Analysis and Measurement of Long Term Evolution Physical Downlink Shared Channel

Raman Trivedi, Rashi Bhargava

Abstract— LTE (Long Term Evolution) is a next generation standard by 3rd Generation Partnership Project (3GPP) consortium. In this paper, the physical layer (PHY) of LTE transceiver is analyzed in downlink transmission for Tactical LTE application. Simulations of the physical layer of LTE transceiver are obtained with the use of LTE System Libraries by AWR Visual System Simulator (VSS) ver.10.04-trial license. The LTE resource grid for transmission on air is generated using Mathworks MATLAB 2014b LTE System Toolbox- Evaluation License. Measurements of PvT, Occupied bandwidth, CCDF and BER are obtained using Texas Instruments Evaluation Modules (EVMs). These results are presented to show the performance of LTE transceivers in Physical Downlink Shared Channel (PDSCH).

Index Terms— CCDF, eNode-B, EVMs, LTE, MIMO, OFDM, PDSCH, PHY, PvT, Simulation.

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1 INTRODUCTION

We live in the era of a mobile data revolution that has been witnessed by the mass-market expansion of smartphones, tablets, notebooks, and laptop computers. Users demand services and applications from mobile communication systems that go far beyond mere voice and conventional telephony. The growth in data intensive mobile services and applications such as Web browsing, social networking, and music & video streaming has become a driving force for development of the next generation of wireless standards. As a result, new standards are being developed to provide the data rates and network capacities necessary to support worldwide delivery of these types of rich multimedia applications while using highly spectrum efficient communication techniques for mobile cellular technology.

LTE (Long Term Evolution) and LTE-Advanced have been developed to respond to the requirements of this epoch and to realize the goal of achieving global broadband mobile communications. The goals and objectives of this evolved system architecture include higher radio access data rates, improved system capacity and coverage, flexible bandwidth operations, significantly improved spectral efficiency, low latency, reduced operating costs, multi-antenna support, and seamless integration with the Internet and existing mobile communication systems. LTE and LTE-Advanced are representatives of what is known as a fourth generation wireless systems. The overview of the wireless standards evolution is shown in Fig. 1. In the past two decades, we have seen the introduction of various mobile standards, from 2G to 3G to the present 4G, and the trend would continue further as specifications for 5G are already getting formalized by international bodies.

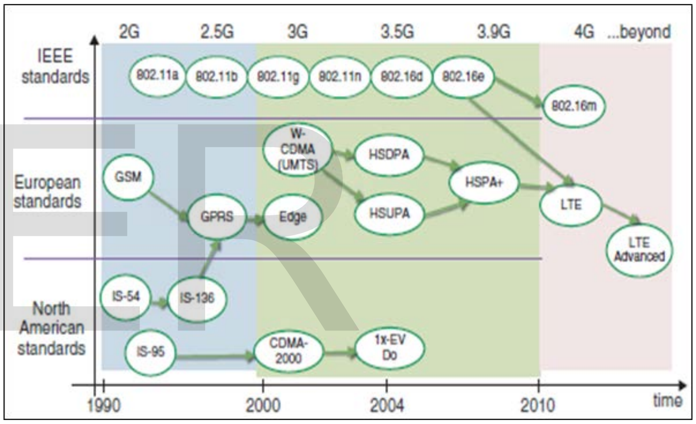

Fig. 1: Evolution of Wireless Standards

The primary mandate of 2G standards was to support mobile telephony and voice applications. The 3G standards marked the beginning of packet-based data revolution and support for Internet applications such as e-mail, Web browsing, text messaging and other client-server services on the move. The 4G standards will feature all-IP packet-based networks and support the explosive demand for bandwidth-hungry applications such as mobile video-on-demand services. Peak data rate requirements addressed by various wireless standards over the past two decades are given in Table I.

