement noise bandwidth is 4.515 MHz, because the downlink contains 301 subcarriers. The first offset (A) is at 5 MHz, with an integration bandwidth of 4.515 MHz. The second offset (B) is at 10 MHz with the same integration bandwidth.

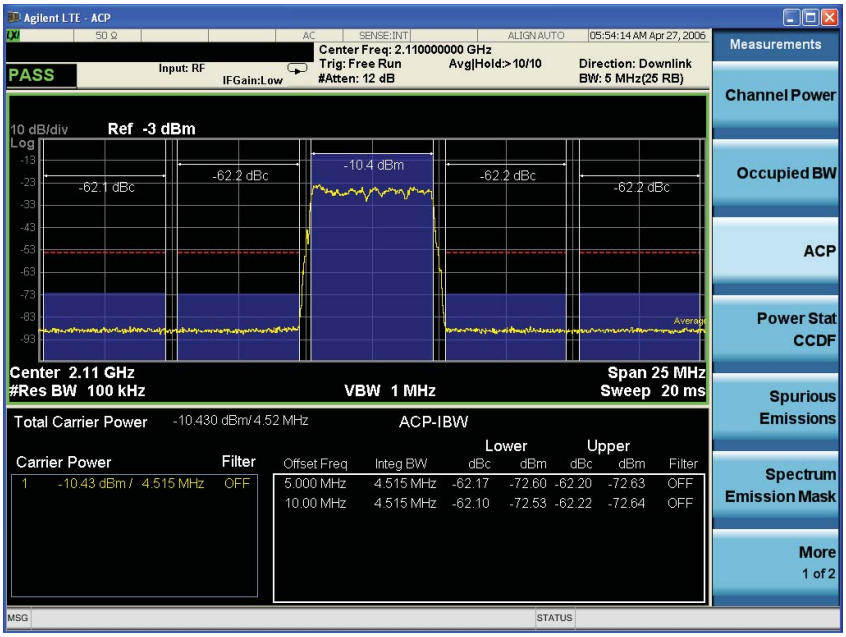


Figure 6. ACLR measurement result using Agilent X-Series analyzer before optimization

Optimizing the analyzer settings

This one-button measurement gives a very quick, usable ACLR measurement according to the LTE standard. While the result in Figure 6 of about -62 dBc is good, the analyzer settings can be optimized to get even better performance. Four ways to further improve the measurement results are (1) optimize the signal level at the mixer; (2) change the resolution bandwidth filter; (3) turn on noise correction; and (4) use a different measurement methodology called filtered integration bandwidth.

To optimize the signal level at the input mixer, the attenuator is adjusted for minimal clipping. The X-Series signal analyzer will automatically select an attenuation value based on the current measured signal value. This automated technique provides a good starting point for achieving optimal measurement range. Signal analyzers such as the X-Series, which have both electronic and mechanical attenuators, can use the two in combination to optimize performance. In such cases the mechanical attenuator can be adjusted slightly to get even better results of about 1 or 2 dB.

Next the resolution bandwidth can be lowered by pressing the bandwidth filter key. Note that sweep time increases as the resolution bandwidth is lowered. For example, with the MXA signal analyzer, sweep time at 30 kHz is 676.3 ms. At a lower 10 kHz RBW, the sweep time is about 6 seconds. The slower sweep time reduces variance in the measurement, but reduces measurement speed.

Another step is to turn on noise correction. The analyzer then takes one sweep to measure its internal noise floor at the current center frequency, and in subsequent sweeps subtracts that internal noise floor from the measurement result. This technique substantially improves ACLR, in some cases by up to 5 dB.

Optimizing the analyzer settings
(continued)

Changing the measurement method is a fourth way to optimize the analyzer. In this case the default measurement method (integration bandwidth or IBW) is changed to the filtered IBW method. Filtered IBW uses a sharp, steep cutoff filter. This technique does degrade the absolute accuracy of the power measurement result, but it does not degrade the relative power accuracy, and ACLR is a relative power measurement. Therefore, filtered IBW does not degrade the ACLR result.

