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Visual analysis of radio frequency conformance test results

Faculty of Electronics, Communications and Automation

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Tässä diplomityössä esitellään visuaalinen menetelmä kolmannen sukupolven matkapuhelimien yhdenmukaisuustestien tulosten analysointiin. Työssä käsitellyt testit käsittävät matkapuhelimen lähettimen ja vastaanottimen ominaisuuksien radiotaajuuksisia mittauksia. Analyysimenetelmä perustuu normalisoitujen mittaustulosten graafiseen esittämiseen. Esitys mahdollistaa laitteiden keskinäisen vertailun sekä vertaamisen testirajoihin. Työssä analyysimenetelmää sovelletaan kolmen eri laitteen testituloksiin. Analyysituloksista voidaan päätellä, että menetelmä sopii kyseisen tiedon havainnollistamiseen ja analysointiin.

Analyysituloksiin perustuen valitaan suoritetuista testeistä suositus testijoukoksi käytettäväksi laitteiden vertailumittauksiin tuotekehityksessä. Kyseisten testien tulokset osoittivat eroja laitteiden välillä.

Avainsanat: 3GPP, WCDMA, UMTS, radiorajapinnan yhdenmukaisuustesti, laatikkokuvio, laatikko-viikset-kuvio, visuaalinen analyysi

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ABSTRACT OF THE
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This thesis presents a visual method for analysis of third generation mobile phone conformance test results. The tests included are radio frequency transmitter and receiver tests. The analysis method is based on presenting the normalised measurement results as boxplots. The method allows benchmarking of devices and comparing results against test limits. The method is applied to results of three devices, which confirms that the method is suitable for visualising this type of data.
Based on the analysis results of the three devices, a test set for comparing devices in the product development is recommended. This set includes test cases that revealed differences between any of the tested devices.

Keywords: 3GPP, WCDMA, UMTS, conformance test, boxplot, visual analysis

Preface

This Master's Thesis was completed in Cellular Modem Compliance Laboratory of Nokia Devices Research & Development unit. Head of the laboratory is Aleksi Heino who was also the instructor of this thesis. I would like to thank Aleksi for enabling this thesis and for his devoted support during the whole project.

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Special thanks to the two last minute proof readers for their attention and ideas: Troels Forchhammer from Nokia Copenhagen, who has been my mentor in test analysis since I joined Nokia in 2007, and Mikko Jokinen, my future father-in-law.

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And finally I would like to express my greatest gratitude to my fiancée, Essi. She has given me inspiration and motivation on this sometimes stressful journey. Apologies for the long days I have spent writing this thesis.

Salo, 1.4.2010

Tero Lempiäinen

Contents

Abbreviations and terms

Abbreviations

2G	2nd generation
3G	3rd generation
3GPP	3rd Generation Partnership Project
ACK	Acknowledged
ACS	Adjacent channel selectivity
AICH	Acquisition indicator channel
AWGN	Average white Gaussian noise
BCCH	Broadcast control channel
BER	Bit error ratio
BLER	Block error ratio
BS	Base station
CE	Communitas Europae
CRC	Cyclic redundancy check
CW	Continuous wave
DC	Direct current
DCH	Dedicated channel
DPCCH	Dedicated physical control channel
DPCH	Dedicated physical channel
DPDCH	Dedicated physical data channel
DUT	Device under test
E-DCH	Enhanced dedicated channel
E-TFCI	Enhanced transport format combination indicator
EDGE	Enhanced data rates for GSM evolution
EVM	Error vector magnitude
FDD	Frequency division duplexing
GCF	Global Certification Forum
GERAN	GSM/EDGE radio access network
GMSK	Gaussian minimum shift keying
GSM	Global System for Mobile Communications
HSDPA	High-speed downlink packet access
HSPA	High-speed packet access
HSUPA	High-speed uplink packet access
HS-DPCCH	High-speed dedicated physical control channel
I	In-phase
IP	Internet protocol
L1	Layer 1 (physical layer)
m-QAM	QAM using m constellation points
NACK	Not acknowledged
OVSF	Orthogonal value spreading function
PC	Personal computer
PCS	Personal Communications Service

PRACH	Physical random access channel
PSD	Power spectral density
PTCRB	PCS Type Certification Review Board
Q	Quadrature
QAM	Quadrature amplitude modulation
RACH	Random access channel
RF	Radio frequency
RRC	Root raised cosine
RRM	Radio resource management
RX	Receive
R&TTE	Radio and telecommunications terminal equipment
SS	System simulator
TCP	Transmission Control Protocol
TFC	Transport format combination
TPC	Transmit power control
TX	Transmit
UE	User equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS terrestrial radio access network
WCDMA	Wideband code division multiple access

Terms

IEEE-488	A standard bus for traffic between measuring instruments
TCP/IP	Protocol for Internet traffic
Downlink	Transmission from network to user equipment
Uplink	Transmission from user equipment to network
User equipment	3GPP Terminology for the mobile phone
Mobile station	3GPP Terminology for the mobile phone
Release	3GPP term for set of features
Spreading factor	Ratio between the chip rate and the symbol rate
Node B	The base station of WCDMA system
Band(here)	A 3GPP designated frequency band of WCDMA systems
Test case	A set of methods and parameters for testing certain characteristics of a system

1 Introduction

Before a mobile phone ends up in the market for the consumer to use it must fullfill all the necessary regulatory and organisational requirements. In general, the regulatory requirements are mandatory because each country or region has its own legislation specifying which requirements different equipment have to comply. For example, in the European Union all radio or telecommunication devices must conform to the requirements given in the Radio and Telecommunications Terminal Equipment(R&TTE) directive[1]. As a sign of conformity the manufacturer labels the products with the CE marking. The organisational requirements typically come from associations founded by various network operators. For example Global Certification Forum(GCF)[2] and PCS Type Certification Review Board(PTCRB)[3] are the major ones operating in Europe and America respectively. Fullfilling the requirements set by these organisations will work as proof to the network operators that the device will work as expected and can be accepted to sales through the operators.

For a manufacturer to be able to declare that a device fills the necessary requirements, it is usually tested in many sectors including safety, interference and conformance. This thesis concentrates on the radio transmission and reception conformance tests for UMTS WCDMA interface. UMTS or Universal Mobile Telecommunications System is one of the third generation mobile communication systems and wideband code division multiple access, WCDMA, is its air interface technology. UMTS is specified by the Third Generation Partnership Project(3GPP), which was founded by the major regional standardisation bodies in 1998 to provide a global standard for the third generation mobile networks. UMTS was the result of this co-operation and since the first networks opened for commercial use in 2001 the standard has spread almost throughout the world. An introduction to UMTS and WCDMA is given in chapter 2 of this thesis.

Besides complete specifications of the UMTS 3GPP has also specified conformance requirements for the user equipment and base station. These 3GPP documents are often used as reference for the regulatory and organisational requirements, e.g. for the EU's R&TTE directive. The conformance specification for the frequency division duplexing(FDD) user equipment[4] is the basis for the tests discussed in this thesis. The tests are divided into multiple test cases arranged in chapters based on the nature of the test. This thesis includes test cases from chapters 5 and 6 of the above mentioned specification. These chapters describe Transmitter Characteristics and Receiver Characteristics. The chapter numbers from the specification have been included and used throughout the thesis. This makes it easy to refer each test case by using the corresponding chapter number and thus avoiding the writing of the whole name of test case. The included test cases are discussed in chapter 3 of this thesis.

Conformance test cases are typically used for verification of a specific device model to comply the requirements of a certain specification. For example, for devices to be sold in the EU, the manufacturer should issue a declaration of conformity which states that the device complies to the requirements set in the R&TTE directive.[1]

Easiest way to show proof of compliance to the requirements is to run a set of conformance tests defined in the harmonised standard.[5] These tests represent a subset of test cases specified in the 3GPP conformance specification.[4] The tests are typically performed in R&D phase to a limited number of samples.

The R&TTE directive also requires production control and quality system to ensure conformity of each individual device. These processes are out of the scope of this thesis.

The manufacturers generally perform the tests to ensure that the product fullfills the requirements. This can lead to interpreting the test results only in the level where a test case is passed or not. The result of a test case is seen as a 'pass' if the measurements are inside limits or as a 'fail' if the limits have been exceeded. The key question studied in this thesis is how to more effectively illustrate and use the results of the conformance test cases. The chosen method should allow the comparisons between different products and pointing out risky areas of a single product. Single run of a test case typically includes only one measurement per each set of parameters resulting in low total number of measurement results. This presents a challenge because conventional statistical tests rely on the sample size to achieve precision. The approach taken in this thesis is to represent the measurement results of the conformance test cases by using a graphical visualisation method called boxplot. The boxplot allows showing the results of several devices along with the test limits in the same figure. The measurement results of the test cases are transformed to common scale to enable combining of data. These analysis methods are described in detail in chapter 4.

To test and verify the usefulness of the methods, three device models were selected to be included as a reference. All the test cases which were decided to be included in the scope of the thesis were run once with each device by using three frequency bands. The results of these tests are presented by using the discussed methods in chapter 5 of this thesis.

The analysis results are also used to compose a group of test cases which could be used as a basis for test planning when time is limited. Test planning is addressed in chapter 6 of this thesis. The chapter includes discussion of a recommended test set derived from the results to use in research & development when performing all the tests is not feasible due to the duration of the full test set.

2 Universal Mobile Telecommunications System

Universal Mobile Telecommunications System(UMTS) is globally one of the most widely used third generation mobile systems. Other comparable systems include cdma2000 mainly used in the USA and Time Division Synchronous Code Division Multiple Access(TD-SCDMA), which is being ramped up in China.[6] The air interface of UMTS is WCDMA which is based on multiple access scheme called direct sequence code division multiple access, DS-CDMA. Using this scheme the already source and channel coded symbol stream is expanded over a large bandwidth in a process called spreading. In this same process the different channels in a cell are separated allowing multiple access using the same frequency band. Different channels can be used to distinguish different UEs and there can be multiple channels per UE used simultaneously.

The spreading code bits are referred as chips and the code has the chip rate of the system which in WCDMA is 3.84 million chips per second, 3.84Mcps. The spreading codes come from a orthogonal code tree based on Hadamard codes and they are known as orthogonal variable spreading functions, OVSFs in UTMS terminology. The spreading factor, SF is used to separate different levels of codes in the tree and determines the length of the spreading code. Possible values for spreading factor are $SF = 2^n, 2 \leq n \leq 9$ which results in values between 4 and 512. The spreading factor can also be seen as the ratio of the chip rate to the symbol rate. Because the chip rate of the system is constant, the variable data rates between channels require different lengths of spreading codes. Thus more chips are used to transmit single symbol when spreading factor is increased. [7, 8]

The spreading process can be done by modulating the symbol stream with the spreading code. With BPSK signal this can be done by multiplication and an example of this is shown in figure 1. In the figure a bipolar signal presentation is used meaning that the signal values can be either -1 or +1. The x-axis represents time and the unit is set to symbol interval. Because the used spreading factor is 8, each symbol interval contains 8 chips. The different phases of the spreading/despreading process can be seen from top to bottom. The upper signal is the spreading code$(+, -, +, -, -, +, -+)$ which is repeated for each symbol. Next is the symbol stream, i.e. the signal to be spread. In the middle is the multiplication product of the spreading code and the symbol stream representing the result of the spreading process. In the next row is the same spreading code as in the top, now used to despread the data. At the very bottom is the multiplication product of the spread data and the spreading code. As can be seen this is the same signal that was the input signal. [7, 8, 9]

After spreading the signal already has the final chip rate and bandwidth. The power however is not necessarily equally distributed to the frequency range. The next phase flattens out the spectrum and also separates different cells in downlink and different terminals in the uplink. This scrambling operation is done in complex multiplication for I and Q branches separately using a pseudo noise sequence generated for this purpose. Multiplication with the noise-like sequence transforms the signal to pseudo noise having flat spectrum minimising interference to other

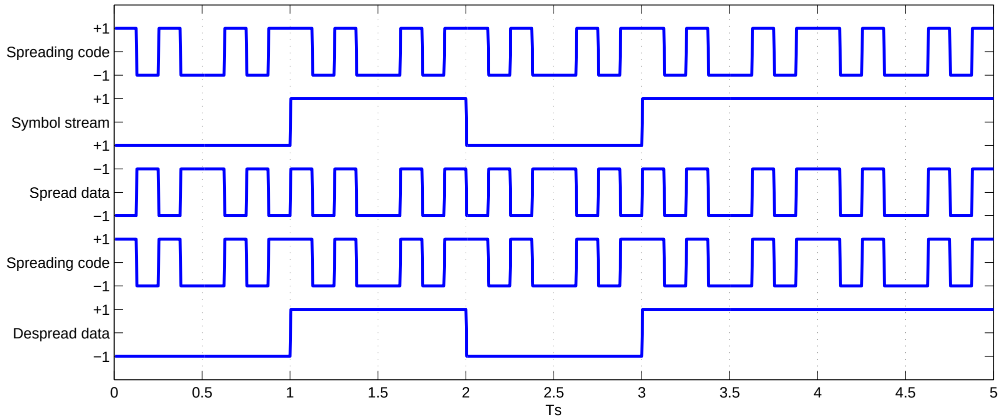

Figure 1: Signal spreading/despreading for BPSK signal with spreading factor 8

terminals. [9]

The use of wideband CDMA provides some useful benefits: Tolerance against narrowband interference is good because of the (de)spreading process spreads the interferer to large bandwidth so it can be effectively filtered out. Tolerance against wideband interference is also good because of the used channelisation and scrambling codes have auto- and crosscorrelation properties that allow effective isolation of the wanted signal. WCDMA systems also can take advantage of multipath propagation by using a RAKE receiver which consists of multiple receivers each receiving the signal with different path delay. [7, 8, 9]

The drawbacks, or challenges of WCDMA systems come from the same principles as the benefits. Because the same frequency is used by all the terminals in the cell the observed noise level is increased the more transmissions are taking place in the cell. All the excess transmit power used causes unnecessary interference thus the transmit power control must be very fast and responsive to allow operation in fading conditions using only the necessary amount of output power. This is achieved by using closed loop power control in which the base station provides terminals with power control commands based on the measured signal to interference ratio. The power control cycle is done with 1.5kHz rate which effectively eliminates fading in terminal point of view provided that the maximum output power is not reached. [7, 8, 9]