This paper is organized as follows: In Section II, brief about LTE Release8 requirements and enabling technologies are given with the preview of key advancements in Release10 and beyond. In Section III, the PDSCH transmission is analyzed and the results are shown. Part A shows the resource grid generation using LTE System Toolbox and also the analysis & simulation results that are carried out with LTE System Libraries of AWR's Visual System Simulator (VSS) for the Physical

Table I: Peak Data Rate Requirements of Various Wireless

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Standards

Technology	**Theoretical Peak Data Rate (at low mobility)**
GSM	9.6 kbps
IS-95	14.4 kbps
GPRS	171.2 kbps
EDGE	473 kbps
CDMA-2000 (1xRTT)	307 kbps
WCDMA (UMTS)	1.92 Mbps
HSDPA (Rel. 5)	14 Mbps
CDMA-2000 (1x-EV-DO)	3.1 Mbps
HSPA+ (Rel. 6)	84 Mbps
WiMAX (802.16e)	26 Mbps
LTE (Rel. 8)	300 Mbps
WiMAX (802.16m)	303 Mbps
LTE-Advanced (Rel. 10)	1 Gbps

Downlink Shared Channel (PDSCH). Testing and measurements conducted using Texas Instrument's High Speed Analog Evaluation Modules for LTE downlink transmitter is presented in Part B. Finally, conclusions are given in Section IV for further discussions.

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2 LTE REQUIREMENTS AND ENABLING TECHNOLOGIES

The LTE standard specified by the 3rd Generation Partnership Project (3GPP) in Release8, defines the next evolutionary step in 3G technology [9]. LTE offers significant improvements over previous technologies such as Universal Mobile Telecommunications System (UMTS) and High-Speed Packet Access (HSPA) by introducing a novel physical layer and reforming the core network architecture. The main reasons for these changes in the Radio Access Network (RAN) system design are the need to provide higher spectral efficiency, lower delay, and more multi-user flexibility than the currently deployed networks. LTE requirements cover two fundamental components of the evolved UMTS system architecture: the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC) as shown in Fig. 2.

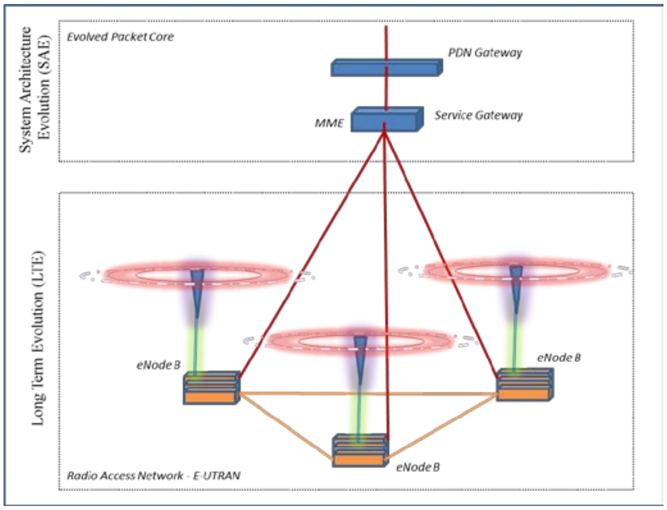

Fig. 2: Flat architecture of LTE

The enabling technologies of LTE and their evolution include OFDM, MIMO, turbo coding, and dynamic link-adaptation techniques. The LTE radio interface is based on Orthogonal Frequency Division Multiplex (OFDM); OFDM Access (OFDMA) in downlink (DL) and Single Carrier Fre uency Division Multiple Access (SC-FDMA) in uplink (UL). OFDM is an attractive modulation technique in a cellular environment to combat frequency selective fading channels with a relatively low- complexity receiver. The main reason why LTE selects OFDMA to the multipath fading channel, high spectral efficiency, low-complexity implementation, ability to provide flexible transmission bandwidths and support for advanced features such as frequency-selective scheduling, MIMO transmission, and interference coordination etc. However, one of the drawbacks of OFDMA multicarrier transmission is the large variations in instantaneous transmit power due to high peak-to-average power ratio (PAPR), which implicates an inherently inefficient power amplifier and results in higher mobile-terminal power consumption. In UL transmission, the design of complex power amplifiers is especially challenging. As a result, a variant of the OFDM transmission known as SC-FDMA is selected in the LTE standard for UL transmission. The Multiple Input Multiple Output (MIMO) methods can improve mobile communication in two different ways: by boosting the overall data rates and by increasing the reliability of communication link. In the LTE standard, turbo coding is the only channel coding mechanism used to process user data. Link adaptation is defined as a collection of techniques for changing and adapting the transmission parameters of a mobile communication system to better respond to the dynamic nature of the communication channels. Depending on the channel quality, we can use different modulation and coding techniques (adaptive modulation and coding), change the number of transmit or receive antennas (adaptive MIMO), and even change the transmission bandwidth (adaptive bandwidth) and transmission power (automatic transmit power control) as well. All of these methods enable operators to deploy LTE in different regions with different frequency bands and bandwidths available to fulfil the following goals for the overall system:

- Improved system capacity and coverage
- High peak data rates
- Low latency (both user-plane and control-plane)
- Reduced operating costs

- Multi-antenna support (SIMO, MIMO, MISO)
- Flexible bandwidth operations and
- Seamless integration with legacy & existing systems (GSM, UMTS, Wi-Fi, etc.)

LTE documentation was formalized in 2008 (Release8) and LTE-A documentation (Release10) started from release 2010 onwards. The comparison of key parameters and enhancements done in LTE-A w.r.t LTE is given in Table II.

Table II. Comparison of LTE and LTE-Advanced Key Characteristics

	LTE (Release 8)	LTE Advanced (Release 10)
Peak Downlink Data Rate	300 Mb/s	3 Gb/s
Peak Uplink Data Rate	75 Mb/s	1500 Mb/s
Peak DL Spectrum Efficiency	15 bps/Hz	30 bps/Hz
Peak UL Spectrum Efficiency	3.75 bps/Hz	15 bps/Hz
Bandwidth	Up to 20 MHz	Up to 100 MHz
Modulation Schemes	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM
DL Access	OFDMA	OFDMA
UL Access	SC-FDMA	SC-FDMA
MIMO Support	Up to 4x4	Up to 8x8
Carrier Aggregation	No	Yes

3 LTE DOWNLINK TRANSMITTER

As we know that LTE downlink transmission from eNode-B to User's Equipment (UE) is based on OFDMA. LTE is interoperable with widely used technologies such as GPRS, WCDMA and HSPA. The use of OFDMA, MIMO, Robust Channel Coding, Link Adaptation and Scheduling features of LTE made enable mobile operators deploying this to provide a seamless service and multi-mode devices for customers. OFDM transmissions have a unique signature in the frequency domain because the waveform visually resembles a signal that has been filtered by a brick-wall filter. In fact, we can visualize an OFDM signal as a combination of multiple subcarriers as shown in Fig. 3.

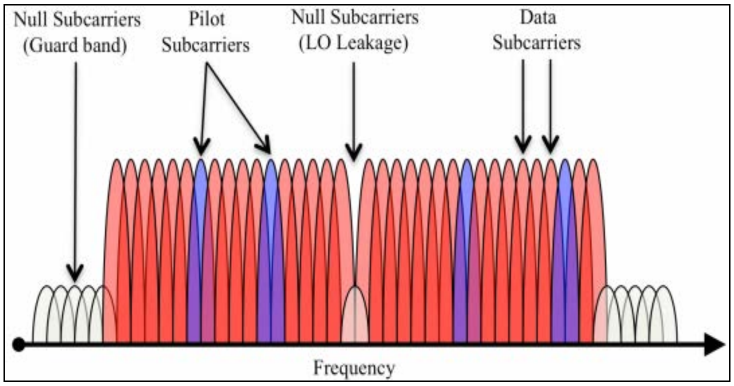

Fig. 3: OFDM Signal in the Frequency Domain

3.1 PDSCH Transmitter System Simulations

AWR Corporation is Electronic Design Automation (EDA) Software Company develops markets, sells and support engineering software that provides a computer-based environment for the design of hardware for wireless and high speed digital products [12]. AWR's product portfolio includes Microwave Office, Visual System Simulator (VSS), Analog Office, APLAC, AXIEM and Analyst. AWR's worldwide customers include companies involved in the design and development of analog and mixed signal semiconductors, wireless communications equipment, aerospace and defense systems [1] [12]. MathWorks develops MATLAB and Simulink—software that transforms the way engineers and scientists think and work. MATLAB® is the high-level language and interactive environment used by millions of engineers and scientists worldwide. It lets you explore and visualize ideas and collaborate across disciplines including signal and image processing, communications, control systems, and computational finance.

