Stimulus-Response Testing for LTE Components

Application Note

Agilent Technologies

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1. Introduction

The 3GPP Long Term Evolution (LTE) specifications present some new challenges for manufacturers of components and equipment for LTE systems. The standard is quite complex, with multiple channel bandwidths, different transmission schemes for the downlink and uplink, both frequency and time domain duplexing (FDD and TDD) transmission modes, and use of multiple-input, multiple-output (MIMO) antenna techniques. LTE will co-exist with current 2G and 3G cellular systems, so potential interference is an important issue. All of this leads to high performance targets for LTE systems, and the performance of the underlying components and devices will be a key factor in whether those targets will be met.

Although the term "component test" is rather general, in this application note the term refers to devices such as power amplifiers and RFICs for transmitters, receivers, or transceivers. It does not include testing of base station (BS, also referred to as enhanced node B or eNB) or user equipment (UE) transmitters or receivers, since these topics are covered in other application notes from Agilent Technologies. The focus is on stimulus-response testing using LTE signals and measurements of transmitted signals from RFICs. Complete characterization of such components may require a variety of additional measurements, including testing using CW signals (e.g., S-parameters, gain compression, or intermodulation distortion), noise figure, or power consumption, but those tests are beyond the scope of this document.

This application note begins with a brief overview of the physical layer in the LTE standards. Next it examines some of the testing requirements that apply to components for LTE systems, using the LTE conformance tests as a starting point, but focusing on the implications for testing components instead of eNBs and UEs. An overview of measurement setups describes some of the equipment and test solutions that are available from Agilent for LTE. This is followed by a discussion on creating suitable LTE signals for component test and analyzing transmitted signals from LTE components.

2. Brief Overview of the LTE Physical Layer

2.1 General characteristics

The physical layer for LTE utilizes orthogonal frequency division multiple access (OFDMA) for the downlink, and single-carrier frequency division multiple access (SC-FDMA) for the uplink. Both are multiple access technologies that allow multiple users to transmit at the same time. Six different channel bandwidths from 1.4 to 20 MHz may be used, with a fixed subcarrier spacing of 15 kHz, or 7.5 kHz for multimedia broadcast multicast service (MBMS). As a result, the number of OFDM subcarriers that is used changes for different channel bandwidths.

2.2 Frame structures

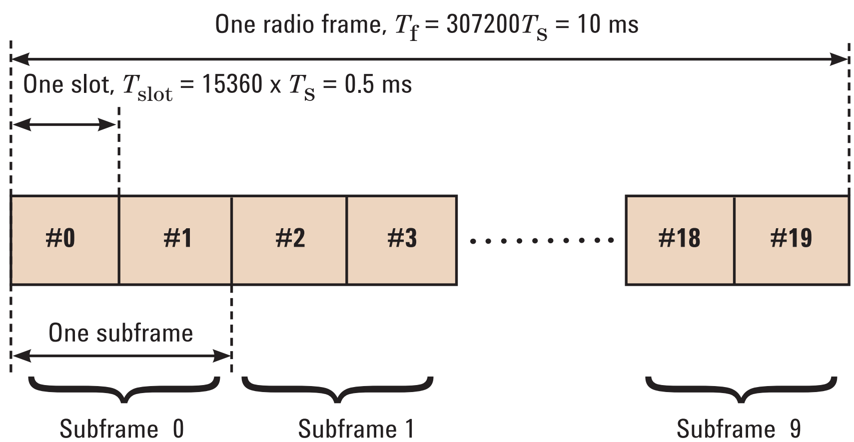


Figure 1. LTE frame structure type 1 for FDD (TS 36.211)

There are two types of frame structures defined for LTE. Frame structure type 1 (FS1) is for FDD, while frame structure type 2 (FS2) is used for TDD. For both types, one frame is 10 ms in duration, divided into ten subframes that are each 1 ms long, as shown in Figure 1. One subframe contains two slots, each with 0.5 ms duration. For FS1, the entire frame is used for either downlink or uplink transmission.

For TDD, one 10 ms frame in FS2 consists of two half-frames that are each 5 ms long, and each half-frame is divided into 5 subframes that are each 1 ms long, as shown in Figure 2. Two switch-point periodicities are supported, 5 ms and 10 ms. For frames with 5 ms switch-point periodicity, subframes 1 and 6 are special subframes consisting of three fields: downlink pilot timeslot (DwPTS), guard period (GP), and uplink pilot timeslot (UpPTS). Frames with 10 ms switch-point periodicity have only subframe 1 as the special subframe; subframe 6 is a regular downlink subframe. Table 1 shows the possible combinations of downlink and uplink subframes that are defined in the LTE standard for TDD mode.

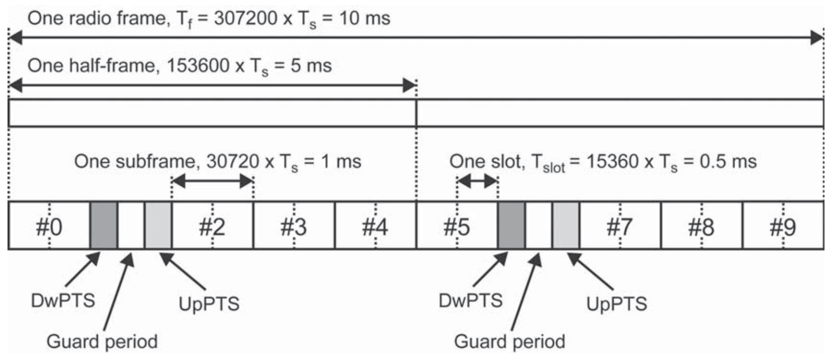


Figure 2. LTE frame structure type 2 for TDD with 5 ms switch-point periodicity (TS 36.211)

Uplink-downlink Configuration	Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Table 1. TDD Uplink/downlink configurations (TS 36.211 Table 4.2-2)

2.3 Resource blocks

The smallest time-frequency unit used for transmission is called a resource element, defined as one symbol on one subcarrier. A group of 12 contiguous subcarriers over one slot in time forms a resource block (RB), and data transmissions are allocated in units of RBs. The number of symbols in one RB varies depending on the length of the cyclic prefix. For the normal cyclic prefix, there are 7 symbols in one RB. For the extended cyclic prefix, there are 6 symbols when the subcarrier spacing is 15 kHz. In the downlink for multimedia broadcast, there is also a case with extended cyclic prefix in which there are 3 symbols and a subcarrier spacing of 7.5 kHz.

Since the size of an RB is the same for all bandwidths, but the number of subcarriers varies by bandwidth, the number of available physical RBs will be dependent on the channel bandwidth as shown in Table 2. Note that the number of used subcarriers shown in Table 2 applies for the normal subcarrier spacing of 15 kHz.

Transmission bandwidth (MHz)	1.4	3	5	10	15	20
Number of used subcarriers	72	180	300	600	900	1200
Number of resource blocks per slot	6	15	25	50	75	100

Table 2. Number of subcarriers and resource blocks for different bandwidths

2.4 Physical signals and channels

The LTE air interface consists of physical signals and physical channels. Physical signals are generated in Layer 1 and used for system synchronization, cell identification, and radio channel estimation. Physical channels carry data from higher layers including control, scheduling, and user payload. Table 3 provides a summary of the physical signals. In the downlink, the primary and secondary synchronization signals contain the cell identification, allowing the UE to identify and synchronize with the network. In both the downlink and uplink there are reference signals (RS), known as pilot signals in other standards, which are used by the receiver to estimate the amplitude and phase flatness of the received signal.

DL signals	Full name	Modulation sequence	Purpose
P-SS	Primary synchronization signal	One of 3 Zadoff-Chu sequences	Used for cell search and identification by the UE. Carries part of the cell ID (one of 3 orthogonal sequences)
S-SS	Secondary synchronization signal	Two 31-bit BPSK M-sequences	Used for cell search and identification by the UE. Carries the remainder of the cell ID (one of 168 binary sequences)
RS	Reference signal (pilot)	Complex I+jQ pseudo-random sequence (length-31 Gold sequence)	Used for downlink channel estimation. Exact sequence derived from cell ID, one of 3 x 168 = 504 sequences

UL signals	Full name	Modulation sequence	Purpose
DM-RS	Demodulation reference signal	Zadoff-Chu	Used for synchronization to the UE and UL channel estimation
S-RS	Sounding reference signal	Based on Zadoff-Chu	Used to monitor propagation conditions with UE

Table 3. LTE physical signals

The physical channels carry the system information and user data. These are summarized in Table 4. The different channels can result in frame structures that are quite complex. For testing components, it is usually not necessary to create signals that contain all of these physical channels.

DL channels	Full name	Modulation format	Purpose
PBCH	Physical broadcast channel	QPSK	Carries cell-specific information
PDCCH	Physical downlink control channel	QPSK	Scheduling, ACK/NACK
PDSCH	Physical downlink shared channel	QPSK, 16QAM, 64QAM	Payload
PMCH	Physical multicast channel	QPSK, 16QAM, 64QAM	Payload for multimedia broadcast multicast service (MBMS)
PCFICH	Physical control format indicator channel	QPSK	Carries information about the number of OFDM symbols (1, 2, 3 or 4) used for transmission of PDCCHs in a subframe
PHICH	Physical hybrid ARQ indicator channel	BPSK modulated on I and Q with spreading factor 2 or 4 Walsh codes	Carries the hybrid-ARQ ACK/NACK
UL channels	**Full name**	**Modulation format**	**Purpose**
PRACH	Physical random access channel	Zadoff-Chu	Call setup
PUCCH	Physical uplink control channel	BPSK, QPSK	Scheduling requests, ACK/NACK, Channel Quality Indicator (CQI)
PUSCH	Physical uplink shared channel	QPSK, 16QAM, 64QAM	Payload, ACK/NACK, CQI

Table 4. LTE physical channels

This brief overview of the physical layer covers some of the elements at a relatively high level to provide a basic background. For further details, including information about modulation and mapping to physical resources, please see the literature references at the end of this application note.

3. Testing Requirements

3.1 Amplifiers

The use of OFDMA for the downlink in LTE results in a signal that has a high peak-to-average power ratio (PAPR) or crest factor, which is a result of the independent phases of the multiple subcarriers adding constructively. The high crest factor requires a large dynamic range for the power amplifier in the transmitter, which is a challenge to provide while trying to optimize performance vs. cost and complexity. SC-FDMA is used in the uplink to reduce the crest factor, but amplifiers for UEs still need to deal with varying power levels.

Operating an amplifier in its nonlinear region results in gain compression or clipping that causes distortion, leading to adjacent channel interference and reduced spectral efficiency. Operating the amplifier with a back-off from its compression point allows the amplifier to remain in its linear region and minimizes distortion, but this comes at the cost of reduced efficiency.

An important task for the design engineer is to understand the performance of the amplifier under different conditions and with input signals that have different PAPR in order to determine the best trade-off within these constraints. Tests that are typically used include power measurements, modulation quality measurements such as error vector magnitude (EVM), and distortion measurements such as adjacent channel leakage ratio (ACLR, also referred to as adjacent channel power ratio or ACPR) and spectral regrowth.

3.2 Transmitter, receiver, and transceiver RFICs

A simplified high-level block diagram of the transmitter and receiver in an LTE device is shown in Figure 3. The lower-level components in the transmitter or receiver chain are determined by the type of architecture used in the design (e.g., super-heterodyne vs. direct conversion) and may include additional components such as filters or variable-gain amplifiers (VGAs). LTE includes the use of MIMO technology, so LTE transmitters and receivers will include multiple antennas, each connected to a transmit and receive chain, which are not shown in Figure 3 for simplicity.

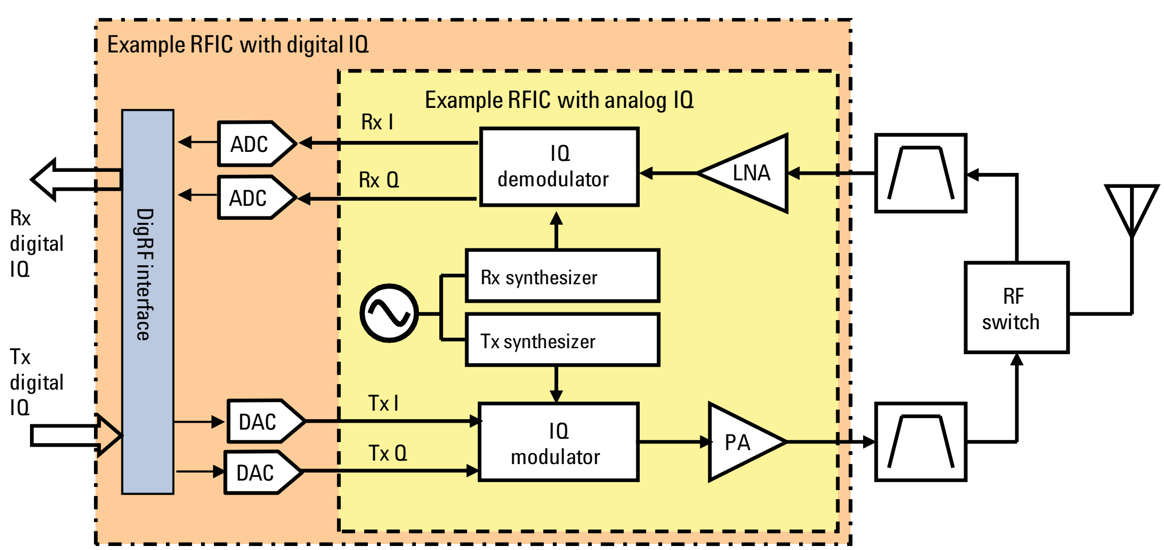


Figure 3. Simplified high-level block diagram of transmitter and receiver

RFICs may include different portions of this block diagram, with some containing either the transmitter or receiver only, or containing transceivers that combine both transmitter and receiver in one component. Devices may also be multi-band, with multiple output paths for each frequency band following the IQ modulator or multiple input paths going from the RF switch/multiplexer into the IQ demodulator.