UMTS was first introduced to one frequency band pair for FDD use. The uplink and downlink bands were centered around 2100MHz. This band still is the main band in Europe and Japan but additional bands have been specified in order to efficiently use the radio spectrum and to adapt to regional regulations. Even all the bands listed in table 1 are not yet physically in use new bands are studied and expected to be included in new versions of specifications. [7]

3GPP specifications of UMTS have evolved since they fist introduced in 2000. 3GPP uses a system of releases to allow addition of features while still providing stable specifications for product development. This means that the manufacturer

Table 1: 3GPP WCDMA FDD frequency bands with uplink and downlink frequencies. Also geographical areas of use are stated where known. [10, 11]

Name	**Uplink [MHz]**	**Downlink [MHz]**	**Area**
Band I	1920-1980	2110-2170	Europe and Asia
Band II	1850-1910	1930-1990	USA and Americas
Band III	1710-1785	1805-1880	Europe, Asia and Brazil
Band IV	1710-1755	2110-2155	USA and Americas
Band V	824-849	869-894	USA, Americas and Asia
Band VI	830-840	875-885	Japan
Band VII	2500-2570	2620-2690	New 3GPP band(Global)
Band VIII	880-915	925-960	Europe and Asia
Band IX	1750-1785	1845-1880	Japan
Band X	1710-1770	2110-2170	New 3GPP band(USA)
Band XI	1427.9-1452.9	1475.9-1500.9	New 3GPP band(Japan)
Band XII	698-716	728-746	New 3GPP band(USA)
Band XIII	777-787	746-756	New 3GPP band(USA)
Band XIV	788-798	758-768	New 3GPP band(USA)

of the UE must declare which release the UE is compliant to. All the features in a certain release are not mandatory but using features of a newer release in UE declared to be older is not allowed. The most important releases from TX/RX conformance test point of view are currently R99 specifying the baseline WCDMA features, R5 in which HSDPA was introduced and R6 which includes also HSUPA. [12]

3 Test Cases

Test cases included in this thesis are a subset of test cases specified in [4]. All included test cases belong to chapters 5 or 6 of the specification representing radio transmission and reception tests. These chapters were selected because they describe the fundamental requirements for RF performance. The specification also lists a number of test cases for other aspects of the radio interface such as Layer 1 performance(ch.7), radio resource management(ch.8), HSDPA performance(ch.9) and HSUPA performance(ch.10). Part of the Layer 1 performance test cases have been analysed in special assignment [13] using partly the same methods that are used in this thesis.

The test cases in question are specified to exclude the antenna performance by stating that the test system is connected to the DUT by an electrical conductor. This allows the test environment to be controlled more accurately as the air interface is left out. Conformance tests for antenna performance are specified in a separate document[14].

The environmental conditions of the DUT are controlled and some tests are specified for extreme conditions in addition to normal conditions. Varied conditions include temperature and supply voltage of the DUT. Normal temperature is nominally +25 °C where low and high extremes are −10 °C and +55 °C. Voltages are tied to the nominal battery voltage indicated by the manufacturer. When a power supply is used, normal testing voltage is the nominal voltage, low voltage is 0.9× nominal and high voltage is 1.1× nominal. Humidity is not varied but it is required that relative humidity of the test environment is between 25% and 75%. [4] The extreme conditions are tested in all four combinations so environmental conditions can be divided into five groups:

1. Normal conditions (NC)
2. High temperature, high voltage (HTHV)
3. High temperature, low voltage (HTLV)
4. Low temperature, high voltage (LTHV)
5. Low temperature, low voltage (LTLV)

In the following chapters test cases are grouped by the type of measurement instead of the common way of arranging them to the order they are listed in the specification. For identification and reference the original names and chapter numbers are also included and used throughout the thesis.

3.1 Power Control Measurements

This group includes test cases that measure transmit power of the UE. The upper end of transmitter dynamic range is evaluated with maximum output power test cases. The tests specify requirements for output power when the UE is transmitting at full power. The UE must comply to the limits according to which power class it is assigned. Power class is directly related to the maximum power output the UE can produce and is specified by the manufacturer. Current commercial UEs are power class 3 with nominal maximum output power of 24dBm or power class 4 with nominal maximum output power of 21dBm. Higher output power can help improving transmission data rates or enabling communication in weak coverage areas such as areas far away from the base station. [11]

Test case 5.2 specifies requirements for all UEs using only features from release 99. Test is conducted by simply having the UE transmit at full power and measuring the output power. [4]

HSDPA in 3GPP release 5 specifications include additional control channel, HS-DPCCH, which is not synchronous with the release 99 channels transmitted in parallel. This results in higher peak-to-average ratio in uplink. Taking this into consideration 3GPP has specified relaxed requirements for time slots HS-DPCCH is in use. The target power level is the same, but the lower limit is reduced. The amount of reduction is depending on the ratio of HS-DPCCH and uplink data channel DPDCH amplitudes and is 0, 1 or 2dB. For higher amount of control data the reduction is larger. Test case is divided to four sub-tests based on channel configuration. The test case number for maximum output power with HS-DPCCH is 5.2A. [4, 11]

For release 6 two new test cases were specified. The reasons are similar to HSDPA case explained above, and since release 6 includes HSUPA transmission as an additional feature the amount of control channels and code domain channel amplitude combinations is even higher. Release 6 test case numbers for maximum output power in [4]are 5.2AA for UEs without HSUPA but with HSDPA and 5.2B for UEs supporting both HSDPA and HSUPA. These test cases are also divided into subtests based on uplink channel power allocation.

The open loop power control is only in use when the UE starts the transmission and is not in the control of the node B. The requirements are given in test case 5.4.1 Open Loop Power Control in the Uplink. The functioning of open loop power control ensures that the UE does not create excess interference in the cell but starts with the minimum power when requesting a radio connection. The test procedure is simply to measure the power of the random access channel(RACH) preamble when UE is initiating connection. The measurement is done with three power levels from receiver sensitivity level to upper dynamic end. The tolerance in every measurement is ±9dB for tests in normal environmental conditions and ±12dB for extreme conditions.[4, 8]

Test case 5.4.2 tests functionality of inner loop power control of the UE. The functioning of this fast closed loop power control procedure is essential in WCDMA networks since excess error in transmit power control results e.g. in capacity losses or call drops. Using inner loop power control the transmit power of UE is controlled by node B via transmit power control (TPC) commands sent via control channel. Value of TPC can be either 0, -1 or +1. The stepsize is determined by system parameter ΔTPC which is transmitted with other system information on BCCH. Possible values are 1dB and 2dB. There are two possible modes for power control, power control algorithm 1 with full 1500Hz one command per timeslot resolution and power control algorithm 2 with 5 TPC commands grouped together resulting in

300Hz resolution. Only algorithm 1 is tested in this test case. During the test case TPC commands are sent in five different patterns. First three patterns contain only one type of command from the possible values of -1, 0 and +1. Two more patterns are used to verify slower rate of TX power. These patterns consist of repetitions of four commands of zeros followed by either -1 or +1 depending on the pattern. The requirements are defined in [4] for power change after each TPC command and also for total change after 10 consecutive pattern repetitions.[4, 11]

Test case 5.4.3 measures the minimum controlled output power of the UE. This requires that both inner loop and open loop power control indicate minimum transmit power is required. It is important that UE is capable of operating also at low output powers because any excess power transmitted reduces system capacity.

Test case 5.4.4 out-of synchronization handling of output power sets requirements for UE's responses for DPCCH quality changes. The UE shall monitor the DPCCH quality at all times and when the quality drops below a certain threshold the UE should stop transmitting in 40ms period. Again when the DPCCH quality improves the transmitter must be activated in 40ms. The purpose of the test case is to make sure UEs out of synchronisation do not cause interference to other communication in the cell. The root cause for the interference would be errors in transmission of TPC commands as the UE's transmit power would not be in the control of node B any longer. [4]

Test case 5.5.1 contains measurement of output power when UE is not transmitting. This power should obviously be as low as possible. Excess output power when not transmitting increases interference which decreases overall system capacity. [7] This test case is usually measured as part of test case 5.5.2.

Test case 5.5.2 specifies requirements for transmit on/off time mask. Output power levels are measured during and between random access channel preambles. Transmit on power requirements are applied to the power measured during preamble and transmit off requirements to the power measured between preambles. There are transition periods of 50μs between TX on and TX off power measurements centered at the edges of preambles. [4]

3.2 Transmit Modulation

The measurements of error vector magnitude(EVM) and frequency error are done by using the Global In-Channel Tx-Test described in [4], Annex B. This method uses reference signal generated by the test system which is filtered with pulse shaping filter and compared to the actual transmit signal produced by the UE filtered with the same type of filter. The filter is root raised cosine(RRC) type with bandwidth of 3.84MHz and roll off factor $\alpha = 0.22$. The parameters of the reference and the actual transmit signal are varied in order to achieve best fit between the two signals so that their difference is minimised. Following parameters are varied for the TX signal: frequency, timing and phase. The reference signal is only varied by altering code domain amplitude. The minimum measurement interval is one timeslot except for test cases with HS-DPCCH enabled. For those test cases shorter measurement interval is used because the code powers can vary during one timeslot period. [4]

Single test case 5.3 is dedicated for measuring frequency error of the UE transmitted signal. Reference for the UEs transmit frequency is the received signal from node B so the test also covers receiver's ability to track the signal and provide a correct reference for the transmitter. The test is done at receiver sensitivity level and the test requirement is ±(0.1ppm+10Hz). For example in band I middle channel with center frequency of 1950MHz this requirement is ±205Hz. [4]

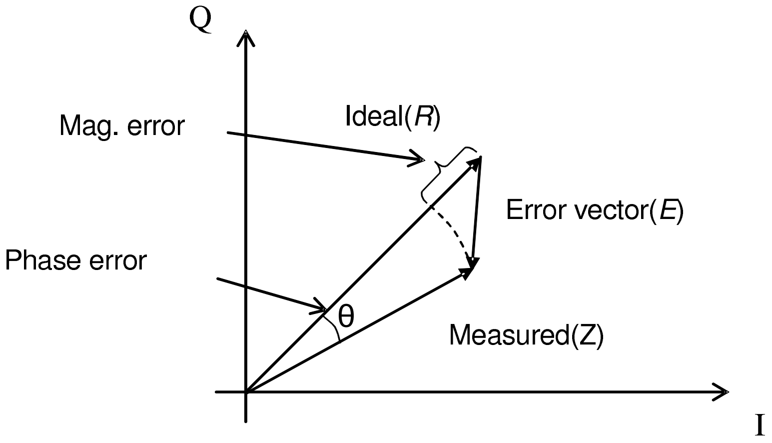

Figure 2: Error vector in complex plane.

The quality of modulation is mainly measured by the error vector magnitude, EVM. Error vector is the difference between the ideal vector and measured signal. Figure 2 shows the concept in the complex plane. It also shows how the error vector can be seen as composed from phase and amplitude errors. The requirements for EVM are specified as RMS power ratios between the error vector and the reference vector. The formula for EVM value after [4] is

$$EVM = \sqrt{\frac{\sum_{v=0}^{N-1} \left|Z'(v) - R'(v)\right|^2}{\sum_{v=0}^{N-1} \left|R'(v)\right|^2}} * 100\% \tag{1}$$

where $Z'(v)$ and $R'(v)$ are the varied transmitted and reference vectors and N is the number of samples in the measuring interval. The modulation used in all the EVM tests included is QPSK so there are four constellation points. The limit for all EVM tests is 17.5%. The measured EVM consists of nonlinearities cumulated over the whole transmitter path. Local oscillator leakage in the modulator as well as asymmeries in the baseband I and Q paths can cause increase in EVM. Also the RF output power amplifier distorts the signal especially when the saturation level of the amplifier is approached. [15, 16]

Test case 5.13.1 is the basic test of EVM applicable for all UEs starting from R99. The test case is conducted with two output power levels: maximum and -18dBm. Test case 5.13.1A is the HSDPA equivalent of 5.13.1 using HS-DPCCH as measurement channel. This test case is applicable for R5 UEs supporting HSDPA. The test case includes also measurements with the two aforementioned power levels but in addition the measurement is repeated in four different phases of HS-DPCCH transmission including two measurements with HS-DPCCH transmitting at highest level and two measurements with HS-DPCCH transmission off.

Test case 5.13.1AA is much like the previous test case but it has additional requirement for phase discontinuity between the transition periods when HS-DPCCH transmission is switched on and off. The measurement of EVM is done, as described above, for the four measurement positions. The resulting phase discontinuity is then calculated between the first and last pairs as the difference in the absolute phase values of the transmitted signal used in generating minimum EVM. Test case is applicable for R6 and later releases for UEs supporting HSDPA.

Test case 5.13.3 UE phase discontinuity measures changes in phase between two timeslots. The measurement is done as described above but for two whole consecutive timeslots. This test is done for the full dynamic range of the UE transmitter by starting from the maximum TX power and gradually setting the UE to the minimum output power repeating TPC commands in a predefined pattern of [-1 -1 -1 -1 -1 +1 +1 +1 +1]. This results in a total change of 1dB per 9 timeslots. When the minimum output power has been reached the power is gradually increased to maximum by repeating the inverse TPC pattern: [+1 +1 +1 +1 +1 -1 -1 -1 -1]. EVM is measured for all timeslots and phase discontinuity calculated between all the consecutive timeslots.