LTE downlink processing is a combination of Downlink Shared Channel processing (DLSCH) and Physical Downlink Shared Channel Processing (PDSCH). Physical layer modeling involves all the processing performed on bits of data that are handed down from the higher layers to the PHY. It describes how various transport channels are mapped to physical channels, how signal processing is performed on each of these channels, and how data are ultimately transported to the antenna for transmission.

The LTE transmission scheme provides a time resolution of 12 or 14 OFDM symbols for each subframe of 1ms, depending on the length of the OFDM cyclic prefix. Regarding the frequency resolution, it provides for a number of resource blocks ranging from 6 to 100, depending on the bandwidth, each containing 12 subcarriers with 15 kHz spacing. There are essentially three types of information contained in the physical resource grid. Each resource element contains the modulated symbol of either user data or a reference or synchronization signal or control information originating from various higher-layer channels. Fig. 4 shows the relative locations of the user data, control information, and reference signal in a resource grid as defined for a unicast mode of operation.

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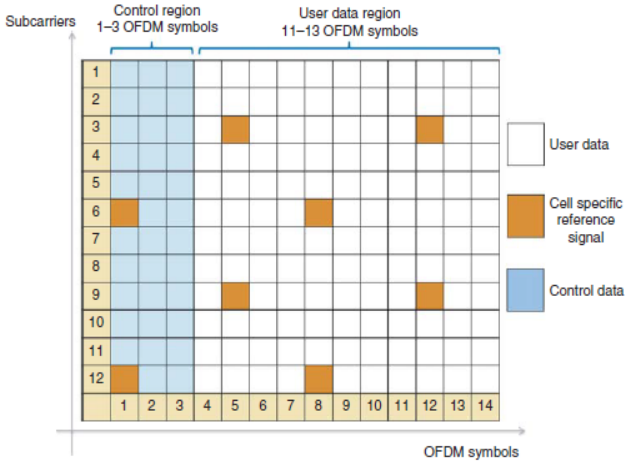


Fig. 4: Physical channel and signal content of LTE downlink subframe in unicast mode

Now, in Fig. 5 we will show the resource grid generated for transmission on air interface before OFDM modulation using LTE System Toolbox. It contains Physical Downlink Control Channel (PDCCH), Physical Downlink Shared Channel (PDSCH), Physical Control Format Indicator Channel (PCFICH), Physical Broadcast Channel (PBCH), Physical Hybrid ARQ Indicator Channel (PHICH) symbols along with Cell-specific Reference (CSR), Primary Synchronization (PSS) and Secondary Synchronization (SSS) signals. We have focussed only on the PDSCH data(2, 3, 4, 11, 12, 13 OFDM symbols in our case) further [3].

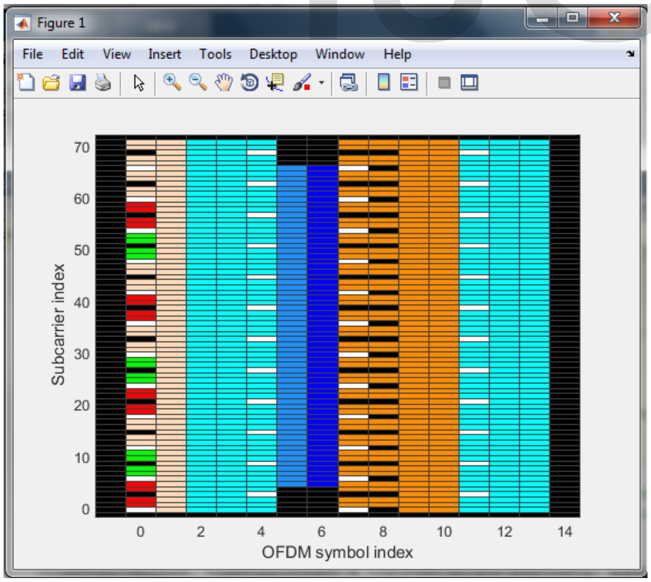


Fig. 5: Resource Grid containing PDSCH, PDCCH, PCFICH, PBCH, PHICH symbols, CSR, PSS and SSS signals.