Traditionally most RFICs have used analog baseband IQ inputs and outputs. However, digital IQ interfaces are becoming more common. The Mobile Industry Processor Interface (MIPI) Alliance developed the DigRF v3.09 standard to describe the digital baseband to RFIC interface for dual-mode 2.5G and 3G devices, but this standard does not handle the complex nature of LTE signals including high data rates and use of MIMO technology. The DigRF v4 standard is now under development to address these requirements.

To see what measurements may be needed for characterizing these RFICs, it is useful to consider the conformance tests that are required in the LTE standards.

3.3 Transmitter conformance tests from the LTE standards

The transmitter tests for the base station (eNB) are described in Section 6 of 3GPP TS 36.141. These tests are performed using specific configurations of downlink signals that are known as E-UTRA Test Models (E-TM). Table 5 provides a summary of the tests, the subsections in which they are described in the standard, and the test models that are used. It also includes the measurement in the N9080A LTE FDD and N9082A LTE TDD applications for the Agilent X-Series (PXA, MXA, EXA, and CXA) signal analyzers that can be used to perform these tests. These applications and measurements are discussed in more detail later in this application note.

TS 36.141 section	eNB transmitter test	E-TM used	Measurements on X-Series N9080A/82A LTE measurement applications
6.2	Base station output power	1.1	Channel power
6.3	Output power dynamics		
6.3.1	RE power control dynamic range	2, 3.1, 3.2, 3.3	Modulation analysis
6.3.2	Total power dynamic range	2, 3.1	Modulation analysis
6.4	Transmit ON/OFF power	Note: This is for TDD only	Transmit On/Off power
6.4.1	Transmitter OFF power	TBD	(N9082A LTE TDD App)
6.4.2	Transmitter transient period	TBD	
6.5	Transmitted signal quality		
6.5.1	Frequency error	2, 3.1, 3.2, 3.3	Modulation analysis
6.5.2	Error vector magnitude (EVM)	2, 3.1, 3.2, 3.3	Modulation analysis
6.5.3	Time alignment between transmitter branches	1.1	Modulation analysis
6.5.4	Downlink RS power	1.1	Modulation analysis
6.6	Unwanted emissions		
6.6.1	Occupied bandwidth	1.1	Occupied BW
6.6.2	Adjacent channel leakage power ratio (ACLR)	1.1, 1.2	Adjacent channel power
6.6.3	Operating band unwanted emissions	1.1, 1.2	Spectrum emission mask
6.6.4	Transmitter spurious emissions	1.1	Spurious emissions
6.7	Transmitter intermodulation	1.1	Spectrum analyzer mode

Table 5. Base station transmitter conformance tests (TS 36.141 V8.5.0)

Transmitter tests for the UE are described in Section 6 of 3GPP TS 36.521-1. Table 6 provides a summary of these tests, along with the measurements in the X-Series LTE applications that can be used to perform the tests. Most of these are similar to the eNB tests in Table 5, but there are a few tests that are unique to the uplink, such as In-Band Emissions for Non-Allocated RB (6.5.2.3). The uplink channel configurations used for these tests are called reference measurement channels (RMCs).

TS 36.521-1 section	UE transmitter test	Measurements on X-Series N9080A/82A LTE measurement applications
6.2	Transmit power	
6.2.2	UE maximum output power	Channel power
6.2.3	Maximum power reduction	Channel power
6.2.4	Additional maximum power reduction	Channel power
6.2.5	Configured UE transmitted output power	Channel power
6.3	Output power dynamics	
6.3.2	Minimum output power	Channel power
6.3.3	Transmit OFF power	Channel power
6.3.4	ON/OFF time mask	N/A
6.3.5	Power control	Channel power
6.5	Transmit signal quality	
6.5.1	Frequency error	Modulation analysis
6.5.2	Transmit modulation	
6.5.2.1	Error vector magnitude (EVM)	Modulation analysis
6.5.2.2	Carrier leakage	Modulation analysis
6.5.2.3	In-band emissions for non-allocated RB	Modulation analysis
6.5.2.4	Spectrum flatness	Modulation analysis
6.6	Output RF spectrum emissions	
6.6.1	Occupied bandwidth	Occupied bandwidth
6.6.2	Out of band emission	
6.6.2.1	Spectrum emission mask	Spectrum emission mask
6.6.2.2	Additional spectrum emission mask	Spectrum emission mask
6.6.2.3	Adjacent channel leakage power ratio (ACLR)	Adjacent channel power
6.6.3	Spurious emissions	
6.6.3.1	Transmitter spurious emissions	Spurious emissions
6.6.3.2	Spurious emission band UE co-existence	Spurious emissions
6.6.3.3	Additional spurious emissions	Spurious emissions
6.7	Transmit intermodulation	Spectrum analyzer mode

Table 6. UE transmitter conformance tests (TS 36.521-1 V8.4.0)

The tests in Tables 5 and 6 are intended for complete eNB or UE transmitters with full baseband, RF, and protocol capabilities, so some of them may not be applicable for component test. For testing amplifiers and RFICs, the main focus is on examining the characteristics of the components that may impact the quality of the transmitted RF signal—for example, errors in the IQ modulator such as IQ offset or gain imbalance, IQ timing misalignment, LO feedthrough, phase noise, and EVM—as well as distortion characteristics such as ACLR and spectral regrowth.

3.4 Receiver conformance tests from the LTE Standards

Receiver tests for the eNB are described in Section 7 of 3GPP TS 36.141. Table 7 shows the list of these tests. These tests are performed using RMCs that define the uplink test signals. A number of fixed reference channel (FRC) parameters are defined for specific tests in Annex A of TS 36.141. For most receiver tests, the required measurement described in the standard is the system performance based on data throughput under specific conditions, so these tests are not very suitable for components, which generally do not contain the receiver baseband and software needed to obtain the throughput results. The one test that may be applicable in some cases is the Receiver Spurious Emissions test, which measures the emissions seen at a receiver port with the other ports terminated. This test can be performed on a transceiver.

TS 36.141 section	eNB receiver test
7.2	Receiver sensitivity level
7.3	Dynamic range
7.4	In-channel selectivity
7.5	Adjacent channel selectivity and narrow-band blocking
7.6	Blocking (in-band and out-of-band)
7.7	Receiver spurious emissions
7.8	Receiver intermodulation

Table 7. Base station receiver tests (TS 36.141 V8.5.0)

The UE receiver tests are described in Section 7 of 3GPP 36.521-1 and they are listed in Table 8. Many of these tests are also not yet fully defined, but they are similar in concept and objective to the tests for base station receivers. All of these tests require measurements of the data throughput, so they are not relevant for testing components.

TS 36.521-1 section	UE receiver test
7.3	Reference sensitivity level
7.4	Max input level
7.5	Adjacent channel selectivity
7.6	Blocking characteristics (in-band and out-of-band)
7.7	Spurious response
7.8	Intermodulation characteristics

Table 8. UE receiver tests (TS 36.521-1 V8.4.0)

Instead of using these tests for receiver components, we can focus instead on testing the demodulation quality and distortion characteristics for the lower-level receiver components or the full receiver RF front end, depending on where access is available to input test signals or measure signals.

3.5 Measurements for component test

From the preceding discussion on test requirements, we can summarize the measurements that may be of interest for LTE components in Table 9.

Measurement	Amplifier test	Tx/Rx RFIC test
Output power	X	X
Frequency error		X
Peak-to-average power (CCDF)	X	X
Error vector magnitude (EVM)	X	X
IQ parameters (offset, gain imbalance, skew, quadrature error)		X
Adjacent channel leakage power ratio (ACLR), also called adjacent channel power ratio (ACPR)	X	X
Spectrum emission mask	X	X
Spectrum flatness	X	X (UE Tx only)
In-band emissions for non-allocated RB	X	X (UE Tx only)
Spurious emissions	X	X

Table 9. Measurements for component test

Amplifier testing will require stimulus-response measurements in which a signal generator is used to create an RF LTE signal that is input to the device-under-test (DUT), and the output signal from the DUT is measured using a signal analyzer.

Testing the transmitter chain will require using a digital or analog baseband signal from the signal generator to drive the I/Q inputs and a signal analyzer to measure the RF output. For the receiver path, an RF signal can be used to drive the receiver, and the output of the low-noise amplifier (LNA) or I/Q modulator can be measured if access is available. The next sections will discuss measurement setups and the creation and analysis of LTE signals.

4. Measurement Setups

A typical measurement setup for components that have RF inputs and outputs is fairly simple, but testing a transmitter, receiver, or transceiver RFIC is more complex. Figure 4 shows the RFIC block diagram from Figure 3, with some possible setups that are available using Agilent's test solutions for testing at various points in the transmitter or receiver chains. A brief description of these products is provided here. Updated information about these and other Agilent products for LTE design and verification testing is available at **www.agilent.com/find/lte**.

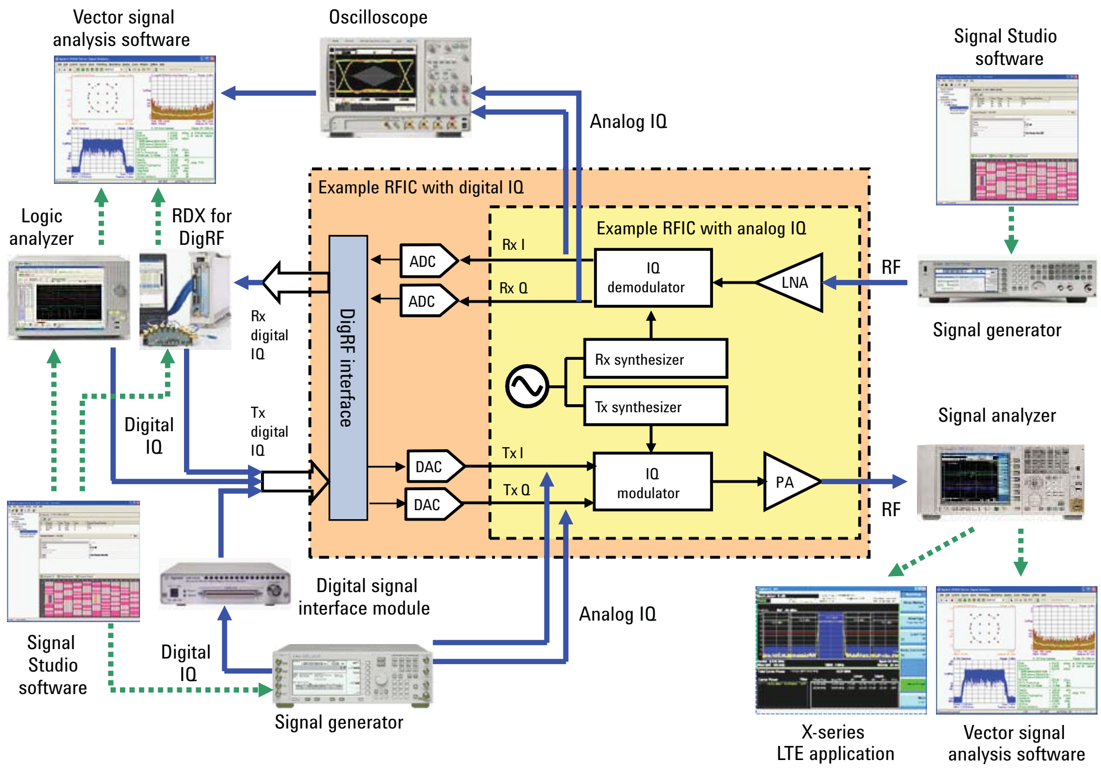


Figure 4. Measurement setups for RFIC test

4.1 Downlink and uplink signal generation

Agilent's Signal Studio software is a family of PC-based applications that provide validated, performance-optimized signals in a variety of formats. The N7624B Signal Studio for 3GPP LTE FDD and N7625B Signal Studio for 3GPP LTE TDD provide coded physical layer LTE signals for both downlink and uplink. The waveform files can be downloaded and played back in a variety of Agilent instruments. Agilent's MXG and ESG signal generators can be used to provide RF or analog IQ signals. The MXG provides the industry's best ACLR performance for power amplifier testing. The ESG can also be used with the N5102A digital signal interface module, which converts the digital IQ data to an appropriate format for the device-under-test (DUT) and offers several breakout boards to facilitate the physical connection to the device. Signal Studio can also be used with Agilent's 16800/16900 series logic analyzers and the N5343A DigRF exerciser module, part of the Agilent RDX solution for DigRF, to create digital IQ signals.