Using these techniques in combination, an Agilent's X-series analyzer can optimize the ACLR measurement automatically for performance versus speed via the analyzer's embedded LTE application. The result for a typical ACLR measurement is improved by up to 10 dB or more. Figure 7 shows an 11 dB ACLR improvement after optimization (compared to Figure 6) using the embedded LTE application. For measurement scenarios requiring the maximum performance, the analyzer settings can be further adjusted.

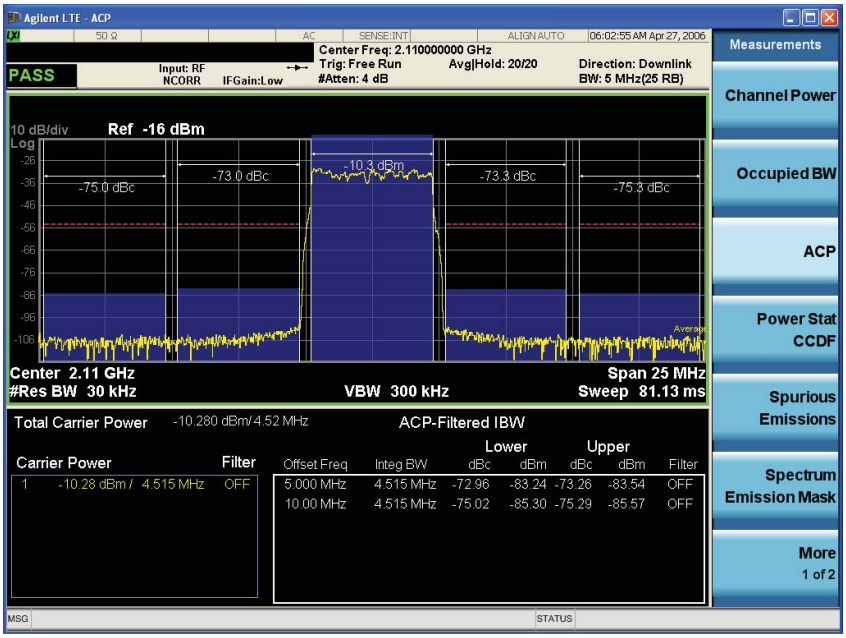


Figure 7. ACLR measurement result using Agilent X-series analyzer after optimization

Conclusion

Standards-compliant spectrum measurements such as ACLR are invaluable for RF engineers developing the next generation radio systems. With LTE, however, these measurements are complicated by factors such as variations in the bandwidth of adjacent channels, choice of transmission filter, and interaction of RF variables between channels of different bandwidth and different susceptibility to interference. A practical solution is to use a spectrum or signal analyzer with a standards-specific measurement application. This combination can reduce error in complex measurements, automatically configuring limit tables and specified test setups and ensuring measurement repeatability.

Acronyms

3GPP	3rd Generation Partnership Project
ACLR	Adjacent channel leakage-power ratio
A-MPR	Additional maximum power reduction
CDMA	Code division multiple access
eNB	Evolved node B
E-TM	E-UTRA test model
E-UTRA	Evolved universal terrestrial radio access
EVM	Error vector magnitude
FDD	Frequency division duplex
GPIB	General purpose interface bus
IBW	Integration bandwidth
LAN	Local area network
LTE	Long term evolution
MPR	Maximum power reduction
MIMO	Multiple input multiple output
OFDMA	Orthogonal frequency division multiple access
PRACH	Physical random access channel
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase-shift keying
RB	Resource block
RBW	Resolution bandwidth
RE	Resource element
RF	Radio frequency
RRC	Root-raised cosine
SC-FDMA	Single carrier frequency division multiple access
SRS	Sounding reference signal
TDD	Time division duplex
TD-SCDMA	Time domain synchronous code division multiple access
UE	User equipment
UMTS	Universal mobile telecommunications system
UTRA	Universal terrestrial radio access
W-CDMA	Wideband code division multiple access

References

[1] 3GPP TS 36.141 V8.4.0 (2009-09) Base Station (BS) Conformance Testing

[2] 3GPP TS 36.521-1 V8.3.1 (2009-09) User Equipment (UE) Conformance Specification; Radio Transmission and Reception Part 1: Conformance Testing