A separate test case, 5.13.4, is specified for measuring PRACH preamble quality. PRACH preamble is used by the UE in the random access procedure to initiate the network access on layer 1. During the process UE sends preambles to node B trough random access channel(RACH) until a positive acquisition indication is received from the acquisition indication channel(AICH). Only after this process the random access message containing details about the wanted connection can be transmitted to the node B and connection can be established if allowed by node B. During the test used RACH sub-channel, PRACH signature and AICH transmission timing are selected randomly from a predefined set and the measurement is repeated ten times with different parameters. The quality metrics include EVM and frequency error. In addition the detected access slot and signature must be correct. [4, 8]

3.3 Transmit Intermodulation

Test case 5.12 measures the intermodulation effects of the transmitter when an interfering signal is present in the antenna. The test is performed with four frequencies of interfering sinusoidal continuous-wave signal: 5 and 10 MHz above and below the carrier frequency. The level of the interferer is 40dB below the transmit power level. Each interferer offset potentially produces two intermodulation products, one above and one below the carrier frequency. The intermodulation attenuation requirements are expressed as the ratio of the root raised cosine(RRC) filtered mean power of the transmit channel signal to the RRC filtered mean power of the intermodulation product. The requirements are -31dB for 5MHz offsets and -41dB for 10MHz offsets. [4]

3.4 Adjacent Channel Leakage Ratio

Test cases 5.10 to 5.10B measure the leaked power ratio on adjacent channels. The purpose of the test case is to limit the interference the UE produces to communications on other UMTS channels. A particular scenario when adjacent channel leakage impacts network performance is when the UE is transmitting to a far away base station(BS) with high power and there is another BS using adjacent channel in close vicinity of the UE. The key components in a transmitter that influence ACLR are the power amplifier and the modulator. Particularly third order distortion in the modulator causes rise in leaked power. Generally improving ACLR by modulator linearity causes more power consumption which is always a drawback in a battery operated device. Finding a proper compromise with filing the requirements and power consumption is thus an important part of transmitter design. [11, 15]

The test is done by first measuring the root-raised-cosine(RRC) filtered power of the actual transmit channel and then comparing the similarly filtered power of adjacent channels to this power. The roll-off factor of this filter simulating that of a real receiver is $r = 0.22$ and bandwidth 3.84MHz. Measurements are made for the first adjacent channels 5MHz above and below UE transmit frequency as well as the second adjacent channels 10MHz above and below the TX frequency. During the measurement the UE is transmitting with full output power.

Test case 5.10 uses basic R99 features and is required for all types of UEs. Test case 5.10A is valid for all UEs supporting HSDPA and is done with HS-DPCCH active. This test case includes measurements with four power allocation configurations between uplink data and control channels. Otherwise requirements and procedures are the same as with 5.10. Test case 5.10B uses also E-DCH in addition to HS-DPCCH. This test is only for R6 UEs supporting HSDPA and HSUPA and includes five subtests with different uplink channel power allocation configurations.

3.5 Receiver Dynamic Performance

The performance of RF front end of the receiver is mainly evaluated by bit error ratio(BER) tests. 3GPP specifies tests to be done with UE test loop mode 2 using UL 12.2kbps reference measurement channel. This loop mode functions as follows: The system simulator(SS) sends the UE test data which the UE loops back with symmetrical DL channel. The SS compares the received data to the original and calculates BER. By using this method all basic functions of WCDMA networks below layer-2 are actually in use including cyclic redundancy check, tail bit attachment, convolutional coding, interleaving and rate matching. This results to the fact that the bit errors are not independent. BER tests are sometimes defined so that they circumvent channel coding which results in independence of the errors but this is not the case with the BER tests in question. [4, 8, 18]

In test case 6.2 the receiver is tested with very low input power. The power level is the minimum a UE is required to work and called reference sensitivity level. The test is conducted by using BER test with downlink power set to the reference sensitivity level. The requirement is to achieve 0.1% BER. Since this test simulates transmission in great distance from node B output power of the UE is set to maximum. Testing the sensitivity of a receiver is important because the specified sensitivity is used in planning coverage of UMTS cells and it is expected every UE works also at the edge of the cell coverage. As the received signal power is very low the noise present in the receiver is the most critical parameter of receiver design. The noise is a sum of multiple sources including thermal noise, input amplifier noise, phase noise of the local oscillator and leaked transmitter power. [8, 11, 15]

Test case 6.3 stresses the UE in the other dynamic end compared to 6.2. In this test the input signal is at maximum level the UE is required to work. Transmit power is set to a predefined value below maximum. This test is also conducted using BER test and the requirement is to achieve 0.1% BER.

For a HSDPA terminal supporting 16QAM there is one additional test for maximum input level. This is because of the need to more accurately preserve the phase and amplitude with this higher modulation scheme. Test case 6.3A is similar to 6.3 but downlink uses HSDPA transfer with 16QAM signal. Also the test is not done as a BER test but as a throughput test. Throughput is calculated by using acknowledged/not acknowledged(ACK/NACK) messages from the UE and the requirement is to achieve 700Kbps or more whereas the nominal bit rate for the used channel configuration is 777Kbps. [4, 11]

3.6 Adjacent Channel Selectivity and Blocking

Adjacent channel selectivity(ACS) is the measure of how large power level can be used at the adjacent channel compared to the received power. The UE is required to operate with ACS of 33dB. This means that the power used in the channel adjacent to UE's received channel is 33dB greater than the received signal power. The test case is done with two power levels starting from rel-5 UEs and for one level for release 99 and 4 UEs. 3GPP test case numbers are 6.4 and 6.4A. The correct operation of the UE is determined by using the BER test while simulated WCDMA signal is used as interferer. The conditions which require good ACS are typical when two or more operators are sharing the same area and frequency band. The ACS is mainly determined by the RF and baseband filtering in the receiver. [11]

Blocking tests are covered in chapter 6.5. Blocking characteristic is a measure of the receiver's ability to receive a wanted signal at its assigned channel in presence of an unwanted interfering signal[4]. Test case 6.5 is separated into three different types of blocking tests: in-band-, out-of-band- and narrowband blocking all measuring BER when an interfering signal is present at the receiver. The filters in the receiver carry the biggest responsibility in complying to the blocking requirements but also nonlinearity of the receiver can cause impaired performance. [15]

During the in-band blocking test the interfering signal is a simulated WCDMA signal with frequency offsets -10MHz, +10MHz, -15MHz and +15MHz to the used receive band's center frequency. The adjacent channels with offsets -5MHz and +5MHz are tested in the ACS test case described above. Each interfering signal is tested separately. This test is required in order to make sure the UE is capable of operating in presence of other WCDMA systems in the same band. The level of the interfering signal is -56dBm with ±10MHz offsets and -44dBm with ±15MHz offsets while the received signal level is set to reference sensitivity +3dB.

Narrowband blocking is only specified for certain frequency bands which are potentially used together with some narrowband second generation mobile network such as GSM. Currently this means FDD bands II, III, IV, V, VIII, X, XII, XIII and XIV. The used interferer is GMSK modulated to simulate GSM signal and the offset from the WCDMA carrier is 2.7MHz for bands III and VIII and 2.8MHz for all the other tested bands. The level of the interferer is also depending on the band being -56dBm for bands III and VIII and -57dBm for the other bands. The received signal level is adjusted to 10dB above the reference sensitivity level.

Out-of-band blocking includes sinusoidal interferer with frequency range of 1MHz to 12750MHz excluding the frequencies tested on other blocking tests or the ACS test. The level of the interferer depends on the frequency band under test and the distance from the carrier but is always between -44dBm and -15dBm while the transmitted signal level is 3dB above the reference sensitivity level. Frequency of the interferer is swept in 1MHz steps and for each frequency a BER test is made. If the measured BER value is above the threshold or the call is disconnected an exception has happened. The frequency of the interferer is recorded for later analysis. The number of allowed exceptions are limited and depend on the frequency range of the interferer and band in use.

The exception frequencies from the out-of-band test are tested in a separate test case, 6.6, with similar blocking test but with the level of interfering signal set to -44dBm. UE received signal power is the same as in the blocking test, 3dB above reference sensitivity.

3.7 Transmit Spectrum Measurements

This chapter includes tests for occupied bandwidth and unwanted emissions from the transmitter. The positioning of test cases in the frequency domain is presented in figure 3.

Test case 5.8 specifies requirements for UE transmitted signal bandwidth. The bandwidth must be below 5MHz. The occupied bandwidth is defined to be the frequency range containing 99% of the total transmitted power. Total power is measured in minimum of 10MHz band around the center of the carrier. [4]

In the transmitter spurious emissions are formed as a result of non-linearities such as harmonic and intermodulation distortion. It is possible that such unwanted products fall into frequencies they can cause interference to other equipment or networks.

For frequencies 2.5MHz - 12.5MHz away from the center frequency of the TX channel transmitter requirements are defined in test cases 5.9 to 5.9B. The requirements are specified relative to the RRC filtered carrier power and depend on the measurement frequency. The measurement filter bandwidth is 30kHz for frequencies 2.5MHz to 3.5MHz away from the carrier center and 1MHz for the rest of the covered spectrum. Test case 5.9 uses basic R99 functionality where test case 5.9A uses HS-DPCCH for downlink and 5.9B also uses E-DCH for uplink. The basic requirements are the same in all the tests.

Test case 5.11 specifies requirements for frequencies more than 12.5MHz away from the carrier center frequency. The measured spectrum starts from 9kHz and ends to 12.75GHz. Measurement bandwidth is 1kHz for frequency range 9kHz - 150kHz, 10kHz for 150kHz - 30MHz, 100kHz for 30MHz - 1GHz and 1MHz for 1GHz and above. The minimum requirements for these ranges are -36dBm for all except the highest range for which the requirement is -30dBm.

In addition to these general requirements there are specific additional requirements for UEs using certain bands. These are guard bands for protecting co-existing networks from excess interference. The measurement bandwidths and requirements are specified in detail in [4]. Usually when it is possible that a narrow band system such as GSM is present in the same area the possible frequency range for that system is measured with narrow filter with bandwidth of 100kHz or 300kHz and the level of allowed emission is lower than in the general test. Similarly in cases where additional WCDMA bands are present the assigned frequencies are measured with bandwidth of 3.84MHz representing the bandwidth of a WCDMA channel.

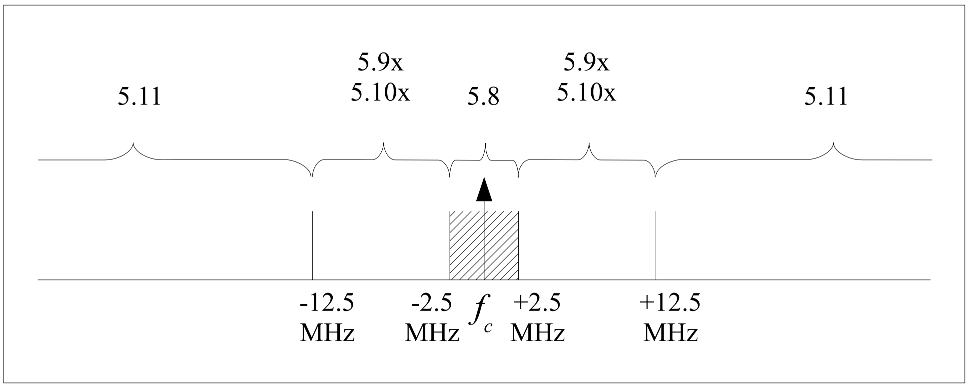

Figure 3: Emission test cases presented in relation to distance from the TX carrier center frequency f_c.

3.8 Receiver Spurious Emissions

Spurious emissions of the receiver are measured in test case 6.8. The requirements are specified for frequencies 30MHz - 12.75GHz with 100kHz measurement bandwidth below 1GHz and respectively bandwidth of 1MHz above 1GHz. The maximum level allowed for the former range is -57dBm and for the latter -47dBm. During the test the UE is not transmitting so the measurement results should not have interference from the transmitter. As above in transmitter test this test case has also specific requirements for multiple guard bands including the UE transmit and receive bands. The limit for the TX and RX bands is -60dBm for measurement bandwidth of 3.84MHz. [4]

4 Analysis Methods

4.1 Normalisation of Results

Because of differences in measured units, limits and test case parameters it is useful to use some normalised scale in which all the results are presented. One approach is to use the 3GPP specified limits as a basis. In addition to the limits an ideal or target value is required in the process. The generation of normalised values can be expressed as

$$x_i \geq \bar{x} : \hat{x}_i = \frac{x_i - \bar{x}}{l_u - \bar{x}} \tag{2}$$

$$x_i > \bar{x} : \hat{x}_i = \frac{x_i - \bar{x}}{\bar{x} - l_l} \tag{3}$$

where x_i is the result from measurement i, $\hat{x}_i$ is the normalised result, $\bar{x}$ is the ideal value, l_u is the upper limit and l_l is the lower limit. In this scale 0 will represent an ideal value and -1 and 1 will be the lower and upper limits. Anything between them shall be a passing result whereas failed tests will have absolute values over 1. This method is a modified version of an method used in the laboratory for 2G test analysis. [17]

The advantage of using this kind of normalisation is that it is easy to look at the data and spot any results that are outside the limits or close to them. The biggest disadvantage is that the true margins to the limits cannot be directly observed. One has to know what is the ideal value and what are the limits in order to return the original information which could be e.g. power levels in dBm. Most useful uses for this normalisation are the test cases with several similar test steps with different limits. Without the normalisation it would make no sense to group these results together. Even when using limit-normalisation the grouping of results from different test cases can cause problems if the distributions of the results are very different in respect to limits. This is most likely to happen between different types of tests. If test cases have significantly different distributions on the limit-normalised scale grouping them should not be done when comparing products. The actual performance difference of the devices may not be observed if the combined distribution has many peaks due to the different test cases. Also the number of results should be similar when combining results of multiple test cases since test case with large number of results can rule over ones with less results. If the purpose of the analysis is only to check the margin to limits then this problem does not exist but it is not practical to include results of very different test cases into one group.

In some cases above method is not practically possible since there is no clear target but the ideal result is as low or as high as possible. This is typical to some emission and output power test cases where results and limits are expressed as decibels and test cases are having only high limit. It is useful to simply scale the results so that the limit is 0 dB. When operating on the decibel scale this procedure includes only subtraction or summation of the limit value from the measurement results. This normalisation allows the margin to the limit to be clearly visible using the same units as the original measurement data.

4.2 Boxplots

The target of this work is to provide a somewhat simple process of exploring the test results allowing comparisons and risk analysis. This can be achieved by using of a graphical presentation and visually exploring the data. Boxplot is a visual exploratory data analysis method suggested by John Tukey.[19] The exploratory data analysis is a branch of statistics where the data is used to formulate the actual hypothesis in contrast to confirmatory data analysis which relies on hypothesis testing. Boxplots are suitable for the needs of this work because they can be used for presenting multiple datasets in a compact presentation and they can be compared to each other or to a known reference.