4.2 Downlink and uplink signal analysis

Testing of complex LTE signals requires signal analysis with detailed modulation analysis in addition to RF power measurements. Signal and spectrum analyzers such as the Agilent X-Series (PXA, MXA, EXA, and CXA) and PSA can be used to perform RF power measurements of LTE signals, and the MXA and PXA can also measure analog IQ signals.

The N9080A LTE FDD and N9082A LTE TDD measurement applications work with Agilent PXA, MXA, and EXA signal analyzers to provide convenient one-button power measurements, modulation analysis of downlink and uplink signals, and programming control using SCPI commands.

Another analysis solution is the 89600 vector signal analysis (VSA) software, a PC-based application that supports a wide variety of formats. Option BHD for LTE FDD and Option BHE for LTE TDD provide comprehensive modulation and MIMO signaling analysis based on current LTE standards, with additional flexibility to go beyond one-button measurements. The VSA software works with a variety of measurement instruments, including the X-Series and PSA signal analyzers, oscilloscopes, logic analyzers, and the N5344A DigRF analyzer module, part of the RDX solution for DigRF. The VSA's compatibility with multiple instruments allows the same software to be used with different hardware for testing at RF, analog IQ, and digital IQ interfaces in the block diagram. The VSA also offers some features not available in the X-Series applications that can be useful for troubleshooting, such as signal recording and playback, up to 6 simultaneous displays, spectrogram displays, and zooming on data displays.

5. Creating LTE Signals

One of the challenges of component test is deciding what type of test signal to use. Ideally engineers want to test the performance of the components with a variety of signals that reflect the range of conditions that the device may be subject to in a real-world LTE system, including different PAPR or varying changes in power from one symbol to another. Due to the complexity of the LTE standard, there are practically endless possible configurations for a downlink or uplink signal, with different channel bandwidths, physical control and data channels, modulation types, number of RBs used, data content, etc. Trying to narrow down these choices to a reasonable number of different test signals can be a daunting task.

Fortunately, the LTE standards define specific downlink and uplink test signals that are used for conformance tests. These are good example signals to use for component testing, although engineers may want to create additional signals for more thorough testing.

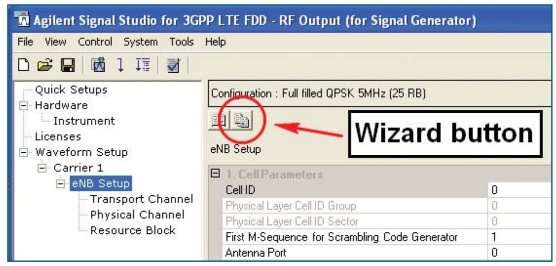
5.1 E-UTRA test models (downlink) for FDD

E-UTRA test models (E-TM) are defined in Section 6 of TS 36.141 for use in base station transmitter testing, so these signals would be suitable for testing BS power amplifiers or transmitter components. The test models to be used for each conformance test were shown earlier in Table 5. The required physical channel parameters for each E-TM are quite detailed; an example of these parameters for E-TM1.2 is given in Table 10. Specific physical resource blocks (PRBs) may have their power level boosted or de-boosted. The configurations for various control and data channels are specified, along with their relative power levels.

Parameter	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Reference, synchronization signals						
RS boosting, $P_B = E_B/E_A$	1	1	1	1	1	1
Synchronisation signal EPRE/E_{RS} [dB]	0.000	–4.730	–4.730	–4.730	–4.730	–4.730
Reserved EPRE/E_{RS} [dB]	-inf	-inf	-inf	-inf	-inf	-inf
PBCH						
PBCH EPRE/E_{RS} [dB]	0.000	–4.730	–4.730	-4.730	-4.730	–4.730
Reserved EPRE/E_{RS} [dB]	-inf	-inf	-inf	-inf	-inf	-inf
PCFICH						
# of symbols used for control channels	2	1	1	1	1	1
PCFICH EPRE/E_{RS} [dB]	3.222	0	0	0	0	0
PHICH						
# of PHICH groups	1	1	1	2	2	3
# of PHICH per group	2	2	2	2	2	2
PHICH BPSK symbol power /E_{RS} [dB]	–3.010	–3.010	–3.010	–3.010	–3.010	–3.010
PHICH group EPRE/E_{RS} [dB]	0	0	0	0	0	0
PDCCH						
# of available REGs	23	23	43	90	140	187
# of PDCCH	2	2	2	5	7	10
# of CCEs per PDCCH	1	1	2	2	2	2
# of REGs per CCE	9	9	9	9	9	9
# of REGs allocated to PDCCH	18	18	36	90	126	180
# of dummy REGs added for padding	5	5	7	0	14	7
PDCCH REG EPRE/E_{RS} [dB]	0.792	2.290	1.880	1.065	1.488	1.195
<NIL> REG EPRE/E_{RS} [dB]	-inf	-inf	-inf	-inf	-inf	-inf
PDSCH						
# of QPSK PDSCH PRBs which are boosted	2	6	10	20	30	40
PRB $P_A = E_A/E_{RS}$ [dB]	3 (*)	3	3	3	3	3
# of QPSK PDSCH PRBs which are de-boosted	4	9	15	30	45	60
PRB $P_A = E_A/E_{RS}$ [dB]	–2.990 (*)	–4.730	–4.730	–4.730	–4.730	–4.730

Table 10. Physical channel parameters for E-TM1.2 (Table 6.1.1.2-1 from 3GPP TS 36.141 V8.5.0)

Creating these complex signals can be quite challenging. Fortunately, these test models are provided as preconfigured selections in Agilent's signal creation software, including the N7624B Signal Studio for 3GPP LTE FDD and N7625B Signal Studio for 3GPP LTE TDD. The test models are available for the "basic" carriers and may be selected by choosing the "eNB Setup" page for FDD or "Downlink" setup page for TDD and clicking on the **Wizard** button at the top. For example, Figure 5 shows the frame structure for E-TM 1.2 for a 5 MHz bandwidth from the N7624B Signal Studio software, which corresponds to the parameters described in Table 10. E-TM 1.2 contains the P-SS, S-SS, and RS signals for synchronization and channel estimation, plus most of the physical channels. All of the available PDSCH RBs are modulated with QPSK. Two separate PDSCH are defined to allow the power in some of the RBs to be boosted while others are de-boosted.



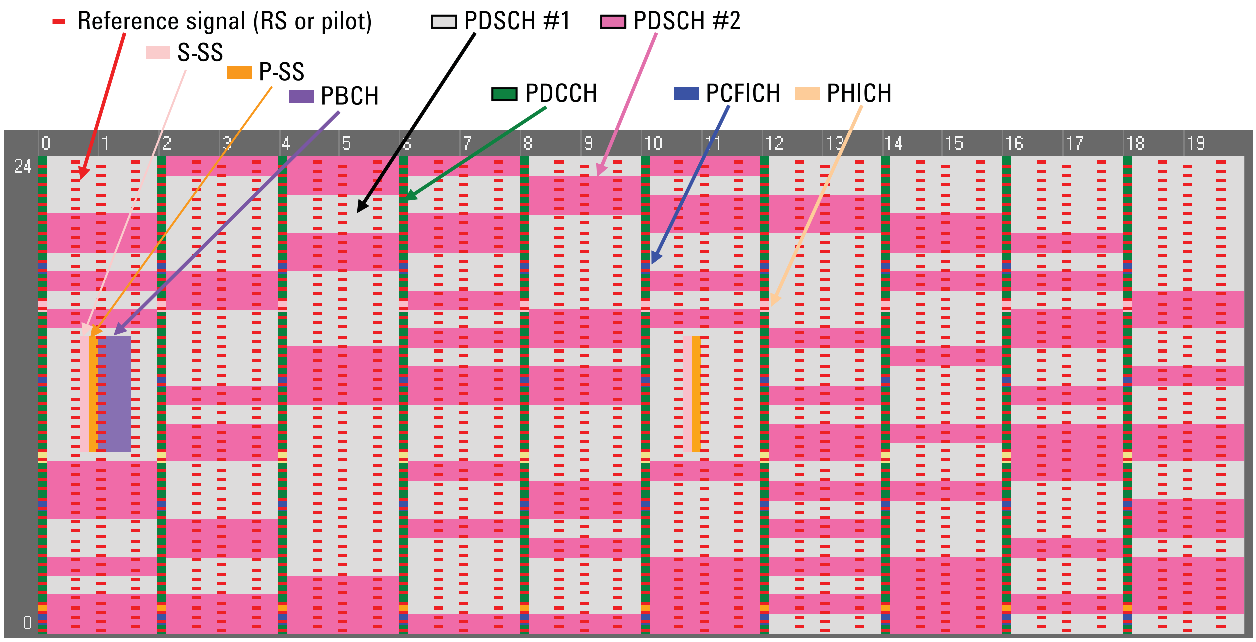


Figure 5. Frame structure for E-TM1.2 for a 5 MHz bandwidth

A review of the physical channel parameter tables for each of the E-TMs shows the main ways in which they differ:

- Power or energy per resource element (EPRE) for various physical signals and channels (e.g., PBCH or PCFICH) relative to the EPRE for the RS resource elements (E_{RS})
- Number of resource element groups (REGs) allocated to the PDCCH (one REG = 4 resource elements) and definition of the PDCCH
- Power boosting or de-boosting of PDSCH physical resource blocks (PRBs)
    - Number of PRBs boosted or de-boosted
    - Amount of power boosting or de-boosting
    - Which PRBs (by number) are boosted or de-boosted in each subframe
- PDSCH definition for EVM measurements
    - Number of PRBs with a specific modulation type within a slot for which EVM is measured
    - Number and modulation type for PRBs within a slot for which EVM is not measured (used for power balancing only), or number of PRBs that are not allocated
    - Ratio of the EPRE for PDSCH resource elements in symbols without RS to E_{RS}

As a result of these differences, the E-TMs have somewhat different spectrum and power characteristics. In particular, E-TM2 has a high PAPR compared to the other E-TMs because only one PDSCH PRB is allocated per slot and there is no power in the other PRBs (except for the RS). In the other E-TMs, all of the PRBs are allocated, although the power levels may be different for different PDSCH. High PAPR can be seen by examining the complementary cumulative distribution function (CCDF) of the signal, which is a statistical description of the percentage of time that the signal is at or above a given power above the average power level. The calculated CCDF can be displayed in the Signal Studio software after a signal is generated, or the actual CCDF can be measured on a signal analyzer using Agilent's 89600 VSA software or the N9080A LTE FDD or N9082A LTE TDD measurement applications for the X-Series signal analyzers. Figure 6 compares the calculated CCDFs from Signal Studio for the 5 MHz bandwidth E-TM1.1 and E-TM2.

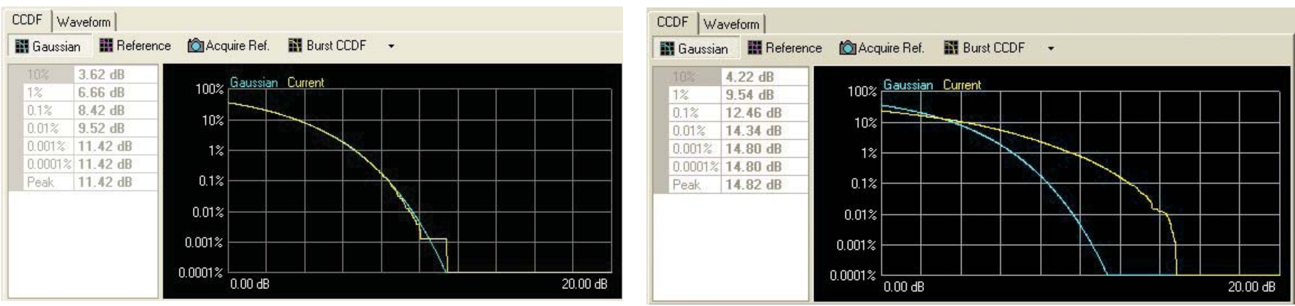


Figure 6. Calculated CCDF curves for E-TM1.1 (left) and E-TM2 (right)

The displays in Figure 6 show the CCDF of the signal in the yellow trace with the CCDF for Gaussian noise as a reference in the blue trace. The x-axis is the power relative to the average power level in the signal. From the display on the left, we can see that the 0.01% CCDF value for E-TM1.1 is 9.52 dB. This value indicates that the signal power exceeds the average power by at least 9.52 dB for 0.01% of the time, or conversely, the signal power is less than 9.52 dB above the average 99.99% of the time. For the E-TM2 signal on the right, the 0.01% CCDF value is 14.34 dB. At every percentage on the y-axis, the E-TM2 signal has a higher peak-to-average value on the x-axis than the E-TM1.1 signal. This signal would be much more stressful for a power amplifier than the E-TM1.1 signal. The other E-TM signals have CCDF characteristics that are much more similar to E-TM1.1, with calculated 0.01% CCDF values ranging from 9.38 to 9.88 dB.