Here, we have modeled LTE PDSCH transmitter using AWR Visual System Simulator (VSS) environment. The system diagram of PDSCH transmitter chain is shown in Fig. 6

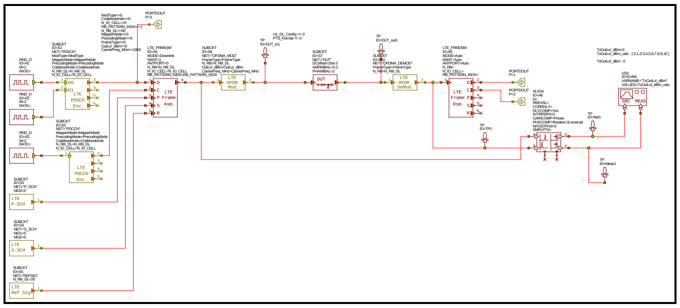
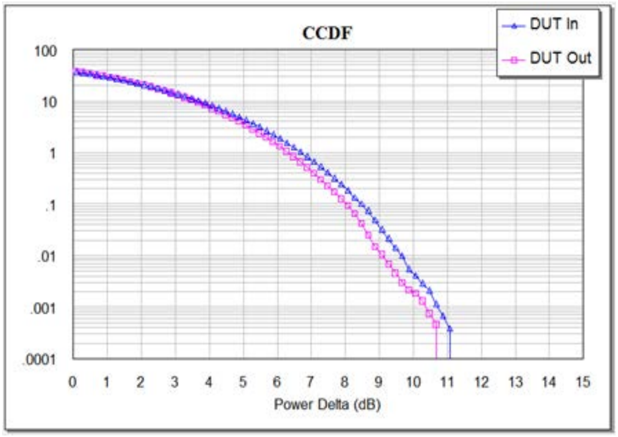


Fig. 6: System Block Diagram of PDSCH Transmitter

The chain of signal processing operations performed in the PDSCH transmitter is composed of following components: LTE signal source, Scrambler, LTE Rate Matching, Modulation Mapper, Layer Mapper, Pre-coder, LTE Frame Assembler, LTE OFDM Modulator, and Signal Analyzer. The processing is completely specified in 3GPP documents describing the multiplexing and channel coding [10] and physical channels and modulation [11].

In order to perform Physical layer processing we have to specify a sequence of operations. First, describe channel coding, scrambling, and modulation resulting in modulated symbols, then describe the steps in mapping the modulated signals to the resource grid, including mapping the user data, the reference signals, and the control data. Then, we need to specify the MIMO modes that enable multiple antenna transmissions which involves specifying layer mapping that describes how many transmit antennas are used in every frame and what precoding transformation is applied to the modulation bits before they are mapped to the resource grids of all transmit antennas. Our initial focus has been on unicast services and single antenna port for transmission. Various analysis and graphs for CCDF curve, BER, Occupied Channel BW, IQ Constellation [2] [5] etc. were evaluated from the simulation of this system architecture block. A typical simulated CCDF curve and IQ Constellation diagram is shown in Fig. 7.



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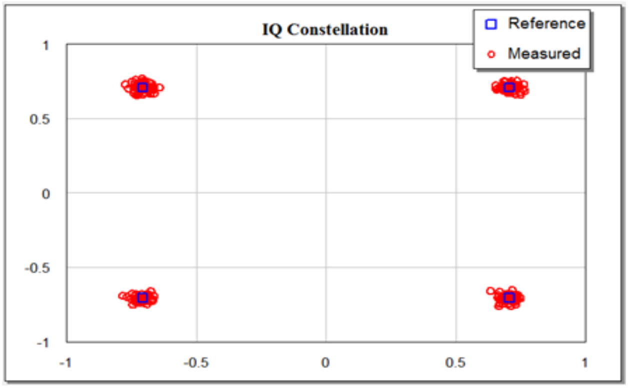

Fig. 7: CCDF Curve and IQ Constellation measured at DUTIN and DUTOUT ports

3.2 High Speed Analog Evaluation Modules for LTE Physical Layer Test and Analysis

The PDSCH carries the downlink data to each user. It is important to note that the PDSCH can support modulation schemes such as QPSK, 16-QAM, and 64-QAM – depending on the channel conditions between the eNode-B and a specific user [6]. The LTE downlink signal is to use OFDMA and in this scheme, the multiple modulated subcarriers are grouped into resource blocks that can be dedicated to individual users. The combination of 12 subcarriers make up one resource block, and the number of available subcarriers and resource blocks that can be allocated for users varies according to bandwidth configuration as shown in Fig. 8 [8] [3].