When generating a boxplot the corresponding data set is first ordered in increasing order. This data set is then divided into four equal parts so that these parts include equal number of data points. The three dividing values are called quartiles of which the middle one is also the median of the data set. The lower and upper quartiles are used as the lower and upper limits of the box in graphical representation whereas the median is drawn as a line inside the box. The distance between the lower and upper quartiles is called the interquartile range and it also is the length of the box. This range is used in finding outliers in the data which are defined to be the samples that lie more than 1.5 times the interquartile range away from the edges of the box. In graphical representation outliers are usually marked with asterisk or other symbol so that they are clearly separated from the rest of the data. The box plot is finalised by showing the smallest and largest values of the data set, excluding outliers, as whiskers or lines attached to the box.

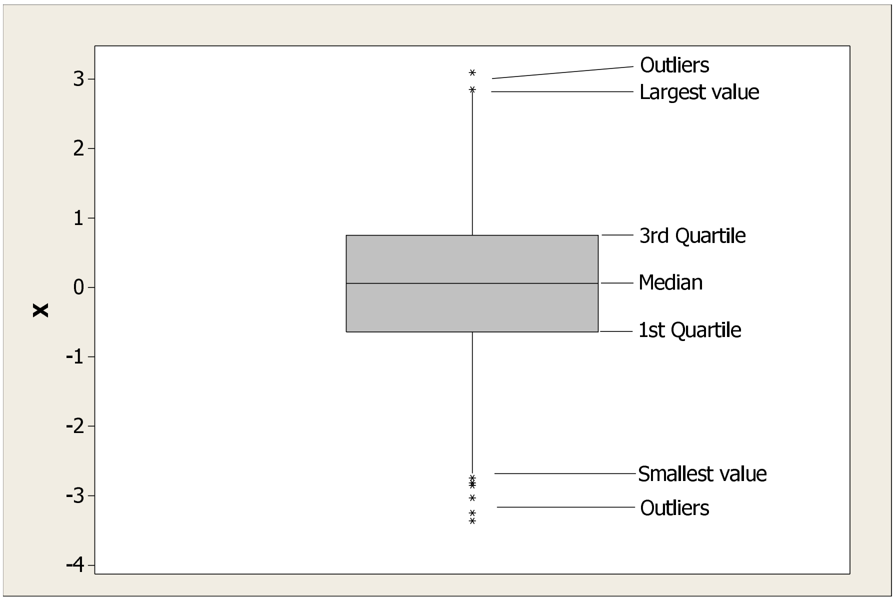

Figure 4: A boxplot created from 1000 samples with standard normal distribution

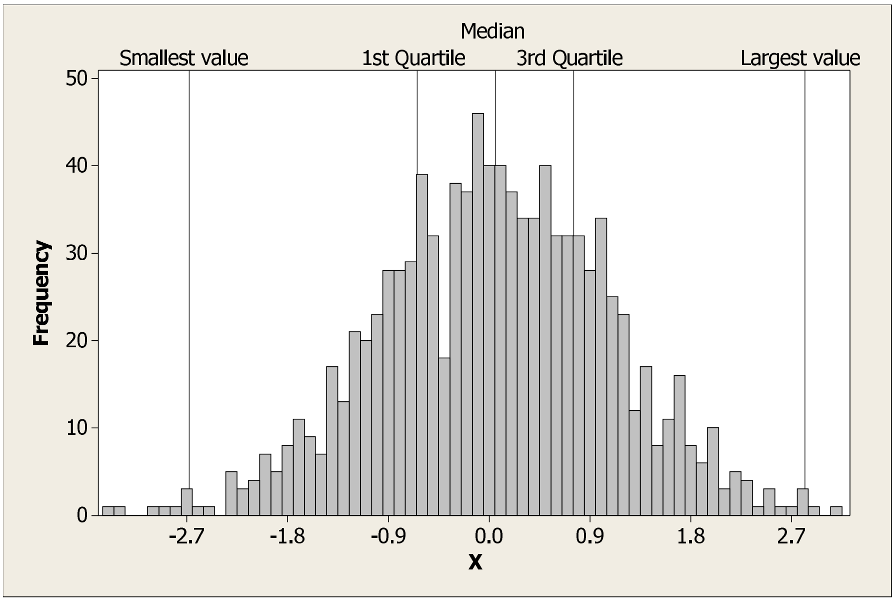

Figure 5: A histogram made of the same 1000 samples as the boxplot in the previous figure

Figure 4 shows an example of a boxplot generated from a set of 1000 samples with standard normal distribution. The histogram of the same data is shown in figure 5. Boxplot shows the shape of the distribution in a very condensed presentation and thus it is effective in data visualising allowing many data sets to be included in a compact space. From this example some typical properties of boxplots can be seen. The median value, shown as a line inside the box, is at the middle and the box is symmetrical around this value. This shows that the underlying distribution peaks at the middle and symmetrically tapers towards high and low values. There are also a few outliers and a pair of whiskers showing the smallest and largest values of the data. The motivation for separating the outliers is that they are potential measurement errors or otherwise do not fit in the data. It is quite natural to have some outliers in boxplots. In this example the outliers are very close to the whiskers so they are not likely very different from the rest of the data. If there was a group of outliers at a far distance from the whisker, the distribution would probably have two peaks. In that case the data set could be partitioned further, if possible, to find out the underlying cause.

When the data is having some anchor points it can be useful to include the anchors in the graph. In the following chapters the data is normalised by the test limits so it is useful to include the limits and the ideal value(if used) in the figures. This allows the reader to see the margin to the limit.

5 Analysis Results

5.1 Measurement Equipment

The test setup consists mainly of the test system and the device under test with wired RF connection between the UE antenna connector and the assigned port in the test system. Other parts include RF-shielding, temperature chamber, voltage source, adapters, cables and possibly other accessories. When testing radio access properties of mobile devices it is important that testing takes place in an environment with no external disturbances which could affect test results. RF shielding the room the test system is located in can be used to achieve this.

The test system provides the UE with signals and environment that resemble those of live networks. Test environment is specified in [20]. This specification includes information about logical, transport and physical channels, test frequencies and message contents.

Test system, as defined in [4], annex A is ”A combination of devices brought together into a system for the purpose of making one or more measurements on a UE in accordance with the test case requirements. A test system may include one or more system simulators if additional signaling is required for the test case.” System simulator is defined in the same document as ”A device or system, that is capable of generating simulated Node B signaling and analyzing UE signaling responses on one or more RF channels, in order to create the required test environment for the UE under test. It will also include the following capabilities:

1. Measurement and control of the UE TX output power through TPC commands
2. Measurement of RX BLER and BER
3. Measurement of signaling timing and delays
4. Ability to simulate UTRAN and/or GERAN signaling”

In addition to a system simulator test systems usually include fading simulators, generators for interfering signals and a power meter. Different tests also require different paths between instruments so a routing unit is required.

The test system used for the measurements was Anritsu ME7873F TRx/Performance Test System[21]. This system consists of multiple discrete instruments and it is capable of performing all the test cases included in this work. The block diagram of the system is presented in figure 6.

RF units(combiner, switch and interface units) handle the routing, amplification, combining and filtering of RF signals between the other units and the device under test. These units are controlled by the RF switch driver.

The signaling tester provides most of the functionality of a system simulator defined above. The functions include simulation of base station(Node B) signaling, higher level call processing procedures to set up and manage calls and measurements of block error ratios. An additional device directly connected to the signaling tester is used for measurement of bit error ratios.

Signal generators are mainly used for providing interference signals to the simulated radio channel according to test case definitions. Vector signal generators produce the simulated WCDMA and 2G signals along with noise whereas CW signal generator is used for sinusoidal interferers. One vector signal generator is dedicated for use with the fading simulator. Together the units provide the simulation of fading radio channel used in layer 1 demodulation performance tests.

The TX tester unit is used for measurement of the properties of DUT TX signal. Different metrics like power levels, EVM, frequency errors or bandwidths are measured with this equipment. It is also used for system self check and adjustment.

DC supply is used for providing the DUT with constant testing voltage during the test run. Temperature chamber is used for keeping the DUT at correct temperature during the test.

The units in test system are controlled by the system controller, which is a PC equipped with special software for remote control of the devices. The remote controlling is done via IEEE-488 bus and Ethernet using standard TCP/IP connection. The controller PC software user interface allows the selection of test cases and the operation of the system is fully automated after the user starts the tests from the user interface. After the completion of the tests report files are stored in the PCs hard drive. [21]

5.2 Measurement Results

The measurement data used in this thesis is gathered from three test rounds each done with a somewhat different device. The results not necessarily represent the final performance of any real device but they are actual measured results. During this thesis the devices are referred only as DUT#1, DUT#2 and DUT#3. From each test round the results for frequency bands FDDI, II and VIII were used because these were available for all the devices. DUT#1 is release 5 compliant while the others are release 6 compliant. In practice this means that some test cases specific to these releases are not available for all the devices, e.g. all the HSUPA tests are only done for DUTs #2 and #3. All test cases are from [4] chapters 5 and 6. The selection of individual test cases from these chapters is done as wide as possible by using every test case available in the system and supported by the devices. The tests are done in all the environmental conditions that are required in the specification for each test.

The actual process of turning test system reports into graphics was started by collecting all the data into Microsoft Excel worksheet. The data was organised and filtered so that essential parameters and measurement results remained while other data was discarded. The normalised values or margins were then calculated and the resulted data set was exported to Minitab statistical software for creating the graphics.

Boxplots or histograms were done for all test cases separately by using different variables such as band, environmental condition or test step in grouping of the data. Different groupings were used until a valid combination of separating variables was found. The justification for a set of variables was to have similar data points inside

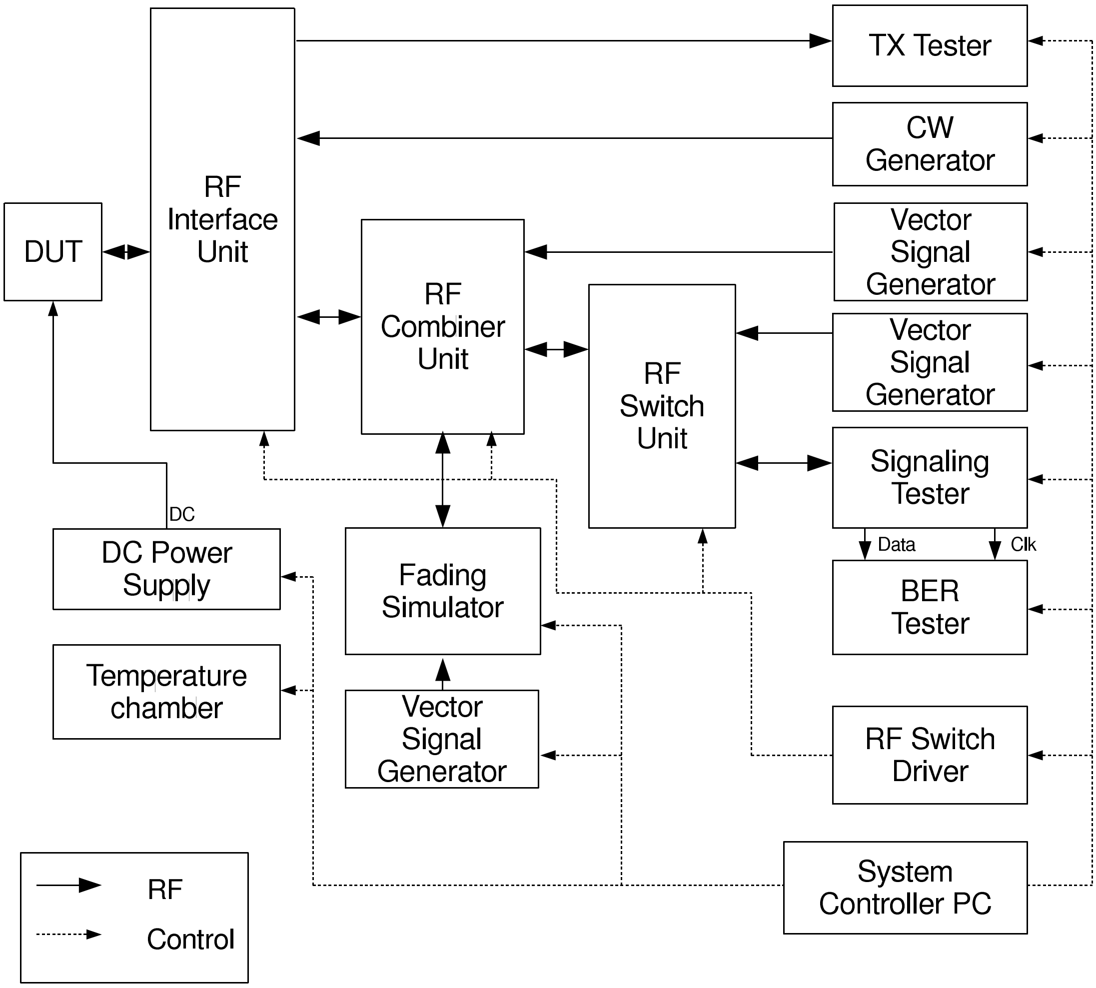

Figure 6: Block diagram of the Anritsu ME7873F test system.[21]

the boxes still keeping the number of boxes reasonable. In practice this meant 1–3 separating variables for each test case. If a test case included different types of measurements(e.g. EVM and frequency error) they were given separate graphs. For some test cases there were multiple approximately equally good sets but only one was selected to be used. The ordering of the separating variables in the figures varies and it is chosen in each test to emphasise the findings made. For some tests only separating variable used was the DUT because others did not give any additional value to the presentation. From the selection of test cases only those showing some possibly interesting information were selected to be presented in this thesis. The results are explained for each test case separately and reasons of not including the graph are also given.