The spectrum and time-domain displays of the test model signals also show some other differences. For example, Figure 7 shows the spectrum and time-domain measurement over a period of 10 ms (1 frame) for the 5 MHz E-TM3.1 signal. Note that the signal power is very uniform both in frequency and time. Figure 8 shows the same measurements for the 5 MHz E-TM2 signal. There is clearly far more variation in power vs. both frequency and time. Figure 9 shows the frame configuration for E-TM2, which explains why these variations are present. The dominant light colored background area represents the unallocated PDSCH resource blocks that contain no power. The pink blocks that span two slots (1 subframe) are the allocated PDSCH resource blocks that contain data with 64QAM modulation. The symbols that contain the RS are indicated by the columns of short red lines. The first and sixth subframes contain the P-SS and S-SS, and the first subframe also contains the PBCH. Comparing this frame configuration with the power vs. time configuration in Figure 8 shows clearly that the higher power symbols correspond to the symbols that contain more allocated RBs.

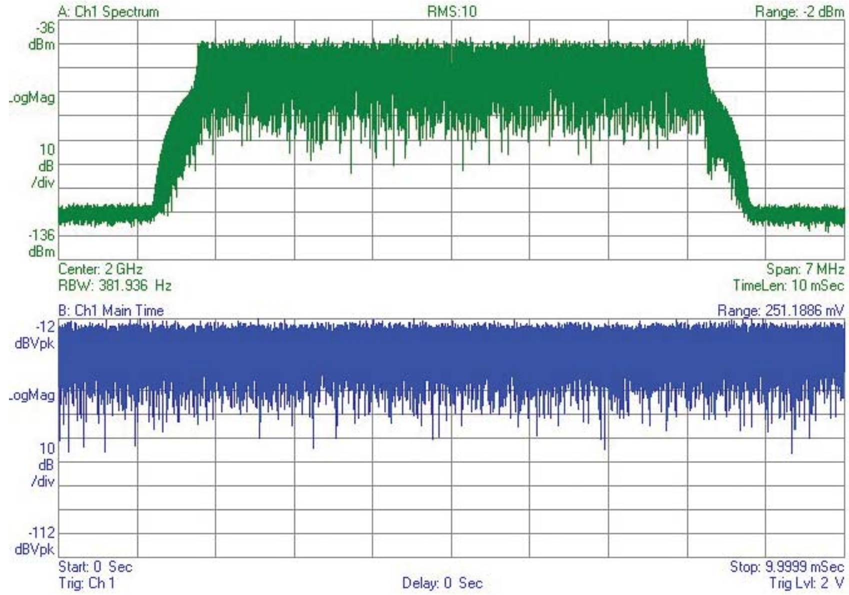


Figure 7. Spectrum and power vs. time for 5 MHz E-TM3.1 signal

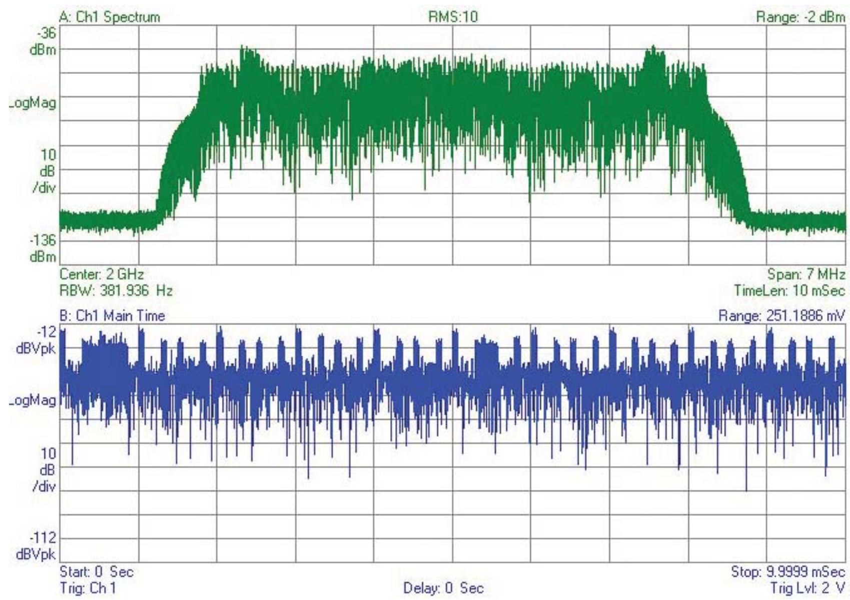


Figure 8. Spectrum and power vs. time for 5 MHz E-TM2 signal

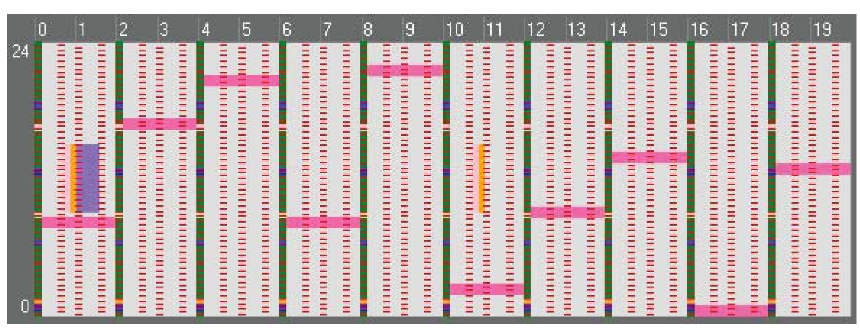


Figure 9. Frame configuration for 5 MHz E-TM2 signal

5.2 E-UTRA test models (downlink) for TDD

For TDD, the test models are based on uplink/downlink configuration 3 (see Table 1) and special subframe configuration 8 defined in TS 36.211. The test models have the following key characteristics:

- Downlink-to-uplink switch-point periodicity: 10 ms
- Number of UL/DL subframes per half-frame (10 ms): 6 DL, 3 UL
- DwPTS: 24144 * Ts (Ts = 32.55 ns)
- Guard period: 2192 * Ts
- UpPTS: 4384 * Ts

The test models are similar to the test models defined for FDD, but the RB allocation is slightly different. Two frames are defined for the test models in TDD, while only one frame is defined for FDD.

Figure 10 shows the spectrum and power vs. time for a 5 MHz E-TM2 TDD signal, and Figure 11 shows the corresponding frame configuration. Only one of the two frames is shown to make the details easier to see.

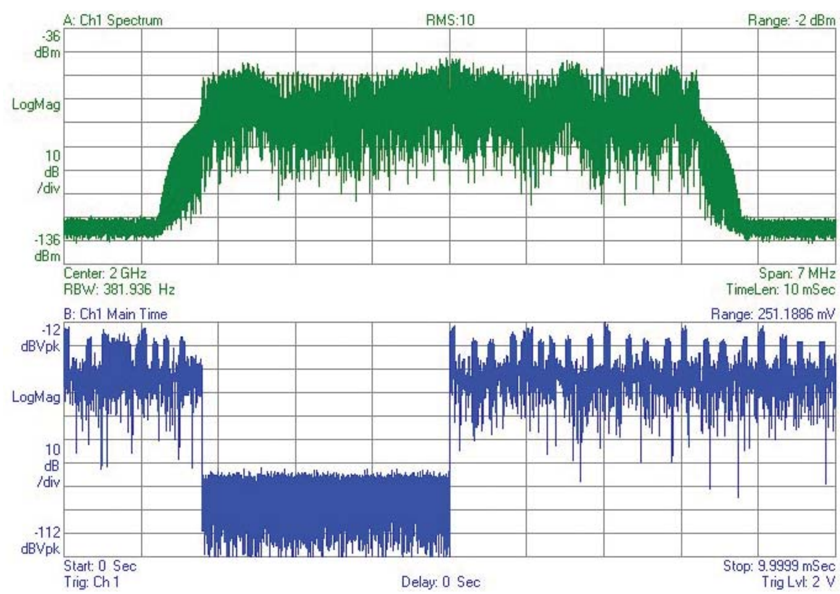


Figure 10. Spectrum and power vs. time for 5 MHz E-TM2 TDD signal

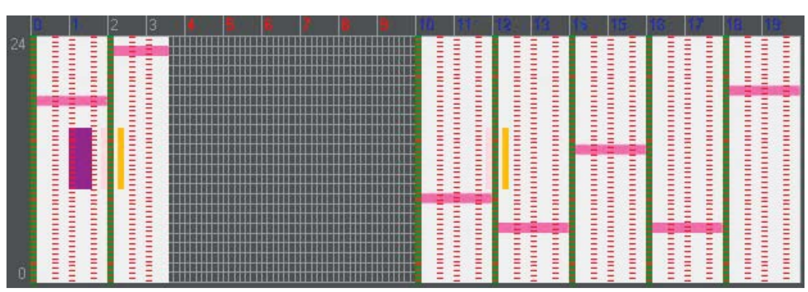


Figure 11. Frame configuration for 5 MHz E-TM2 TDD signal

When a component (especially a power amplifier) is tested with a TDD signal, it may be necessary to synchronize the timing of the input test signal with the measurement of the output signal and with turning the DUT on and off. For example, when the CCDF is measured, it is important to limit the measurement time to the period during which the RF signal is on. Measuring the power for CCDF when the RF burst is off will change the average power value and hence the peak-to-average results. In the case of the E-TM2 signal shown in Figure 10, the calculated 0.01% CCDF value from the N7625B Signal Studio software is 13.82 dB for the RF burst only, but when the entire waveform is included, the value is 15.50 dB. Waveform files created using Agilent's Signal Studio software include a marker output signal at the start of the frame that can be used to trigger other instruments in the test system to aid with synchronization.

5.3 Uplink test signals

There are multiple uplink signals defined in the various standards documents that could potentially be used as test signals for UE power amplifier or transmitter components, or for the BS receiver components.

3GPP TS 36.141 defines uplink signals that are used for testing a BS receiver. These are referred to as reference measurement channels (RMCs). The specific configuration for a particular bandwidth and test is given as a fixed reference channels (FRC) in Annex A. Table 11 shows an example of the FRCs used for performance testing of the BS receiver with QPSK 1/3 modulation and coding. The possibility of using variable reference channels (VRCs) for testing adaptive modulation and coding (AMC) in UMTS was once discussed but never implemented. At this time, the FRC is the only type of RMC defined for LTE, and the terms FRC and RMC are sometimes used interchangeably.

Reference channel	A3-1	A3-2	A3-3	A3-4	A3-5	A3-6	A3-7
Allocated resource blocks	1	6	15	25	50	75	100
DFT-OFDM symbols per sub-frame	12	12	12	12	12	12	12
Modulation	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Code rate	1/3	1/3	1/3	1/3	1/3	1/3	1/3
Payload size (bits)	104	600	1544	2216	5160	6712	10296
Transport block CRC (bits)	24	24	24	24	24	24	24
Code block CRC size (bits)	0	0	0	0	0	24	24
Number of code blocks - C	1	1	1	1	1	2	2
Coded block size including 12 bits trellis termination (bits)	396	1844	4716	6732	15564	10188	15564
Total number of bits per sub-frame	288	1728	4320	7200	14400	21600	28800
Total symbols per sub-frame	144	864	2160	3600	7200	10800	14400

Table 11. FRCs for performance requirements with QPSK 1/3 (Table A.3-1, TS 36.141 V8.5.0)

Table 11 covers the cases of a single RB allocation for A3-1 and full RB allocation (in which all available RBs are used) for the various bandwidths in A3-2 through A3-7. As an example of where these FRCs are used, we will consider the test "Performance requirements for PUSCH" in Section 8.2 of TS 36.141. For a 5 MHz bandwidth, Table 8.2.1.5-3 in TS 36.141 shows that depending on the propagation (fading) conditions, FRC A3-1 or A3-4 may be used to test the BS receiver.

3GPP TS 36.521-1 Annex A.2 defines the RMCs for uplink signals used in UE transmitter testing. Some RMCs are defined for full RB allocation and others for partial RB allocation. For example, Table 12 shows the reference channels for QPSK with full RB allocation.