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Fig. 8: MXA Signal Capture of the OFDMA Carriers

The LTE downlink transmitter measurements are generally designed to ensure interoperability with other cellular and general wireless devices. For example, measurements such as minimum output power and spectrum measurements characterize the amount of unintended interference an LTE transmitter might produce during transmission. In addition, modulation quality is important because its measures the presence of signal impairments that might prevent a UE receiver from demodulating the transmissions. To perform the PDSCH transmitter measurements, connect the Texas Instruments' Transmitter EVM and Pattern Generator EVM as suggested in EVM's users' manual [7] and also shown in Fig. 9.

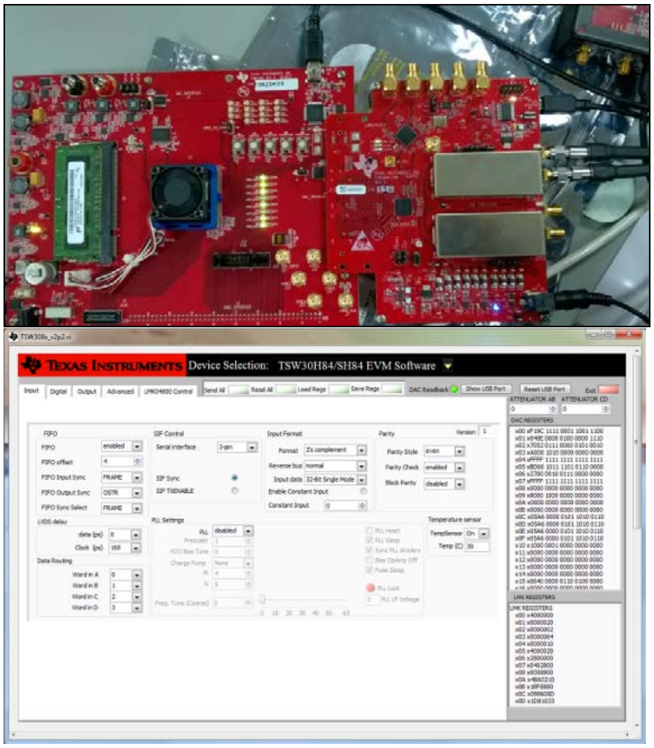


Fig. 9: Test Set-up for Performing PDSCH Transmitter Measurements and GUI set-up

To measure the ON-OFF time mask measurement, simply acquire a power-versus-time (PvT) trace of an LTE burst. As we observe in Fig. 10, a time-domain PvT Measurement provides a full power profile of the burst [8] [3].

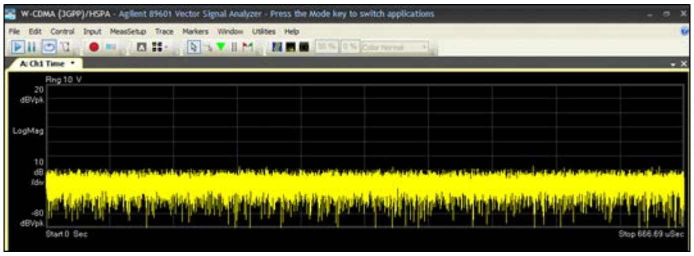
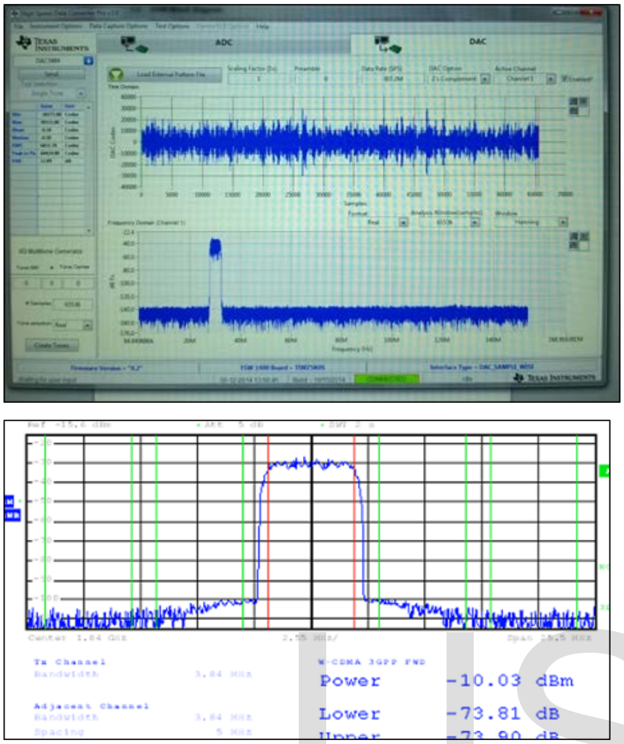