Maximum Output Power(5.2)

Test case 5.2 is performed with all three measurement channels and in all test conditions. This results in 15 measurements per band for each DUT. The measured power levels have been normalised in respect to the limits and presented as boxplots. Figure 7 shows the data split by DUT and environmental conditions. The measured power levels expressed in dBm were normalised as described in chapter 4. The ideal power level is 0 in the normalised scale and also whereas the low limit is -1. The presentation can be used to evaluate differences in behavior of devices' reactions to operating voltages and temperatures. Absolute value of this maximum output power test depends highly on the final tuning of the DUT and since it is not very beneficial to compare properties of single DUTs one should not draw conclusions of general performance of this type of devices from the actual results of the measurements. Instead, a useful way of interpreting the measurements is to look at the differences between results in various conditions and in another hand the magnitude of variance.

From the results in figure 7 can be seen that DUT#2 has the largest variance over the results. Because a single box in this case includes measurements of three bands with three channels each, the conclusion that the maximum output power is not stable between bands and channels can be made. Another fact observed from the figure is the effect of the temperatures. All DUTs have the lowest values in high temperature. In general, DUT#1 has very good results as the output powers are all inside a small window.

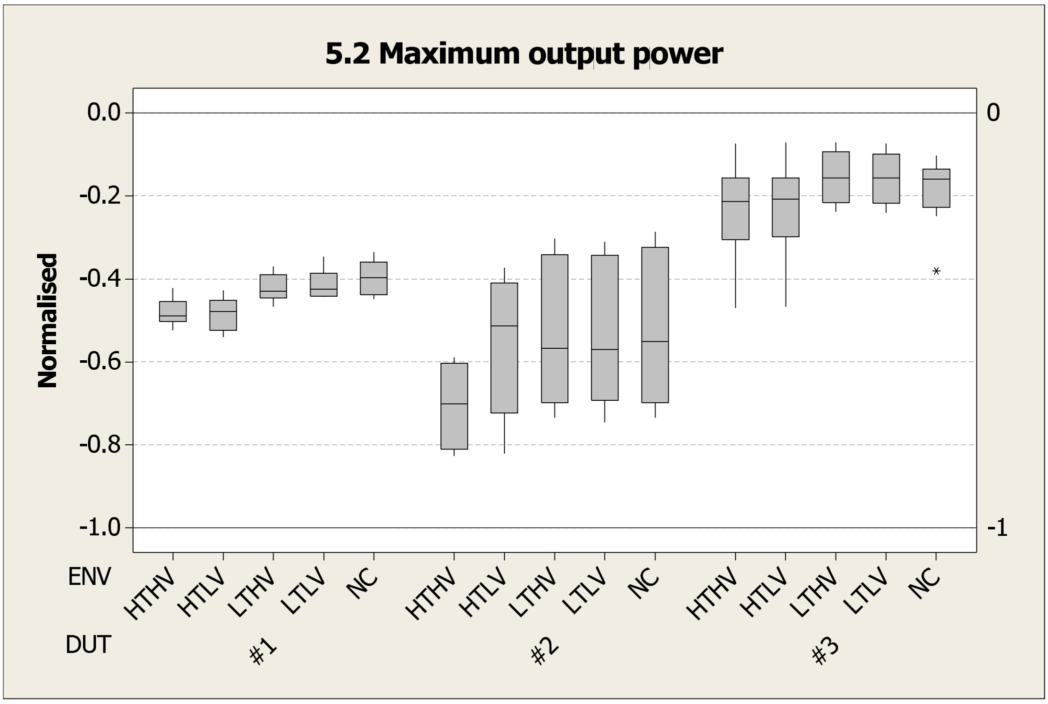

Figure 7: Normalised results of test case Maximum output power(5.2) separated by environmental conditions. Ideal value in this scale is 0 and the low limit is at -1.

Maximum Output Power with HS-DPCCH and E-DCH(5.2B)

Test case 5.2B is consisted of 15 frequency/condition combinations. But, because test is performed as five different subtests, the amount of measurements is 75 per band per DUT. The 5 subtests, as they are referred in [4], each have different channel configurations with different power ratios between logical control and data channels. This test is only done with DUT#2 and DUT#3.

Figure 8 shows the results separated by environmental conditions. It can be seen that DUT#2 has very poor results and is not passing the limits. However with low temperature the results are better than in normal or high temperature.

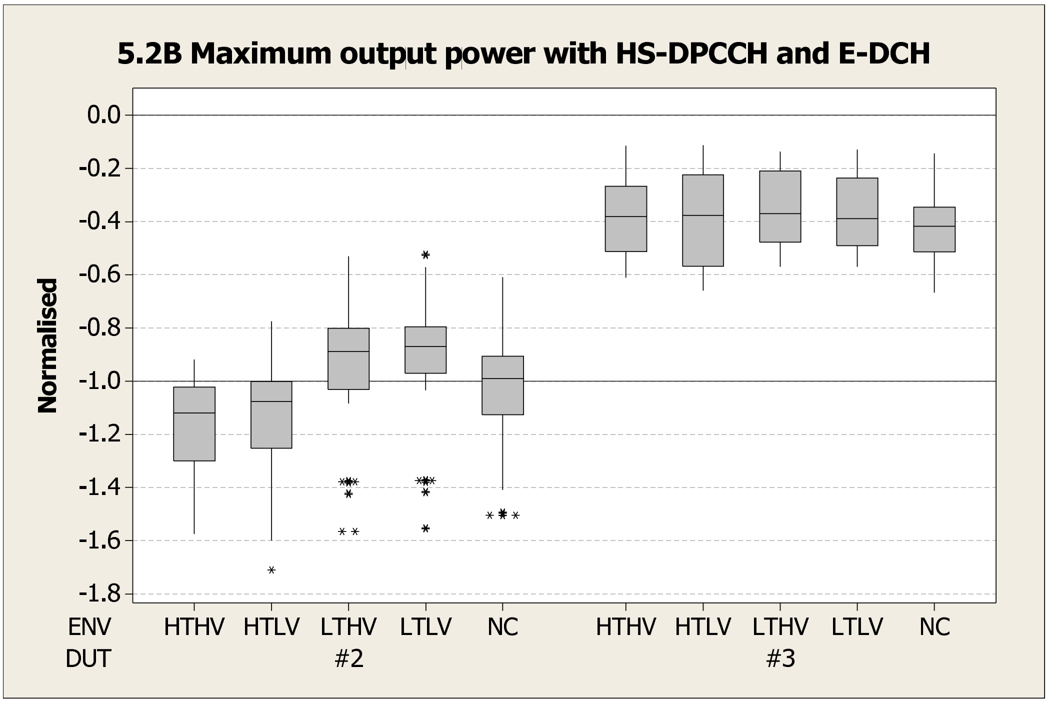

Figure 8: Normalised results of test case Maximum output power with HS-DPCCH and E-DCH(5.2B) separated by environmental conditions. Ideal value in this scale is 0 and the low limit is at -1.

Frequency Error(5.3)

The test is done in all environmental configurations using all three frequency channels. This results in 45 measurements per DUT when three bands was tested. The results were divided by environmental conditions but that did not suggest any dependence of operating temperature or voltage. Therefore the most useful way to look at the data is to only split it by DUT. The results are presented in figure 9. All medians are close to zero and the box heights are reasonable. DUT #3 has the smallest variance.

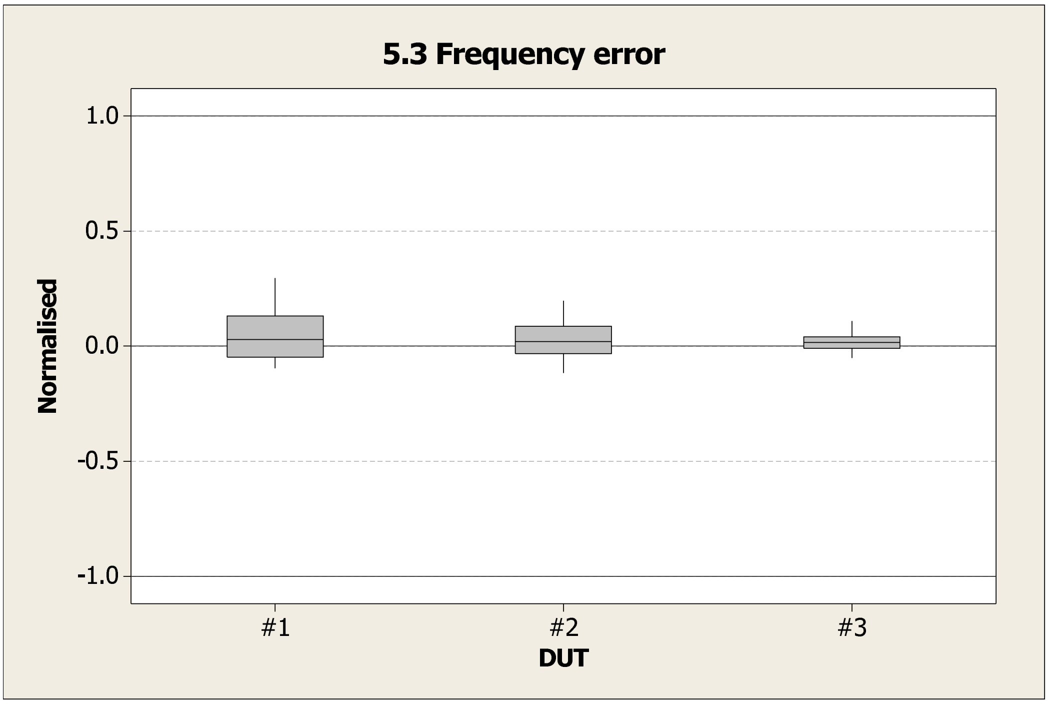

Figure 9: Normalised results of test case Frequency error(5.3). Ideal value in this scale is 0 and the test limits are at -1 and +1.

Open Loop Power Control(5.4.1)

Included data consists of following combination of parameters: three bands, three channels per band, three received power levels and five environmental conditions. The results of this test case show the biggest differences when separated by test step, i.e. RX power level. The results are presented in figure 10. The difference between different DUTs is visible, as DUTs #1 and #2 have less variance over #3. The most obvious observation is however the fact that DUT#1 has problems in the test step with highest RX power.

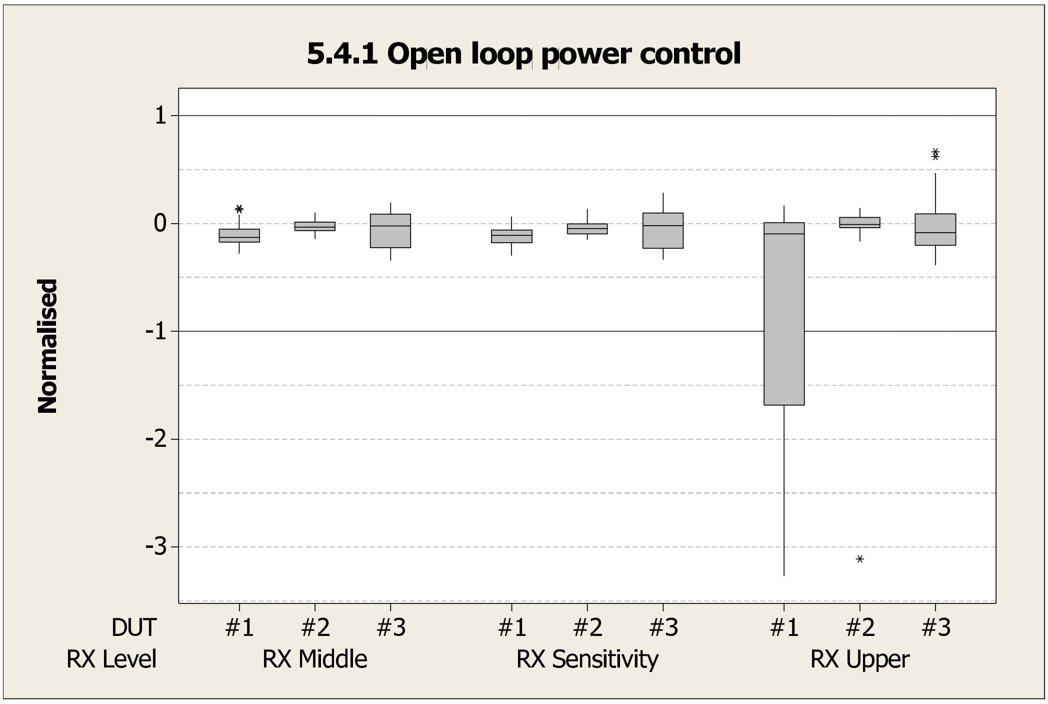

Figure 10: Normalised results of test case Open loop power control(5.4.1). Ideal value in this scale is 0 and the test limits are at -1 and +1.

Inner Loop Power Control(5.4.2)

Compared to the other test cases included the amount of measurement data is very high in this test case. There are approximately 1700 results per DUT even though this test is only performed in normal conditions. One view to the results is achieved by simply looking at the histograms of normalised results for each DUT separately. This allows for a quick comparison of power control accuracy between the devices. By looking at the distributions one can find differences and similarities of tested devices' performance. It would have been possible to use boxplots but histograms are more useful in showing differences in shapes of the distributions especially when the number of individual plots is reasonable. The data visible in figure 11 shows very similar performance between DUTs #1 and #2 where DUT #3 has somewhat greater variance.

Minimum Output Power(5.4.3)

Minimum output power has only upper limit and no apparent ideal value. Test case is run in all bands, channels and environmental conditions. All results show reasonable margin to limit, but DUT #3 has the smallest variance. In practice the results of this test case probably don't tell much about the overall device performance as long as the specified limits are met.