Parameter	Unit	Value					
Channel bandwidth	MHz	1.4	3	5	10	15	20
Allocated resource blocks		6	15	25	50	75	100
DFT-OFDM symbols per sub-frame		12	12	12	12	12	12
Modulation		QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Target coding rate		1/3	1/3	1/3	1/3	1/5	1/6
Payload size	Bits	600	1544	2216	5160	4392	4584
Transport block CRC	Bits	24	24	24	24	24	24
Number of code blocks - C		1	1	1	1	1	1
Code block CRC size	Bits	0	0	0	0	0	0
Total number of bits per sub-frame	Bits	1728	4320	7200	14400	21600	28800
Total symbols per sub-frame		864	2160	3600	7200	10800	14400

Table 12. Reference channels for QPSK with full RB allocation (Table A.2.2.1.1-1, TS 36.521-1 V8.4.0)

Section A.2.2.2 in TS 36.521-1 defines the FDD reference channels for partial RB allocation for each bandwidth with different modulation types. For a 5 MHz QPSK signal, reference channels are defined with 1, 8, or 20 allocated RBs.

Similar reference channels are defined for TDD, assuming uplink-downlink allocation configuration 1 (see Table 1) and a DL/UL configuration ratio of 2DL:2UL.

Uplink signals with fully allocated RBs may make sense for some BS receiver component tests, and Agilent's Signal Studio software provides predefined configurations for fully allocated signals for the basic uplink carriers. However, in real-world situations a UE will often transmit only partially allocated signals since the UE has to share resources with other UEs in the system. Therefore in testing UE amplifiers or transmitter components, it may be useful to also do some testing with a partially allocated uplink signal. In Signal Studio, the RMCs with partial RB allocation are available as predefined configurations for the advanced uplink carriers, since they are defined in the standards for BS receiver test (in TS 36.141). Figure12 shows the spectrum, power vs. time, and frame structure for a fully allocated 5 MHz uplink signal created with Signal Studio. As one might expect, this signal is very uniform in power. The light gray areas in the frame structure diagram are the allocated PUSCH, while the vertical orange lines are the demodulation RS.

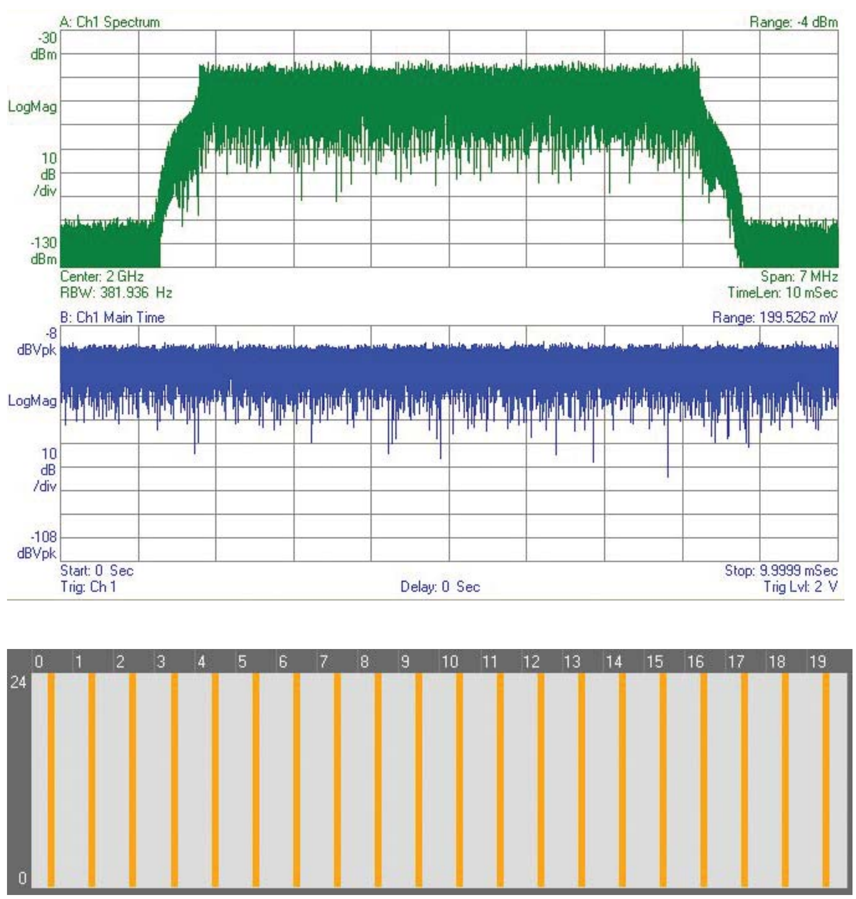


Figure 12. Spectrum, power vs. time, and frame structure for a 5 MHz uplink signal with 25 allocated RBs (QPSK)

Figure 13 shows the same information for a 5 MHz uplink signal with just one RB allocated, as defined for FRC A3-1 (see Table A.3-1 in TS 36.141). In this figure, only RB 0 at the low end of the frequency band is allocated, and the spectrum shows the signal power concentrated at those frequencies. Note that even though no power is supposed to be in the other RBs, the spectrum does show that some is present. For this reason the UE transmitter test of in-band emissions for non-allocated RBs has been defined and will be discussed in more detail later.

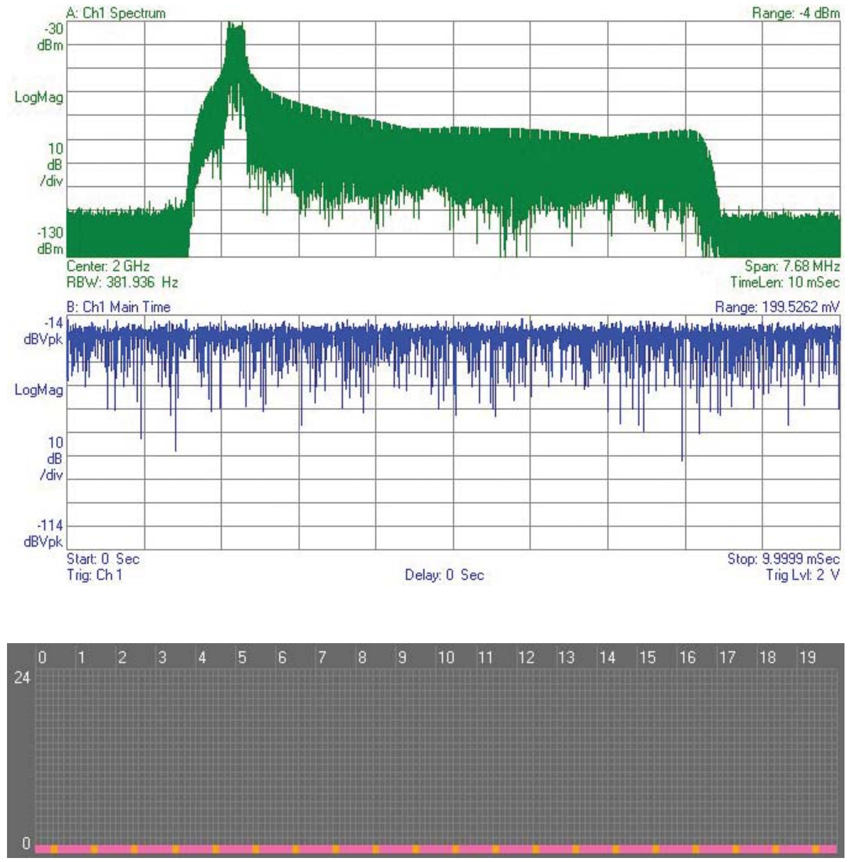


Figure 13. Spectrum, power vs. time, and frame structure for 5 MHz signal with 1 allocated RB (QPSK)

It is also interesting to compare the CCDF characteristics of the uplink signal with those of the downlink signal. Figure 14 shows the calculated CCDF for the 5 MHz fully allocated QPSK uplink signal on the left (the CCDF for the signal in Figure 12 is similar), compared to the CCDF for a fully allocated QPSK downlink signal (E-TM1.1) on the right. The CCDF for the UL signal (yellow trace) shows much lower peak-to-average power characteristics (e.g., the 0.01% value is 6.54 dB vs. 9.52 dB). The lower PAPR allows the use of amplifiers with a smaller linear region in the UE, which is why SC-FDMA was chosen for the UL instead of OFDMA.

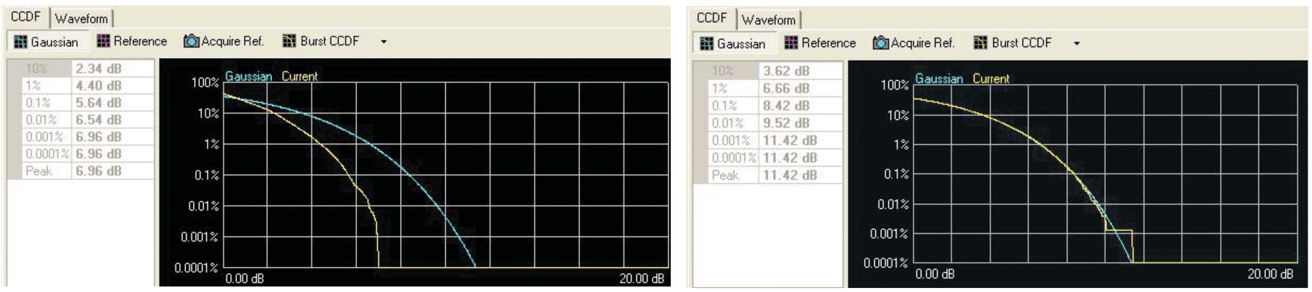


Figure 14. CCDF for 5 MHz fully allocated uplink signal (left) and downlink signal (right)

5.4 Transmission filtering

Unlike previous cellular communications standards such as cdma2000, W-CDMA, or HSPA, the LTE standard does not define a specific transmission filter. This allows various filter implementations, which may optimize either in-channel performance, resulting in improved EVM, or out-of-band performance, resulting in better ACPR and spectrum mask characteristics. There is a trade-off between these characteristics, so optimizing one of them tends to make the other one worse.

For testing components, it is desirable to start with a stimulus signal that has the best possible performance for EVM or ACLR so that any degradation caused by the DUT can be clearly determined. Agilent’s Signal Studio software provides different options for filtering to allow users to modify the EVM and ACPR characteristics of the signal. By default, the software turns on an Agilent-defined baseband filter that provides a good balance between ACPR and EVM performance. To optimize the signal for EVM performance, another type of filtering can be applied by entering a non-zero value for the symbol rolloff length (in units of Ts, where 1 Ts = 32.55 ns). This sets the length of the OFDM windowing that is applied in the time domain to smooth out the discontinuities between OFDM symbols. Increasing the value of this parameter can improve the EVM performance, but it may degrade the ACPR performance.

The examples in the next few figures show results of using different types of filtering. All use a 5 MHz E-TM 1.1 signal that fully allocates all available RBs to the PDSCH using QPSK modulation. Figure 15 shows the results using the default baseband filter. The composite EVM is about 0.53%, while the ACPR is –73.2 dB.

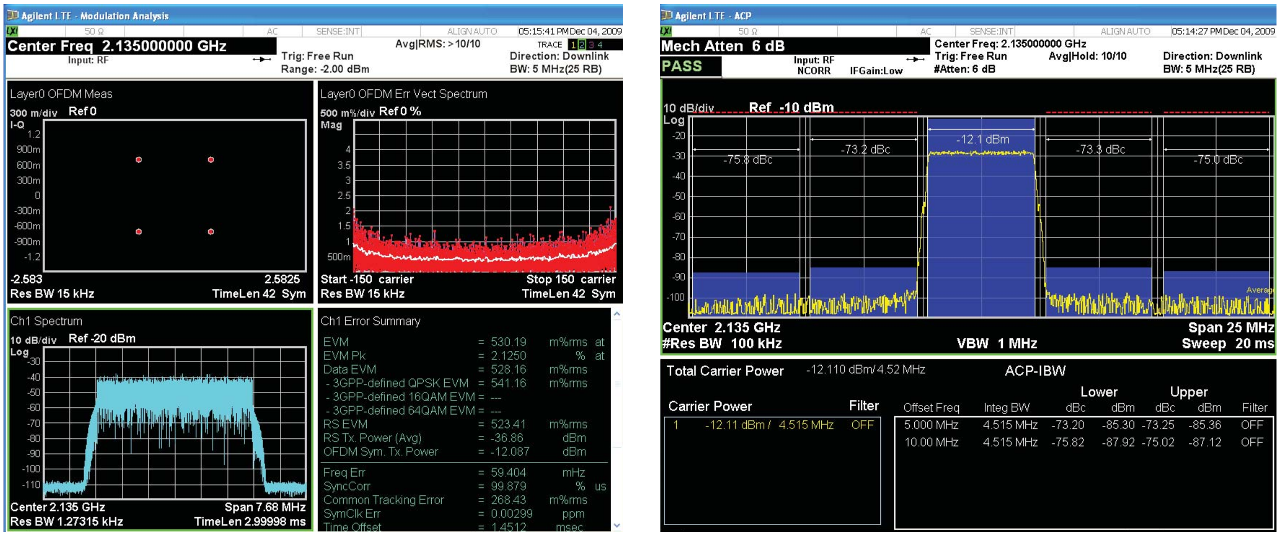


Figure 15. 5 MHz E-TM 1.1 signal with default baseband filter (best ACLR)

Figure 16 shows the results with the baseband filter turned off and the symbol rolloff length set to 20Ts. This combination gives the best EVM, but the spectral regrowth in the adjacent channel is quite high. The EVM is about 0.37% while the ACPR is –43.1 dB.