More Information

For more information about the 3GPP, visit the 3GPP home page

http://www.3gpp.org/

3GPP specifications home page

http://www.3gpp.org/specs/specs.htm

3GPP Series 36 (LTE) specifications

http://www.3gpp.org/ftp/Specs/archive/36_series

For more information about Agilent design and test products for LTE visit

http://www.agilent.com/find/lte

Agilent LTE application notes and technical overviews:

3GPP Long Term Evolution: System Overview, Product Development, and Test Challenges: 5989-8139EN

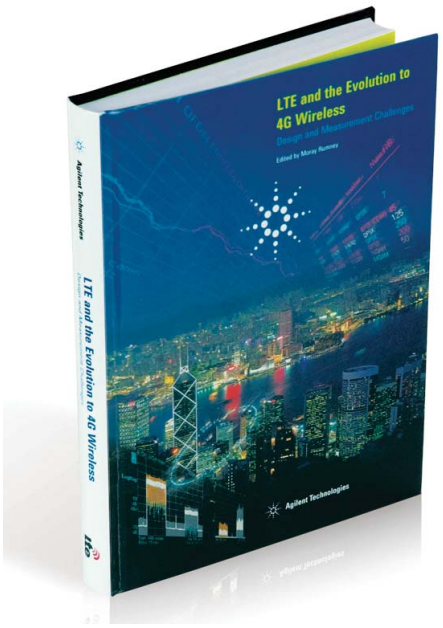
LTE Component Test: 5990-5149EN

MIMO in LTE Operation and Measurement—Excerpts on LTE Test: 5990-4760EN

MIMO Performance and Condition Number in LTE Test: 5990-4759EN

N9080A & N9082A LTE Modulation Analysis Measurement Application Technical Overview: 5989-6537EN

Learn more about LTE and its measurements in the new book written by 30 LTE experts:



LTE and the Evolution to 4G Wireless Design and Measurement Challenges

http://www.agilent.com/find/ltebook

www.agilent.com
www.agilent.com/find/lte

Agilent Email Updates

www.agilent.com/find/emailupdates
Get the latest information on the products and applications you select.

LXI

www.lxistandard.org
LXI is the LAN-based successor to GPIB, providing faster, more efficient connectivity. Agilent is a founding member of the LXI consortium.

Agilent Channel Partners

www.agilent.com/find/channelpartners
Get the best of both worlds: Agilent's measurement expertise and product breadth, combined with channel partner convenience.

Remove all doubt

Our repair and calibration services will get your equipment back to you, performing like new, when promised. You will get full value out of your Agilent equipment throughout its lifetime. Your equipment will be serviced by Agilent-trained technicians using the latest factory calibration procedures, automated repair diagnostics and genuine parts. You will always have the utmost confidence in your measurements. For information regarding self maintenance of this product, please contact your Agilent office.

Agilent offers a wide range of additional expert test and measurement services for your equipment, including initial start-up assistance, onsite education and training, as well as design, system integration, and project management.

For more information on repair and calibration services, go to:

www.agilent.com/find/removealldoubt

For more information on Agilent Technologies' products, applications or services, please contact your local Agilent office. The complete list is available at:

www.agilent.com/find/contactus

Americas

Canada	(877) 894-4414
Latin America	305 269 7500
United States	(800) 829-4444

Asia Pacific

Australia	1 800 629 485
China	800 810 0189
Hong Kong	800 938 693
India	1 800 112 929
Japan	0120 (421) 345
Korea	080 769 0800
Malaysia	1 800 888 848
Singapore	1 800 375 8100
Taiwan	0800 047 866
Thailand	1 800 226 008

Europe & Middle East

Austria	43 (0) 1 360 277 1571
Belgium	32 (0) 2 404 93 40
Denmark	45 70 13 15 15
Finland	358 (0) 10 855 2100
France	0825 010 700*
	*0.125 €/minute
Germany	49 (0) 7031 464 6333
Ireland	1890 924 204
Israel	972-3-9288-504/544
Italy	39 02 92 60 8484
Netherlands	31 (0) 20 547 2111
Spain	34 (91) 631 3300
Sweden	0200-88 22 55
Switzerland	0800 80 53 53
United Kingdom	44 (0) 118 9276201

Other European Countries:
www.agilent.com/find/contactus

Revised: October 1, 2009

Product specifications and descriptions in this document subject to change without notice.

Printed in USA, January 7, 2010
5990-5089EN

Agilent Technologies