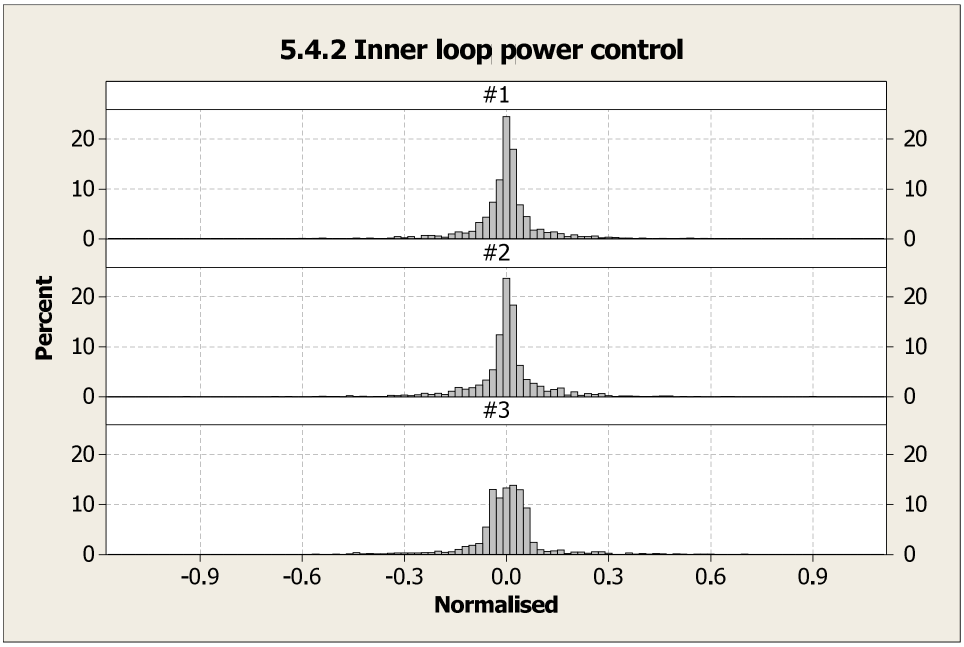

Figure 11: Histograms of normalised results of test case Inner loop power control(5.4.2). Test limits are at x-axis values -1 and +1.

Transmit ON/OFF Time Mask(5.5.2)

The numerical results available from the used test system consist only of power level measurements with TX on and off. The actual timing information is only available as graphic presentations and cannot be therefore analysed with numerical methods. The results consist of three power measurements: one before transmission(TX off) one during transmission(TX on) and one after transmission period(TX off). These results can be used as any other power level measurements taking the tolerances into consideration. The test is performed in normal and extreme conditions with all measurement channels. By looking at the actual results no conclusions can be made because the variations are so small compared to the margins.

Change of TCF(5.6)

The test case provides a single power ratio with DPDCH on/off. The test is performed in normal conditions with center channel only. Therefore the amount of data is very small. This data does not contribute much to overall performance evaluation since all results are clear passes with reasonable margins.

Power Setting in Uplink Compressed Mode(5.7)

There are a total of 72 data points per each DUT in this test case. The test is only done in normal conditions but all three channels are tested. There are several test steps with different power control patterns but the normalised values do not reveal any differences between the DUTs.

Occupied Bandwidth(5.8)

Measurement of occupied bandwidth is performed in normal conditions using all three measurement channels. The result is a figure in MHz. There are no significant variations between the devices in this test case.

Spectrum Emission Mask(5.9)

Test case is performed in normal conditions with all three frequency channels and it is split into several steps each covering different area of the spectrum. The results from these test cases are essentially spectra of the leaked power, but the test system also reports numerical values for each measurement interval. The covered spectrum is divided into intervals because of their different limits and measurement bandwidths. The reported values are decibels scaled so that value zero is the limit and negative values represent power levels below this limit. Reported values represent the highest levels inside each interval.

Figure 12 shows the boxplots of the results separated by DUT and frequency offset from the carrier. This grouping has been achieved by combining the results of intervals with equal negative and positive offsets. There are differences between the DUTs and as the plots show DUT#3 has the greatest safe margin to the limit when the offset is small. When the distance from the carrier increases the measurements even out so that all DUTs have similar performance. With the small offsets the margins to the limit are only under a decibel with DUTs #2 and #3 in the worst results. Medians are between -10dB and -5dB. The shapes of the boxes indicate that the number of values very close to the limit is small, as the median is closer to the bottom of the box.

Spectrum Emission Mask with HS-DPCCH(5.9A)

The measurement methodology and metrics are similar to Spectrum emission mask. The amount of data is higher due to four subtests testing different uplink channel power distributions. In boxplot of figure 13 the results are separated by measurement band offset and device. The results follow the trend of test case 5.9 because the margins are greater with larger offsets. But when looking at differences between devices the two test cases are not similar. The test with HS-DPCCH shows clearly similarities between DUTs #1 and #3 with small frequency offsets but with larger offsets every DUT is different. DUT #2 seems to be the best performing device with the smaller offsets. With the two biggest offsets DUT #1 has the largest margins.

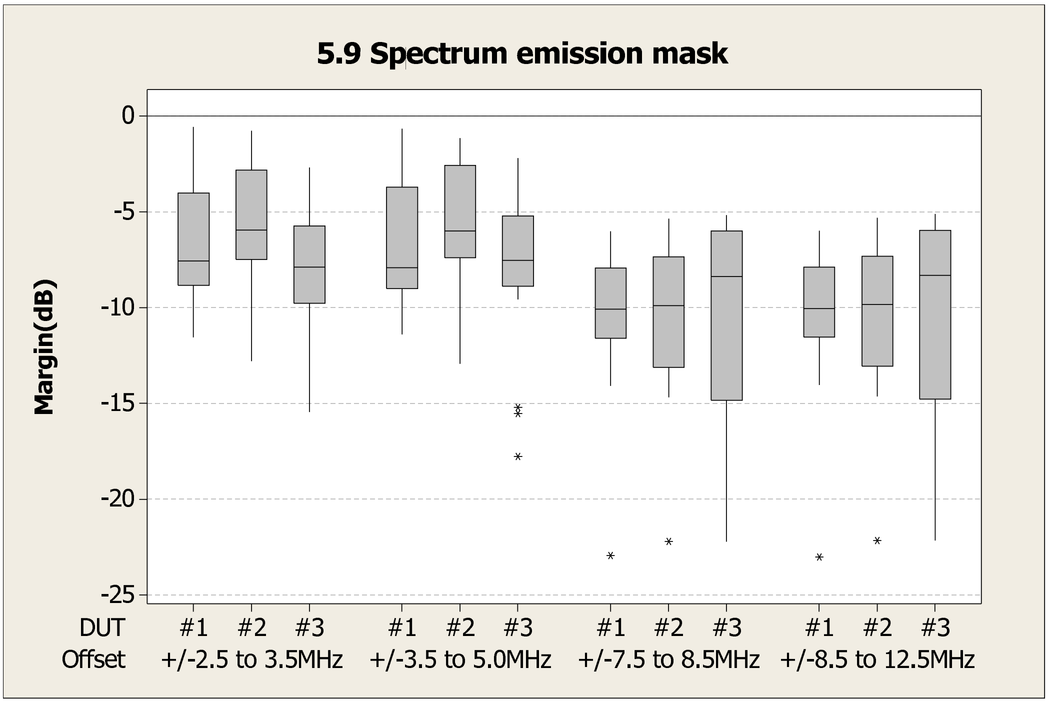

Figure 12: Results of test case Spectrum emission mask(5.9) expressed as margins to the test limit.

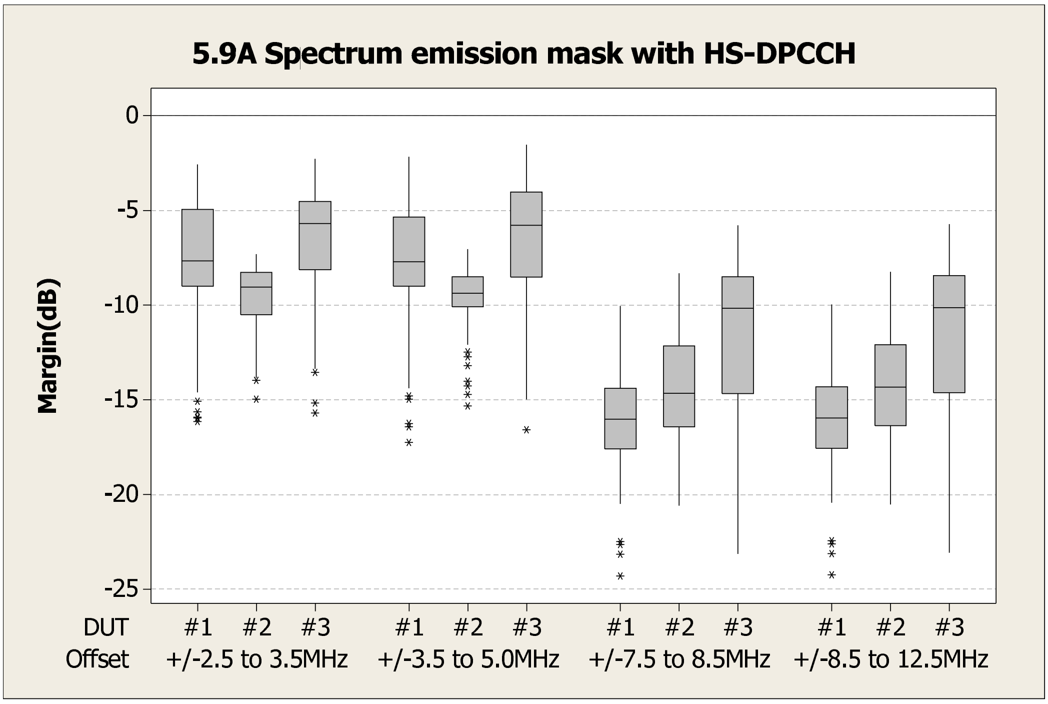

Figure 13: Results of test case Spectrum emission mask with HS-DPCCH(5.9A) expressed as margins to the test limit.

Spectrum Emission Mask with E-DCH(5.9B)

Like the HSDPA version above the HSUPA version of spectrum emission mask has several subtests for different channel power allocations. The test is also done with three channels and only in normal conditions. The results have again been separated by the measurement band offset and device under test. Figure 14 shows the results which are somewhat similar to test case 5.9A: With smaller offsets both DUTs are closer to limit and DUT #2 seems to perform better in every case.

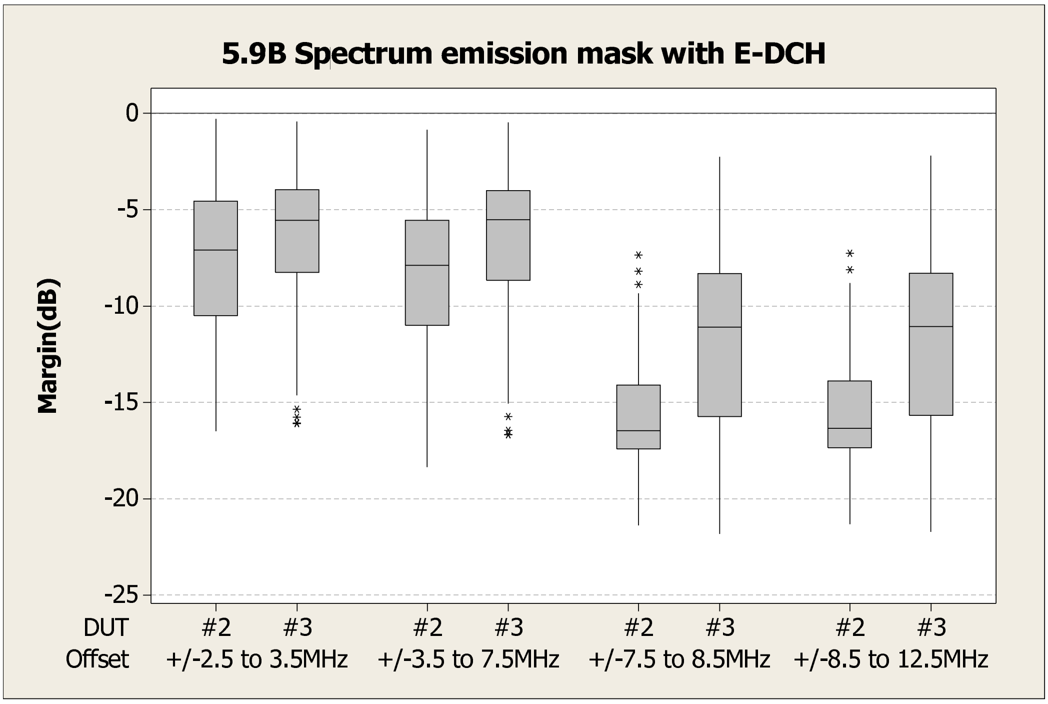

Figure 14: Results of test case Spectrum emission mask with E-DCH(5.9B) expressed as margins to the test limit.

Adjacent Channel Leakage Power Ratio(5.10)

The test case is done in normal and extreme conditions using all three channels. Figure 15 shows the margins to the limit for the each measurement of the test case separated by the band, frequency offset of the measurement channel and device under test. The units in the figure are decibels. Positive and negative adjacent channels with same offsets have been grouped together because the similarity of the results and to keep number of boxes in one plot reasonable. Two major points are visible in the figure, the channel directly adjacent to the TX channel have the smallest margins with every device and devices #1 and #2 have the worst results in band FDDII.

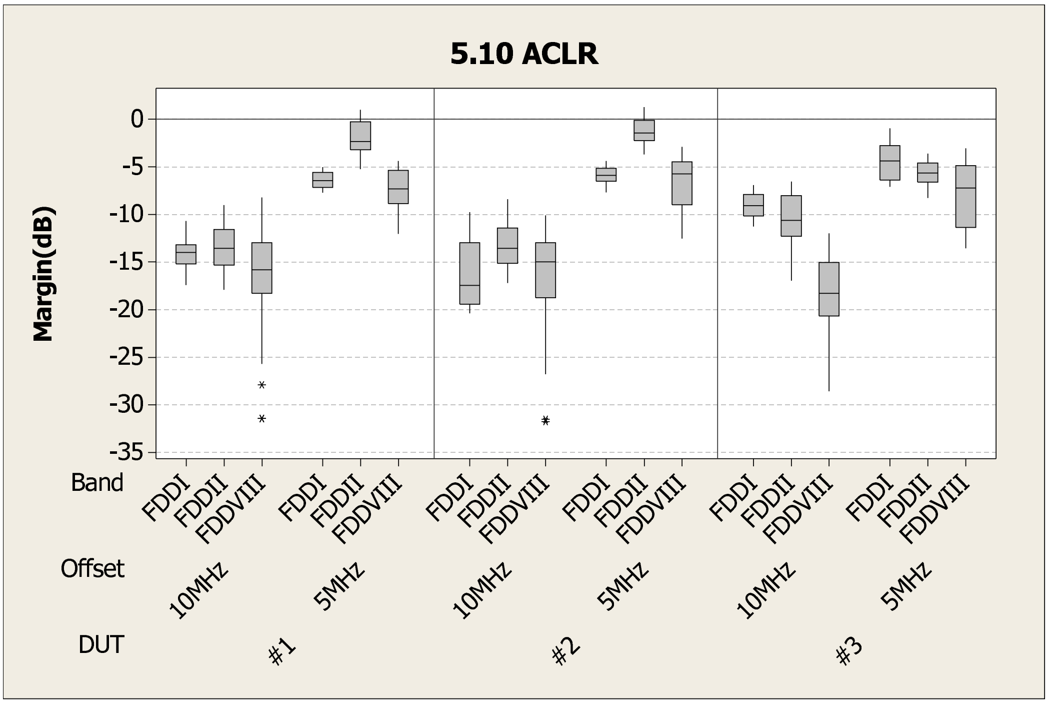

Figure 15: Results of test case Adjacent channel leakage ratio(5.10)expressed as margins to the test limit.