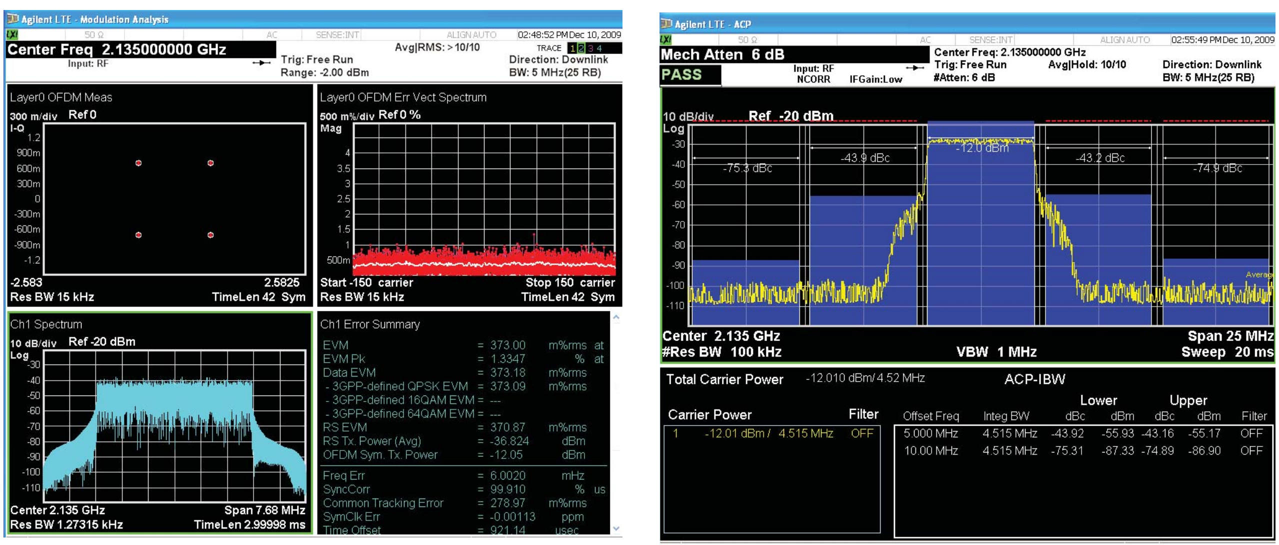


Figure 16. 5 MHz E-TM 1.1 signal without baseband filter and symbol rolloff length = 20 Ts (best EVM)

Both types of filtering can be combined to give better EVM performance while maintaining good ACLR. Figure 17 shows the results with the baseband filter turned on and the symbol rolloff length set to 20 Ts. The EVM is 0.46% while the ACPR is –73.1 dB.

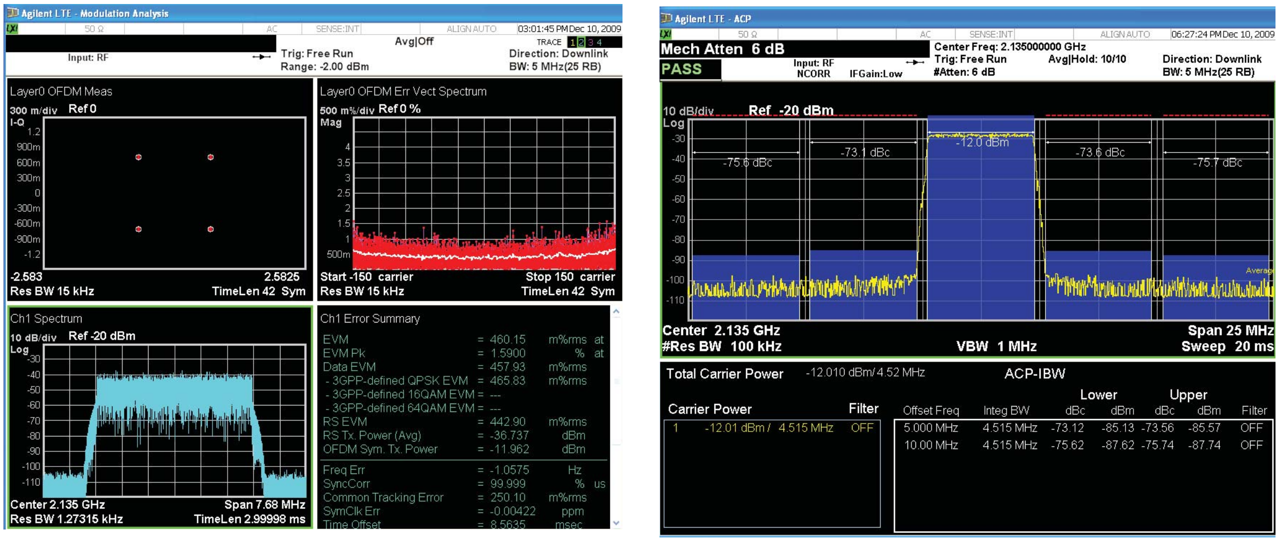


Figure 17. 5 MHz E-TM 1.1 signal with baseband filter and symbol rolloff length = 20 Ts

The measurements in Figure 17 demonstrate the excellent ACLR performance of Agilent's MXG signal generators. A typical measurement of the E-TM 1.1 signal from another vendor's signal generator that has been optimized for best ACLR performance is shown in Figure 18 for comparison. The setup is similar to what was used for Figure 15 with the MXG. Note that the ACLR is –69 dBc compared to about –73 dBc in Figure 15. Depending on the signal parameters, the MXG typically has 3 to 5 dB better ACLR performance than signal generators from other vendors with similar EVM performance, providing additional margin for testing high-performance devices.

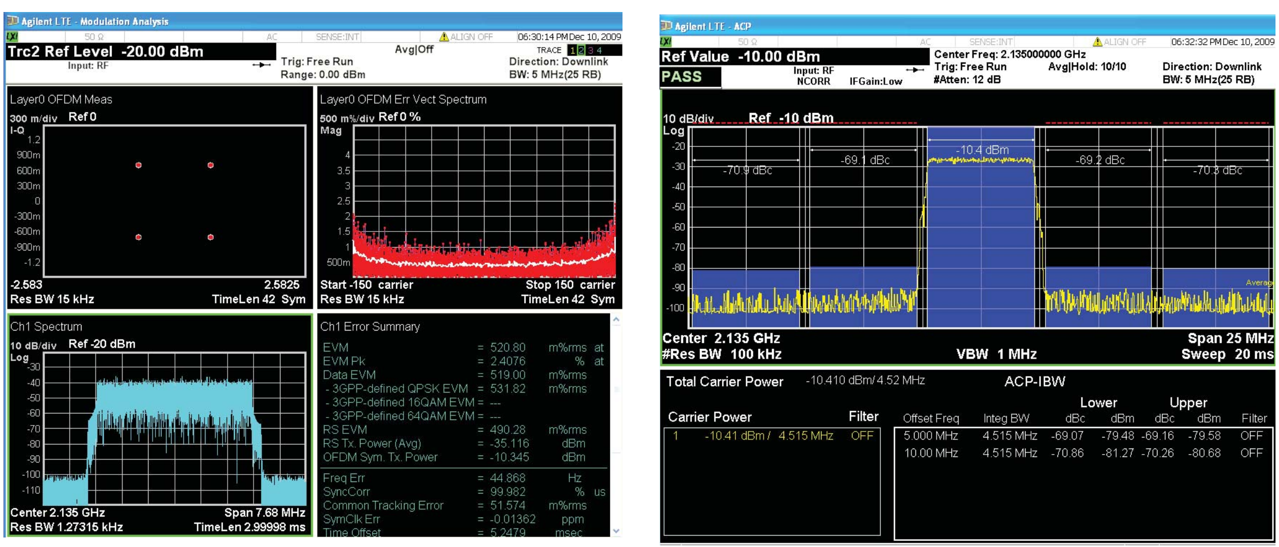


Figure 18. 5 MHz E-TM 1.1 signal optimized for best ACLR from another vendor's signal generator

5.5 Creating multi-carrier signals

Multi-carrier signals are useful for testing base station multi-carrier power amplifiers (MCPAs) or for testing a device with both a desired signal and an interfering signal. Since LTE systems are expected to co-exist with W-CDMA systems, it is useful to be able to create test signals that include both types of carriers. The N7624B Signal Studio for LTE FDD allows the user to create signals containing up to 16 carriers, which may be LTE basic or advanced carriers, downlink or uplink, or basic W-CDMA downlink or uplink carriers. This multi-carrier capability provides a cost savings compared to other solutions that may require the user to purchase separate applications to create the LTE and W-CDMA carriers. Parameters such as frequency offset, power, timing offset, initial phase, and filtering can be set for each carrier. For W-CDMA carriers, the filter setting defaults to a root-raised-cosine Nyquist filter with a rolloff factor alpha = 0.22 as specified in the 3GPP standards, although other filter types are available.

To create signals that combine LTE carriers with formats other than W-CDMA, solutions are available that allow combining of either baseband signals or RF signals. Baseband combining can be accomplished with products such as Agilent's N5106A PXB baseband generator and channel emulator, which can play back signals from up to six baseband generators and sum them, allowing the combined signal to be upconverted to RF using a single signal generator. Each baseband generator in the PXB can generate a signal from a different Signal Studio application, with different frequency offsets and amplitudes. This solution may be less expensive than an RF combining solution in which multiple signal generators are used to create separate RF signals, which are then summed together and applied to the DUT. However, the RF combining solution provides better dynamic range between the desired and interfering signals, making it more suitable for receiver testing applications.

5.6 Adding impairments

During the design phase, it may be useful to test components with signals that contain specific impairments. Impairments can be used to stress test a device or to simulate characteristics that may be added to a signal from other components in the transmit or receive chain. Impairments can also be used to correct for imperfections in the test signals.

Most signal generators allow the addition of various I/Q impairments such as I/Q offset, gain balance, quadrature angle, skew, and delay. Some instruments such as Agilent's N5162A and N5182A MXG RF vector signal generators also allow the addition of phase noise impairments.

6. Measurement and Analysis of LTE Signals

The main measurements for testing LTE components were listed earlier and include the following:

- Output power
- Frequency error
- EVM
- IQ parameters (offset, gain imbalance, skew, quadrature error)
- Peak-to-average power (CCDF)
- ACRL or ACPR
- Spectrum emission mask
- Spectrum flatness (uplink)
- In-band emissions for non-allocated RB (uplink)
- Spurious emissions

These measurements can be made using Agilent's LTE FDD and LTE TDD measurement applications for the X-Series signal analyzers (MXA/EXA), or using 89600 VSA software with LTE FDD or LTE TDD modulation analysis.

The next sections will discuss each of these measurements in more detail. For step-by-step instructions on how to perform these measurements using Signal Studio and the MXA/EXA applications, please refer to the *N9080A and N9082A LTE Modulation Analysis Technical Overview with Self-Guided Demonstration* (literature number 5989-6537EN), which is available for download from the Agilent Web site. The *89600 Vector Signal Analysis Software 3GPP LTE Modulation Analysis Technical Overview and Self-Guided Demonstration* (literature number 5989-7698EN) is also available with instructions for the VSA software.

6.1 Output power measurements

For this application note, output power measurements refer to channel power and occupied bandwidth. Channel power indicates the mean power within the appropriate integrated channel bandwidth. Occupied bandwidth measures the bandwidth of the LTE signal that contains 99% of the channel power. Both of these are available as one-button measurements in the N9080A and N9082A applications for the Agilent X-Series signal analyzers, which have predefined settings for all bandwidths of LTE signals. The measurements can also be performed easily with the 89600 VSA software, using the band power marker function for channel power and the occupied bandwidth marker function.

For the downlink, the conformance tests use E-TM 1.1 for these tests. For the uplink, there are multiple conformance tests for output power using different signal configurations, with partial and full RB allocations. The RMCs are specified in Annex A.2 and the RB allocations are defined in several tables in Sections 6.2 and 6.3 in TS 36.521-1.