Fig. 10: Power versus Time Measurement

The most fundamental LTE spectral emissions measurement, occupied bandwidth, is defined as the bandwidth containing 99 % of the total integrated mean power of the transmitted spectrum on the assigned channel. As exceeding the bandwidth requirements will cause interference in adjacent channels leading to bit errors in adjacent channel transmissions. Spectral flatness is a measure of the flatness of the transmitter chain, including the power amplifier, and is measured in isolation to identify specific frequency-domain response issues in the transmitter. Fig. 11 shows a spectrum used to calculate the occupied bandwidth and Spectral Flatness measurements that have been performed for partially allocated LTE transmission. The occupied bandwidth measurement is fundamentally a frequency domain measurement and it requires that we configured the RF signal analyzer to a span that is least 2 times the bandwidth of the transmitted signal. Thus, when using swept-tuned spectrum analyzer, we must use a Gaussian filter.



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Ref -15.6 dBm          Att 5 dB          SWT 2 s
Center 1.84 GHz        2.55 MHz/         Span 25.5 MHz

Tx Channel                        W-CDMA 3GPP FWD
Bandwidth          3.84 MHz       Power        -10.03 dBm

Adjacent Channel
Bandwidth          3.84 MHz       Lower        -73.81 dB
Spacing               5 MHz       Upper        -73.90 dB
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Fig. 11: Spectral Flatness and Occupied Bandwidth Measurements for Partially Allocated LTE Transmission

The Error Vector Magnitude (EVM) measurement and Complementary Cumulative Distribution Function (CCDF) are the comprehensive metric of modulation quality that summarizes the effect of a wide range of transmitter impairments in the transmitter chain. Fig. 12 shows a CCDF curves that provide critical information about the signals encountered in broadband systems.

These curves also provide meaningful peak-to-average power data needed to describe the stress on a communication system. The two diagrams shown above illustrate this relationship graphically, mapping the time domain of the waveform to the CCDF curve. The x-axis shows the signal power in dB above the root mean square (r.m.s) value. The y-axis shows the percentage of time that the signal spends at or above that level.

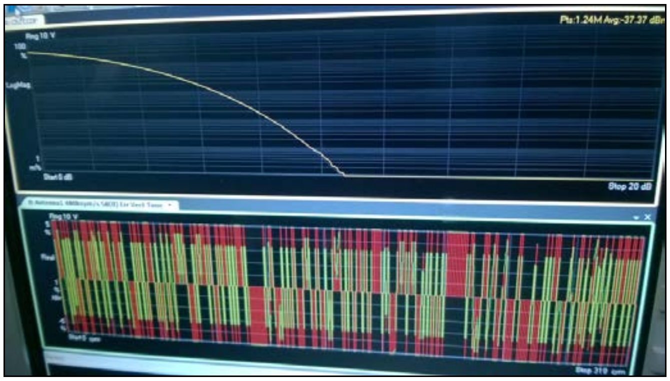

Fig. 12: High Peak-to-Average Waveform in the time domain envelope (bottom) with corresponding CCDF plot (top)

4 CONCLUSION

Improving measurement accuracy and repeatability first requires a working understanding of the instrumentation one might use for LTE transmitter measurements – the RF signal analyzer. In general, one can apply averaging techniques to most transmitter measurements and this technique is commonly used in measurements such as power, EVM, CCDF, BER, ACPR and ACLR. Also, signal analyzers can obtain the most accurate power, EVM and ACLR results when the peak power of the transmitted signal is just below the clipping level of the instrument. Since the PAPR ranges from 10-14 dB for most LTE downlink transmissions – the ideal reference level is usually identical to the average power level of the transmitted signal.

ACKNOWLEDGMENT

The authors would like to thank Field Application Engineering team of both, AWR Inc. and Texas Instruments Inc., for the various discussions on the topics of this paper.

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