Adjacent Channel Leakage Power Ratio with HS-DPCCH(5.10A)

This test case consisting of four subtests is done in normal and extreme conditions using all three channels. The results shown in figure 16 look similar to the results of 5.10 with one interesting detail: The DUT #2 problems with FDDII do not show in this test.

Adjacent Channel Leakage Power Ratio with E-DCH(5.10B)

The test case is also done in normal and extreme conditions using all three channels. Figure 17 shows the results for ACLR with E-DCH as margins to the limit in decibels. The figure shows that especially with DUT #2 the most problematic areas are again the directly adjacent channels and in this case also band FDDI is showing some problems in addition to FDDII.

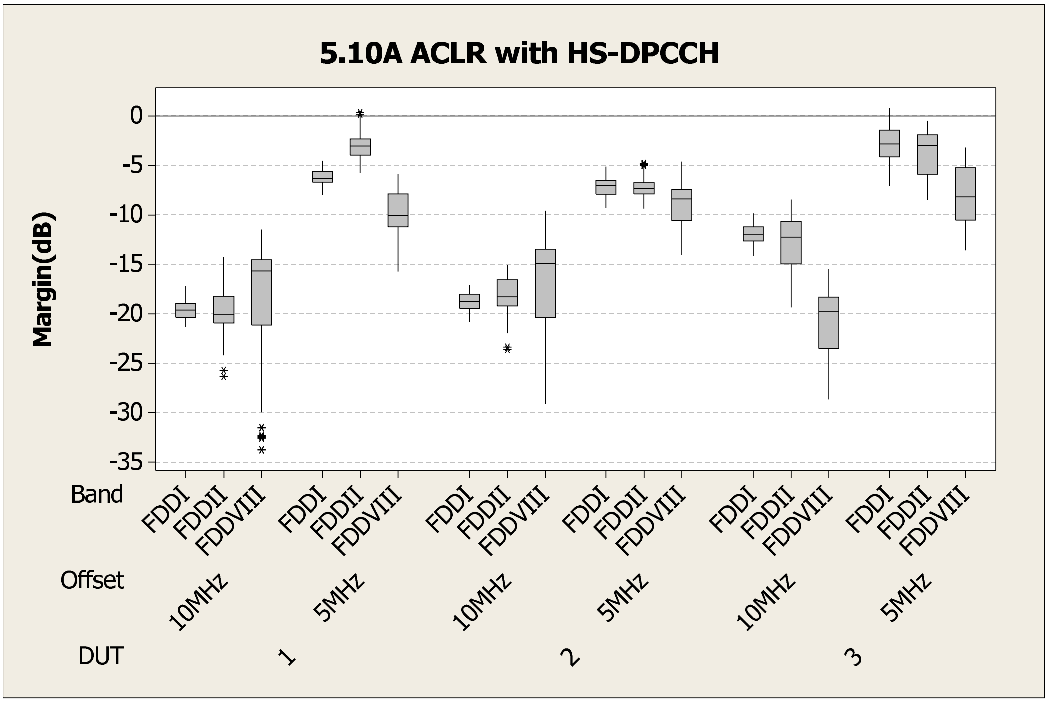

Figure 16: Results of test case Adjacent channel leakage ratio with HS-DPCCH(5.10A) expressed as margins to the test limit.

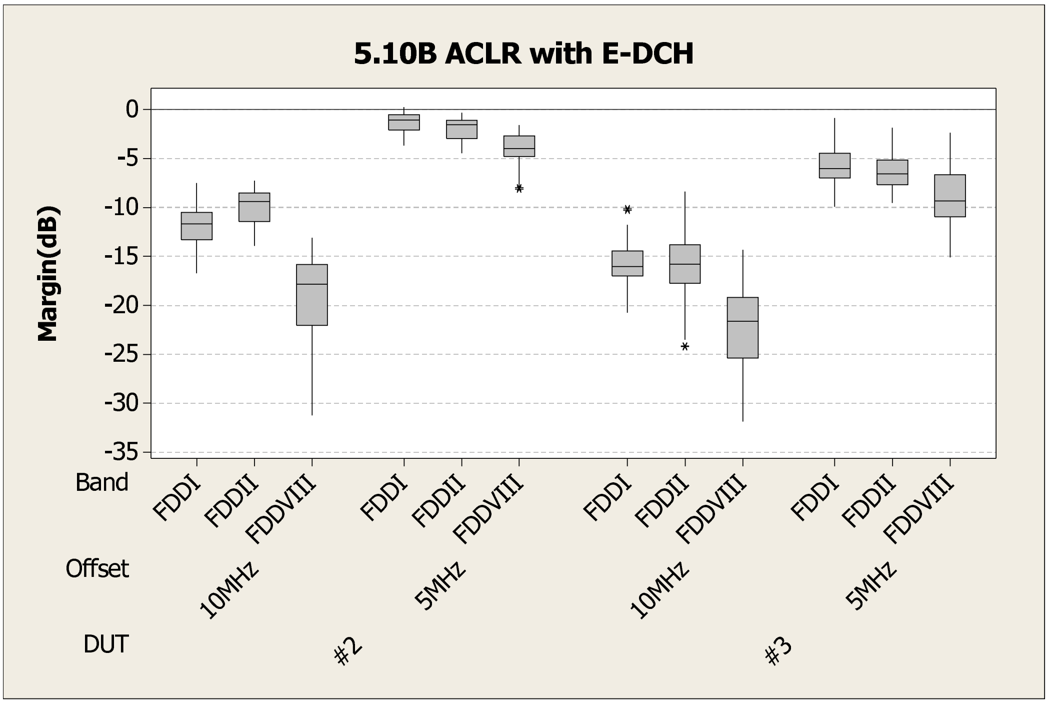

Figure 17: Results of test case Adjacent channel leakage ratio with E-DCH(5.10B) expressed as margins to the test limit.

Spurious Emissions, TX(5.11)

The results of this case can be split into two categories based on the frequency ranges involved. The common ranges for all bands cover the whole spectrum from 9kHz to 12.75GHz. In addition for some bands there are requirements for some specific narrow ranges. The results of the common ranges for all the devices have reasonable margins to the limit and the data does not point out any interesting facts or potential risks. The comparison based on the band specific ranges is not possible since the amount of measurement data is small because the tests are different for each band.

Transmit Intermodulation(5.12)

This test case provides 24 measurements per DUT consisting of eight intermodulation results for each band. The measurement is done with center channel only. Results are presented as boxplots in figure 18. The differences between DUTs are small in this test and there are no big differences between the intermodulation frequencies. This is not visible in the figure but was observed from the data.

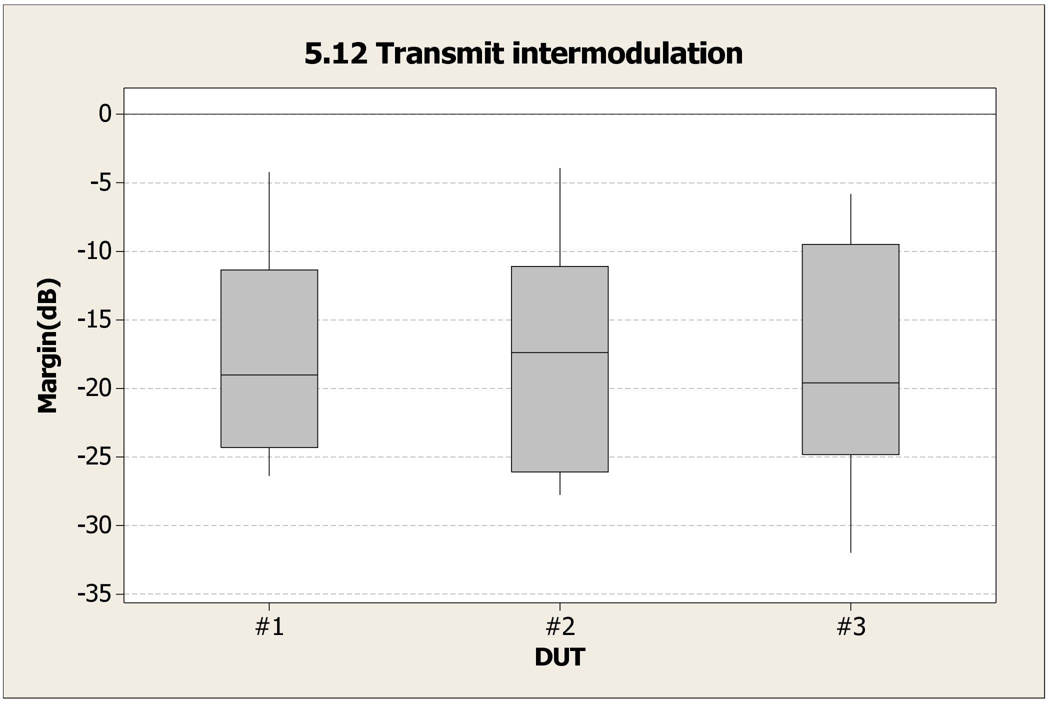

Figure 18: Results of test case Transmit intermodulation(5.12). Values are margins to the test limit in decibels.

Error Vector Magnitude(5.13.1)

The EVM results consist of measurements with all three channels in normal conditions using two transmit power levels. The results in figure 19 show that DUT#3 has the highest measured values. There are some deviations between the bands but those are much smaller than the differences between devices.

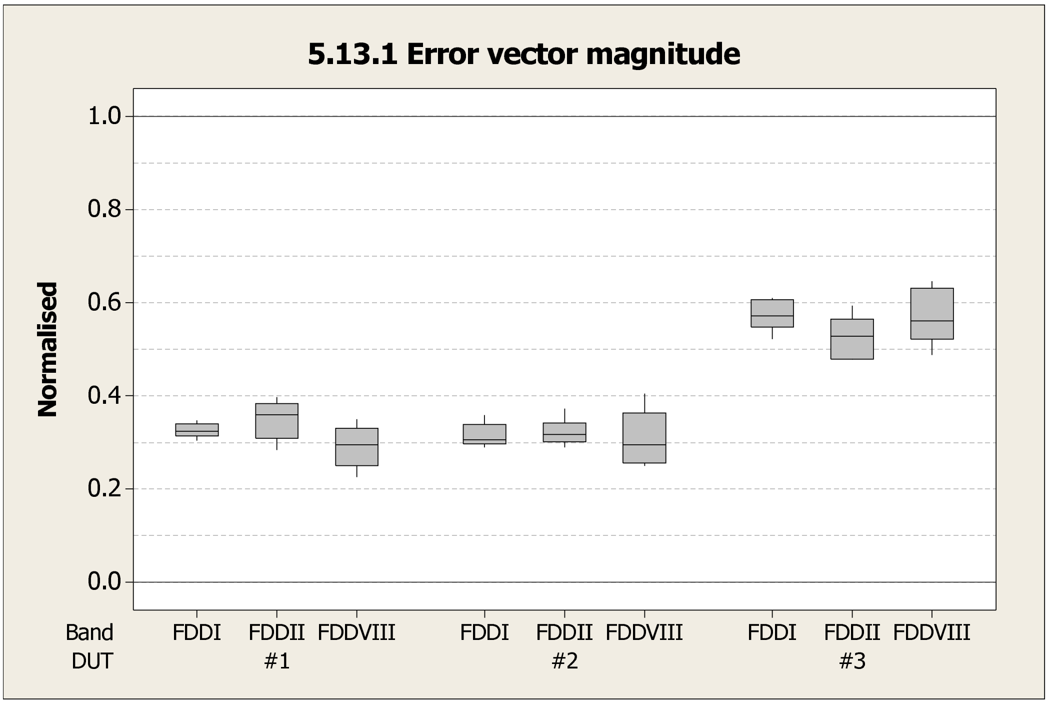

Figure 19: Normalised results of test case Error vector magnitude(5.13.1)

EVM and Phase Discontinuity with HS-DPCCH(5.13.1AA)

This test case has two types of results, EVM and phase discontinuity. Test is done with three channels in normal conditions. The EVM values are measured at four subframe positions and phase discontinuity figures are calculated between the first and last pairs. The normalised results are presented in figures 20 and 21. This test case is only applicable release 6 onwards so DUT#1 is not tested. The most interesting part of the results is that DUT#2 has the biggest values in FDDII where with #3 the FDDI results stand out. For the phase discontinuity results of figure 21 only thing that stands out is the larger range of variation of DUT#3.