Note that for TDD signals, a time-gated measurement is necessary to ensure that data is captured during the period when the burst power is on. The gated LO function in the X-Series analyzers (under the [**Sweep/Control**] front-panel key) or the time gate function in the VSA software should be used to define the measurement period. The standard does not specify the time period for the measurement, but typically it is performed during the period in which burst is completely on, not including the ramp up or ramp down time. The waveform files created by Signal Studio include a frame start marker (marker 1) that can be used as an external trigger for the gating function. The signal from the EVENT 1 output of the signal generator should be connected to the Trigger 1 IN connector on the rear panel of the X-Series analyzer. Figure 19 shows the channel power measurement using an MXA for a TDD signal with gate view turned on.

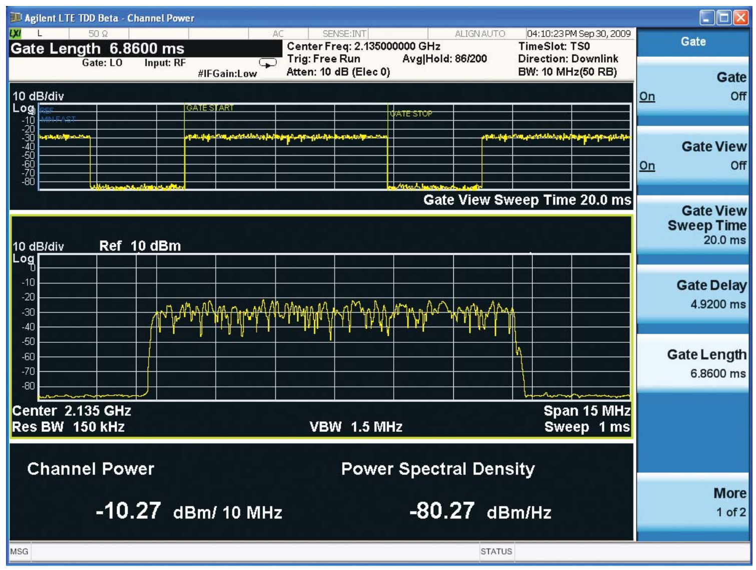


Figure 19. LTE TDD channel power measurement with Gate View on

6.2 Frequency error, error vector magnitude, and IQ parameters

Frequency error is the offset of the signal's center frequency from the desired center frequency and can be caused by problems in the transmit RF section such as LO frequency error. EVM is a key test of modulation quality for a transmitter and indicates the amount of distortion in the signal. IQ error measurements can reveal some of the possible sources for the distortion. The UE transmitter conformance tests require the measurement of the carrier leakage or IQ origin offset, which can be an indicator of the carrier feedthrough or a DC offset in the baseband signal (3GPP TS 36.521-1, Section 6.5.2.2).

The frequency error, EVM, and IQ parameters are reported in the Error Summary trace in the X-Series applications or VSA software, as shown in Figure 20. To obtain the Error Summary results, the modulation analysis parameters need to be set up properly to demodulate the LTE signal. This configuration includes basic parameters such as channel bandwidth, DL or UL, channel profile, and measurement time setup, as well as more advanced parameters such as the equalizer settings and EVM window length. Both the X-Series applications and the 89600 VSA provide convenient preconfigured setup files for EVM measurements of the E-TM signals. These setups are accessed by following the steps below.

- *X-Series applications*
  - Start the LTE application: [**Mode**] **> LTE**
  - Select the Modulation Analysis measurement: [**Meas**] **> More > Modulation Analysis**
  - Recall the EVM setup file: [**Recall**] **> Data > EVM Setup > Open**. Navigate to the folder **My Documents\LTE\data\evmsetup** if it is not already open. Select the filename that matches the test model number and channel bandwidth and click **Open**.
- *89600 VSA*
  - After the VSA software is started, go to **File > Recall > Recall Setup**
  - Navigate to the folder **C:\Program Files\Agilent\89600 VSA\Help\Signals\LTE\E-TM**
  - Select the file matching the signal bandwidth and E-TM number and click **Open**
  - The setup file assumes you are playing back a recording file, so you may see an error message if an appropriate recording file does not exist. Click **OK** to dismiss any error messages. Select **Input > Data From > Hardware** and click on the **Restart** (play) button to start the measurement.
  - Set the center frequency and range as needed for the LTE signal being measured.

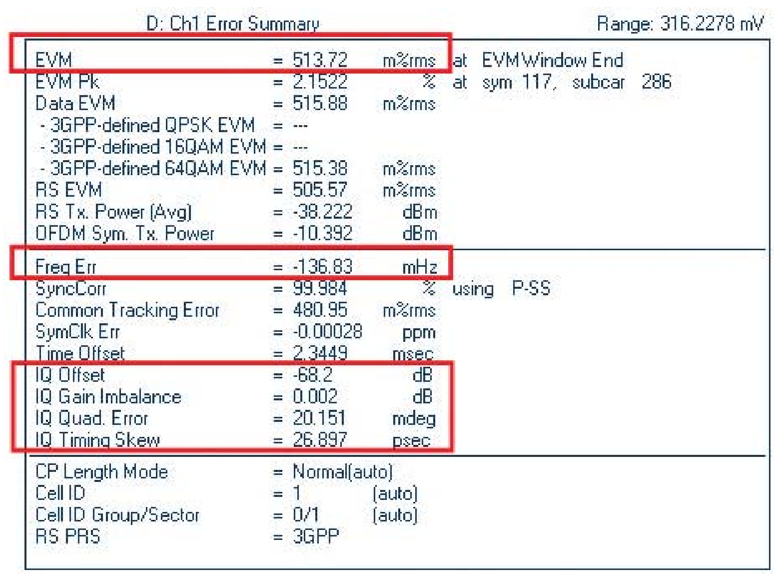


Figure 20. Error summary trace, including frequency error, EVM, and IQ errors

6.3 Peak-to-average power ratio (PAPR) or CCDF

The concepts of PAPR and CCDF were discussed earlier. The X-Series LTE applications provide one-button CCDF measurements and the 89600 VSA also offers CCDF measurements. For TDD signals, the measurement should be limited to a time period in which the RF burst is turned on, since measuring the power during the time when the burst is off will result in an incorrect average power value and cause errors in the CCDF measurement. The frame start marker from the EVENT 1 output in the ESG or MXG signal generator can be used as an external trigger to the signal analyzer for the measurement. In the 89600, the measurement time can be limited by changing the Main Time length or using time gating. In the LTE TDD X-Series application, the user can select the CCDF measurement, go to [**Meas Setup**], and set the [**Meas Offset**] and [**Meas Interval**] times to specify the time span of the measurement. The slot view can also be turned on to show the selected measurement interval by going to [**View/Display**] **> Slot View On**, as shown in Figure 21.

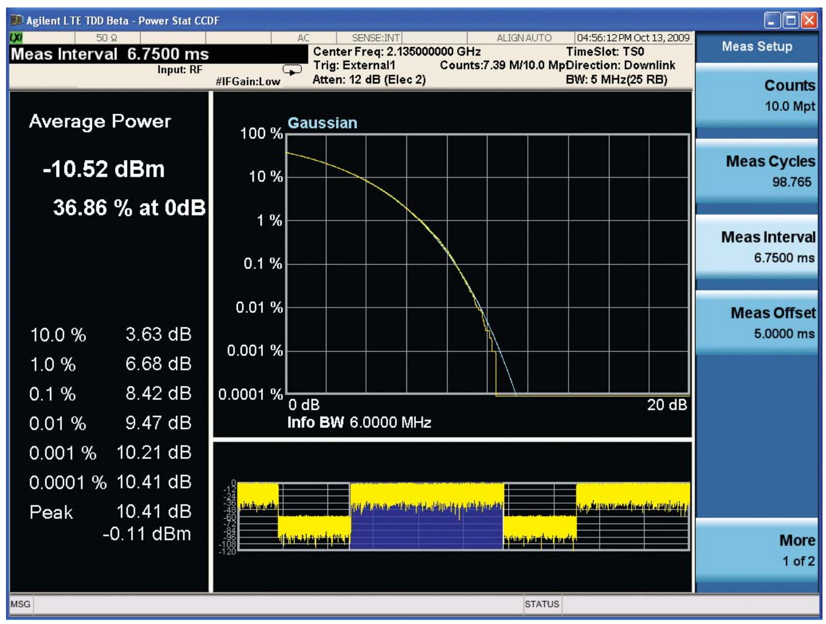


Figure 21. CCDF for downlink LTE TDD downlink signal

6.4 Adjacent channel leakage power ratio (ACLR) or adjacent channel power ratio (ACPR)

ACLR is a key transmitter characteristic and an important parameter to test in power amplifiers, since power amplifiers are a key contributor of distortion in the transmit chain. LTE systems have to co-exist with W-CDMA systems in the same frequency bands, so the LTE RF conformance tests include cases in which the adjacent channels can be either an E-UTRA (LTE) signal or a UTRA (W-CDMA) signal. All E-UTRA channels are measured using a square filter (essentially the same as no filter), while UTRA channels are measured using a root-raised-cosine filter with a rolloff factor of 0.22 and a bandwidth equal to the chip rate (e.g., 3.84 MHz). For base station (downlink) components, the tests are performed using E-TM 1.1 in which all of the PDSCH RBs have the same power, and with E-TM 1.2 in which power boosting and deboosting are used, as previously described. For UE components, the uplink RMCs are specified in Annex A.2 and the tests are performed with both full and partial RB allocation, as defined in Table 6.6.2.3.4.1-1 in TS 36.521-1.

Setup of the ACLR measurement includes configuration of the carriers, offset frequencies, integration bandwidths, resolution and video bandwidths, measurement filters, and limit test. The X-Series LTE application provides a one-button ACP measurement that greatly simplifies the setup process. Once the ACP measurement is selected, the user can recall the appropriate parameters and test limits from a list of available choices using these steps and keystrokes:

- [**Recall**] **> Data > Mask > Open**.
- Open the folder **My Documents\LTE\data\masks**.
- Choose either the **ACP_BS** folder or **ACP_MS** folder, depending on whether you are testing a downlink or uplink signal. The folder contains files for each signal bandwidth for paired or 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.
- Open the appropriate file to recall the settings and limit lines. The correct measurement filters will be selected based on the carrier types.

By default the limit lines are absolute limits and may appear above the top edge of the graticule. To change them to relative limits, go to [**Meas Setup**] **> Offset/ Limits > Limits > Fail Mask** and select **Relative**. Note that these limits are usually more lenient than what is desired from a component, since the limits are intended for a complete BS or UE transmitter, so it may be useful to edit the limits for component testing and save the setups.

The quick setups will provide good ACLR measurements according to the LTE standard, but the analyzer settings can be optimized to provide even better performance. Methods for improving the ACLR measurement include the following:

1. Optimizing the signal level at the input mixer for dynamic range
2. Turning on noise correction
3. Changing the measurement method to use filtered integration bandwidth

To minimize clipping and prevent overload, the signal analyzer automatically selects an attenuation value based on the current measured signal level at the input mixer. A combination of mechanical and electronic attenuation may be used in analyzers that contain both types of attenuators. This is not necessarily the best attenuation for maximum dynamic range, and it is often possible to improve the ACLR by reducing the attenuation slightly. If the electronic attenuator is enabled, turning it off (not just setting the attenuation to 0 dB) can further improve the results.

Turning on noise correction can provide a substantial improvement in the ACLR, particularly when the distortion being measured is close to the noise floor of the analyzer. With noise correction, the analyzer takes one sweep to measure its internal noise floor, and then it subtracts that noise floor from the measurement data in subsequent sweeps.

Finally, the measurement method can be changed. By default, the analyzer uses the integration bandwidth method in which one sweep of the trace is taken and the band power for each offset is computed. For maximum dynamic range, the filtered integration bandwidth method can be chosen. With this method, a sharp cutoff band pass filter is used to limit the resolution bandwidth. This technique increases the dynamic range but also increases the measurement time. The absolute accuracy of the carrier and adjacent or alternate channel power levels may be degraded by up to 0.5 dB, but the ACLR measurement accuracy is not degraded since it is a relative power measurement.

The combination of these optimization methods can improve a typical ACLR measurement by 10 dB or more from the default settings.

6.5 Spectrum emission mask

The spectrum emission mask (SEM) measurement covers the operating band unwanted emissions tests from 3GPP TS 36.141 Section 6.6.3 for base stations and TS 36.521-1 Section 6.6.2 for UEs. These tests measure the out-of-channel emissions over a frequency span that includes the operating band plus one channel above and one channel below the band edge frequencies.

Setup for the SEM measurement is much like the setup for ACLR and includes configuration of the carrier, offset frequencies, integration bandwidths, resolution and video bandwidths, and test limits. As with ACLR, the X-Series LTE application provides predefined limit masks for the SEM measurement, as well as allowing manual configuration of the parameters. To access these masks, use these keystrokes: [**Recall**] > **Data** > **Mask** > **Open**. Navigate to the folder **My Documents\LTE\data\masks**. Choose either the **SEM_BS** folder or **SEM_MS** folder, depending on whether you are testing a downlink or uplink signal. The names of the files indicate the signal bandwidth, Category A or Category B limits, below 1 GHz or above 1 GHz, limits for the additional requirements that apply in certain regions, and limits for the additional requirements for bands 12, 13, 14, and 17. The default limit lines are absolute limits that assume the DUT is transmitting at the maximum power as defined in the conformance tests, but these limit lines can be changed to relative limits as described in the previous section for ACLR. Figure 22 shows an example SEM measurement for a 10 MHz E-TM 1.1 signal.

Similar to ACLR, the SEM limits are less strict than what is desired from a component, so it may be necessary to edit the limit values to make them more appropriate for component test.

Figure 22. Spectrum emission mask measurement for 10 MHz E-TM 1.1 signal

6.6 Spectrum flatness (uplink)

EVM equalizer spectrum flatness is part of the transmit signal quality conformance test for a UE transmitter (3GPP TS 36.521-1, Section 6.5.2.4). It is a useful test in addition to EVM, because EVM measurements are typically performed after the analyzer has estimated and removed the amplitude and phase errors over frequency through the equalization process, as defined in the standard. These errors may be overlooked if only EVM is considered. Spectrum flatness measures the relative power variation across the subcarriers of the allocated RB over one slot in the time domain, for 20 measurements in a frame. The test is performed with a fully allocated uplink signal with QPSK modulation for the RBs, so a test signal can be created using the default uplink carrier configuration in the Signal Studio software, with the appropriate bandwidth and QPSK modulation selected for the channel configuration.

The spectrum flatness measurement can be made by examining the equalizer channel frequency response results that come from the equalization process. This is one of the data types available in the 89600 VSA software and the modulation analysis measurement in the X-Series application. Both applications also provide a display that shows the equalizer channel frequency response per slot, with each slot in a different color trace, as shown in Figure 23. The measurement interval can be modified to focus on the result for a specific slot if desired.

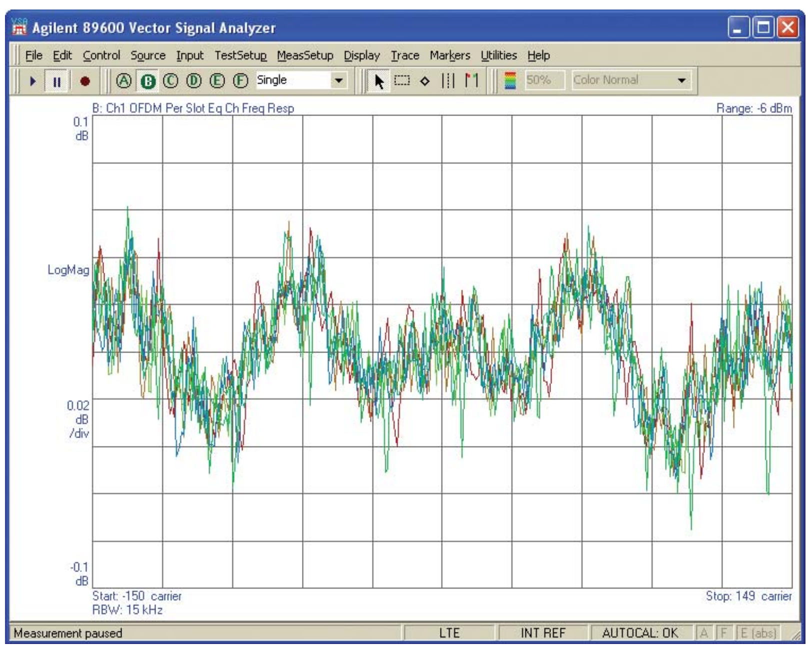


Figure 23. Per slot equalizer channel frequency response for a 5 MHz UL signal

6.7 In-band emissions for non-allocated RB (uplink)

As previously discussed, it is normal for a UE to occupy only a portion of the channel bandwidth, since the uplink channel is shared with other UEs. Figure 12 shows that there can be signal leakage within the channel bandwidth that can cause interference with other UEs, and the in-band emissions for non-allocated RB test is a measure of the amount of power that the UE may transmit into the non-allocated RB. This test applies only to UE transmitters and components. Although the test is not yet fully defined, sufficient information is available for component testing.

The UL signal is configured using the RMC specified in Annex A.2 with partial RB allocation in which the starting RB is defined to be RB #0 and RB# (max +1 – RB allocation) for the channel bandwidth (see Table 6.5.2.3.4.1-1 in 3GPP TS 36.521-1).

There are three types of in-band emissions that are defined: general, IQ image, and DC. General applies to any non-allocated frequencies. The measurement bandwidth is one RB and the measurement is the ratio of the measured power in one non-allocated RB to the measured average power per allocated RB, with the averaging done across all allocated RBs. IQ image applies to image frequencies that are within the allocated bandwidth, based on symmetry with respect to the center frequency, excluding any allocated RBs. The DC measurement applies to the RB containing the center frequency when the number of available RBs is odd, or the two RBs immediately adjacent to the center frequency if the number of resource blocks is even, excluding any allocated RB. For DC, the measurement bandwidth is one RB and the test limit is the ratio of the measured power in one non-allocated RB to the measured total power in the applicable allocated RBs.

These measurements can be performed using the "RB Power Spectrum" data display. This is one of the "Demod" data types in the 89600 VSA software, and one of the "Demod Error" data trace types in the X-Series application. Relative markers can be used to measure the ratio of power in the non-allocated vs. allocated RBs. A detailed example of these measurements is given in the demo guide for the X-Series application which can be downloaded from **www.agilent.com** by using the document literature number "5989-6126EN" as the search term.

Figure 24 shows a measurement of a 5 MHz uplink signal using the X-Series application. The signal has 8 allocated RBs with QPSK modulation as stipulated in 3GPP TS 36.521-1 Table 6.5.2.3.4.1-1. There are 25 available RBs (numbered RB #0 to RB #24), so the DC component would be included in the center RB (#12). Figure 24 shows marker 1 displaying the power at RB #6 for slot 0, while marker 2 shows the power at RB #18, which is the image of RB #6, since both are the 6th RB away from the center. In addition to “Marker X,” which can be set to a point in the x-axis (RB #), “Marker Z” can be used for the time axis to select a specific slot to measure.

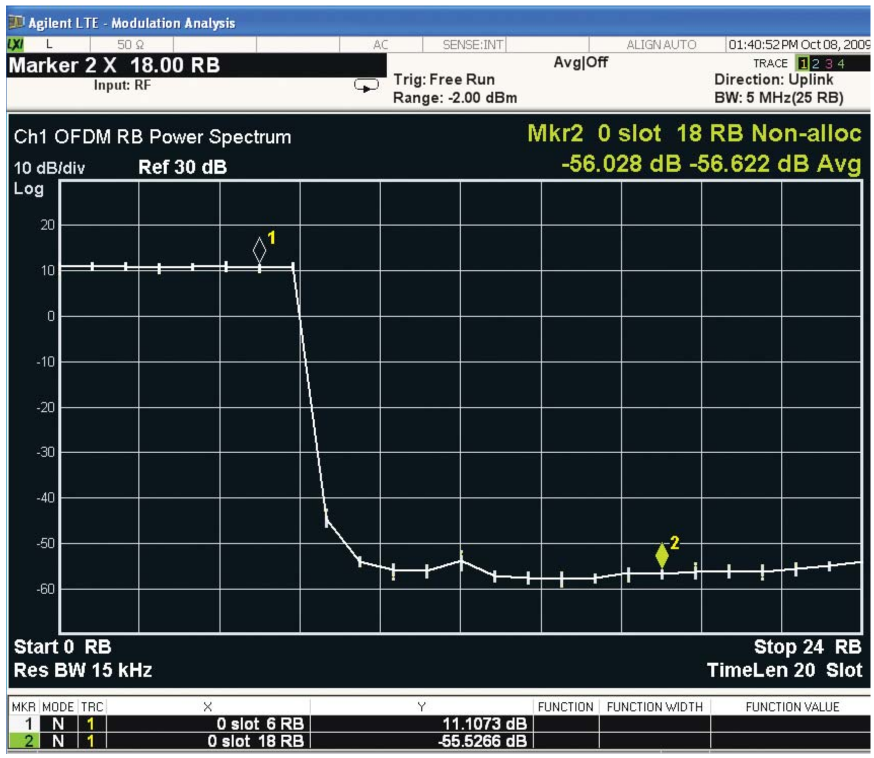


Figure 24. RB power spectrum

6.8 Spurious emissions

Spurious emissions can be caused by transmitter problems such as harmonics, intermodulation products, and frequency conversion products in the power amplifier or other transmit chain components. The conformance tests measure these out-of-band emissions from 9 kHz to 12.75 GHz (excluding the frequency range that is covered by the SEM test) to ensure protection of other radio systems that may be operating in the same geographical area. The conformance tests include the test limits that apply in various frequency ranges, along with the measurement bandwidth to be used in each.

The spurious emission test is performed using the E-TM 1.1 signal for the downlink. For the uplink, the test is performed with three configurations: full RB allocation, one RB allocation located at RB #0, and one RB allocation located at RB #maximum using the RMC defined in Annex A.2.2.

The X-Series application includes a spurious emission measurement that identifies and measures the power level of spurious emissions in the 3GPP defined frequency bands. The measurement allows you to set up a table of frequency ranges with measurement bandwidths and filter types, spur threshold values, and pass/fail limits. The application includes a default range table based generally on the limits for Category B, but the frequencies and limits are not specifically set up for particular LTE frequency bands. Also, the conformance tests contain test limits for specific situations such as co-existence with other systems such as GSM900, DCS1800, PCS1900, PHS, and public safety radio systems, and these situations may not be applicable as they are dependent on regional regulations and the operating band of the LTE equipment. Therefore, the range table should be edited to include the applicable requirements. The conformance test limits may be found in 3GPP TS 36.141 Section 6.6.4 for the BS and 3GPP TS 36.521-1 Section 6.6.3 for the UE.

To improve the signal analyzer's dynamic range for these measurements, the input attenuation settings can be optimized under the **[Amplitude]** menu.

Summary

This application note covered testing requirements and considerations for LTE components and provided information on test equipment setups, creating LTE stimulus test signals for components, and analyzing LTE signals from components and transmitters. Additional information about Agilent's LTE solutions is available online at **www.agilent.com/find/lte**.

Free downloads and free trials are available for the Signal Studio software, 89600 VSA software, and the X-Series measurement applications. These provide a good way to examine the capabilities of Agilent's LTE products in more detail and to explore and learn about the physical layer characteristics of LTE. The demo guides for the 89600 VSA and the N9080A/N9082A X-Series LTE measurement applications provide a comprehensive introduction to the features in those applications.

Literature References and Web Resources

LTE general information

3GPP Long Term Evolution: System Overview, Product Development, and Test Challenges, Agilent Application Note, Literature number 5989-8139EN

Understanding the Intricacies of LTE Agilent Poster, Literature number 5989-7646EN

LTE and the Evolution to 4G: Wireless Design and Measurement Challenges, book written by Agilent experts, available from Wiley: **www.wiley.com**

3GPP Series 36 (LTE) specifications:
www.3gpp.org/ftp/Specs/archive/36_series

Agilent LTE Web page, containing links to application notes, Webcasts, literature, and additional resources:
www.agilent.com/find/lte

LTE application demonstration guides

Agilent N9080A LTE FDD and N9082A LTE TDD Measurement Applications Technical Overview with Self-Guided Demonstration, Literature number 5989-6537EN

Agilent 89600 Vector Signal Analysis Software LTE Modulation Analysis Technical Overview and Self-Guided Demonstration, Literature number 5989-7698EN
www.agilent.com/find/89600

Product information

Move Forward to What's Possible in LTE, Agilent Brochure, Literature number 5989-7817EN

Agilent N5182A MXG and N5162A MXG ATE Vector Signal Generator **www.agilent.com/find/mxg**

Agilent E4438C ESG Signal Generator
www.agilent.com/find/E4438C

Agilent N7624B Signal Studio for LTE FDD
Agilent N7625B Signal Studio for LTE TDD
Technical overview and online documentation available from product Web pages: **www.agilent.com/find/signalstudio**

Agilent N9020A MXA Signal Analyzer
www.agilent.com/find/mxa

Agilent N9010A EXA Signal Analyzer
www.agilent.com/find/exa

Agilent N9030A PXA Signal Analyzer
www.agilent.com/find/pxa

Agilent 89600 Vector Signal Analysis Software LTE Modulation Analysis
www.agilent.com/find/89600

Agilent Oscilloscope Family
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Agilent 16800 Series Portable Logic Analyzer
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