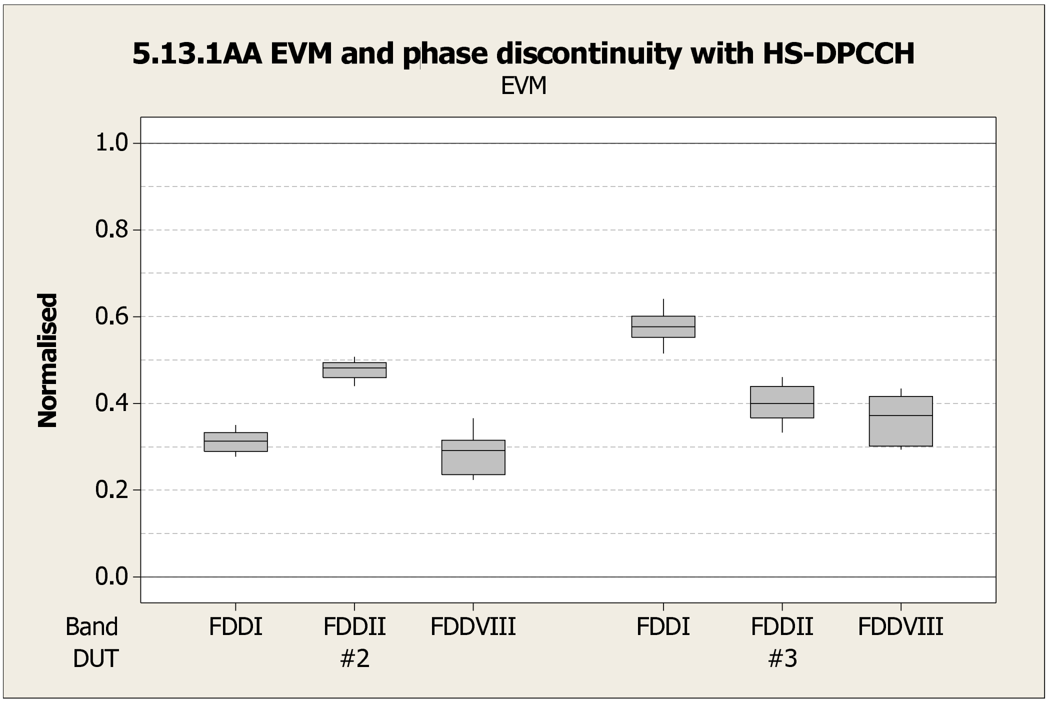

Figure 20: Normalised EVM results of test case Error vector magnitude and phase discontinuity(5.13.1AA)

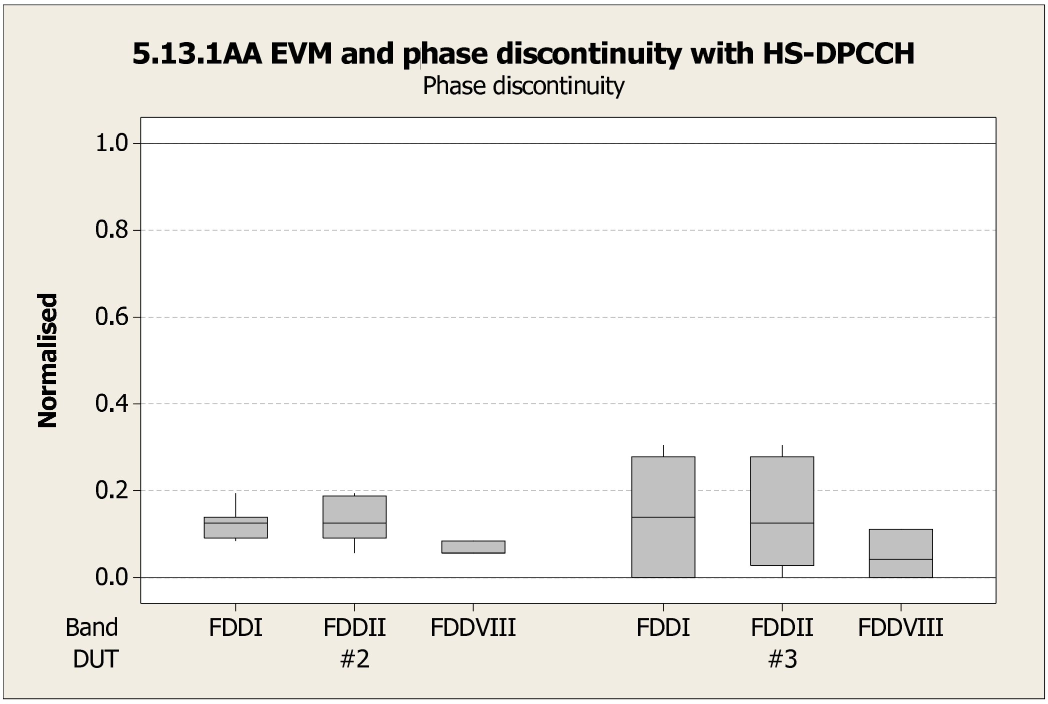

Figure 21: Normalised phase discontinuity results of test case Error vector magnitude and phase discontinuity(5.13.1AA)

UE Phase Discontinuity(5.13.3)

Test case results include phase discontinuity and EVM. The test case is methodologically similar to the previous one(5.13.1AA) but is done without HS-DPCCH and phase discontinuity is calculated between two consecutive timeslots. All the phase discontinuity measurements are between 0.25 and -0.25 on the normalised scale so there is no risk seen in the data nor big differences between the DUTs. EVM values are higher with DUT #3 than with the two others as can be seen in in figure 22. This is very well in line with the results from EVM test case, 5.13.1.

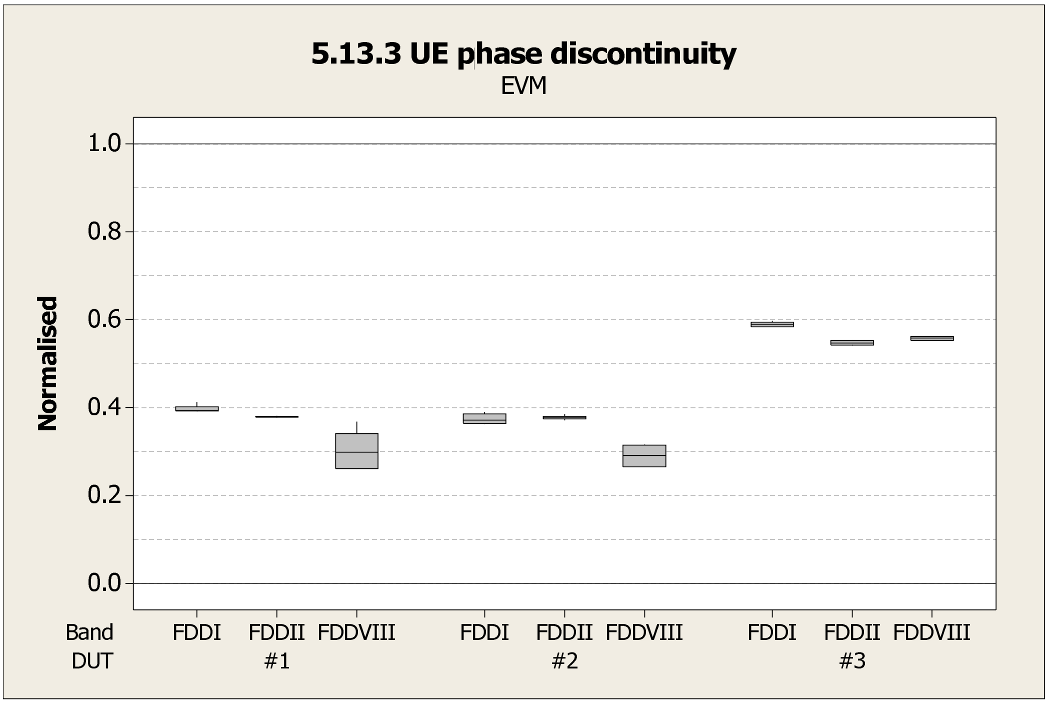

Figure 22: Normalised EVM results of test case UE phase discontinuity(5.13.3)

PRACH Preamble Quality(5.13.4)

The test case is conducted with all three channels in all four environmental conditions. Frequency errors of 5.13.4 are plotted on figure 24 and EVM results in figure 23. The results are separated by band. The frequency errors of DUT #3 are clearly the smallest. The other two DUTs look almost identical in this figure. EVM results are interesting because also here DUT #1 and #2 have similar results: the band VIII has the smallest EVM and bands I and II are almost equal. The frequencies of the bands could be the explaining factor since both FDDI and FDDII uplink frequencies are around 1900MHz where FDDVIII is centered at 900MHz. For DUT #3 the overall results are higher and there is not a clear difference between the bands.

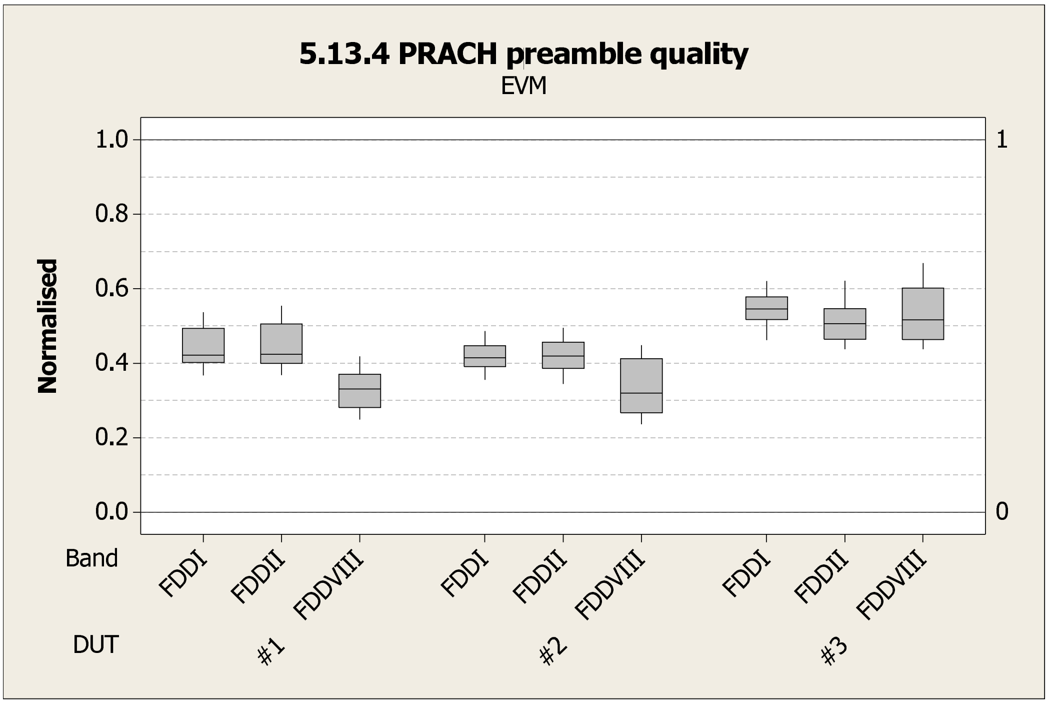

Figure 23: Normalised EVM results of test case PRACH preamble quality(5.13.4)

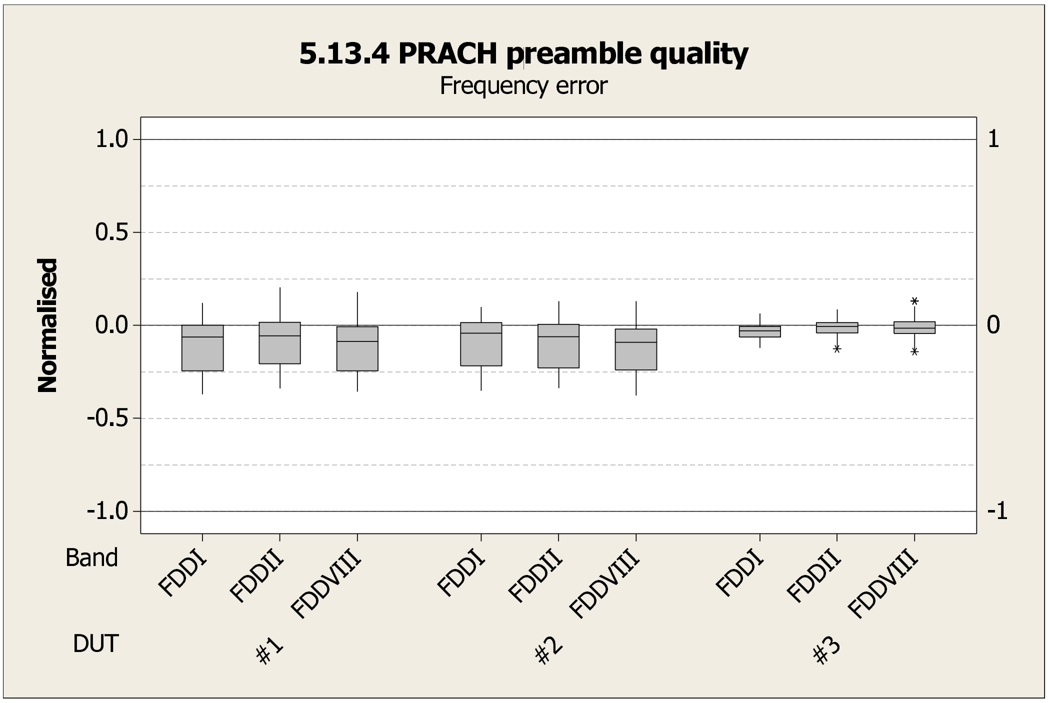

Figure 24: Normalised frequency error results of test case PRACH preamble quality(5.13.4)

Receiver Tests(6.2–6.8)

The measured bit error ratios for test cases 6.2 Reference sensitivity level, 6.3 Maximum input level, 6.3A Maximum input level for HS-PDSCH reception, 6.4A Adjacent channel selectivity and 6.7 Intermodulation characteristics were all zero regardless of the DUT. This result shows that all the tested devices do perform well in the receiver tests, but putting them in order or evaluating weak areas is simply not possible. Analysing of a larger selection of devices should be done to find out if the results can be generalised. One option enabling the comparisons would be to run the test cases with tighter parameters than required.

Blocking(6.5) and spurious response(6.6) test cases were not included in the analysis scope of this work. This is due the nature of the blocking test: A BER measurement is performed over 12000 times. Most of the measurements produce zero BER and those that are something else usually count as exceptions to be measured in test case 6.6. The number of these exceptions could be one starting point for analysis but this test case does not suite the analysis methods used in rest of the test cases in this thesis.

Test case for RX spurious emissions(6.8) does give some information about the similarity of the DUTs #1 and #2. They have larger variance of results and slightly smaller margins than DUT #3. The results are presented as margins to the limit in figure 25 which only includes the common ranges and not the band specific ones.

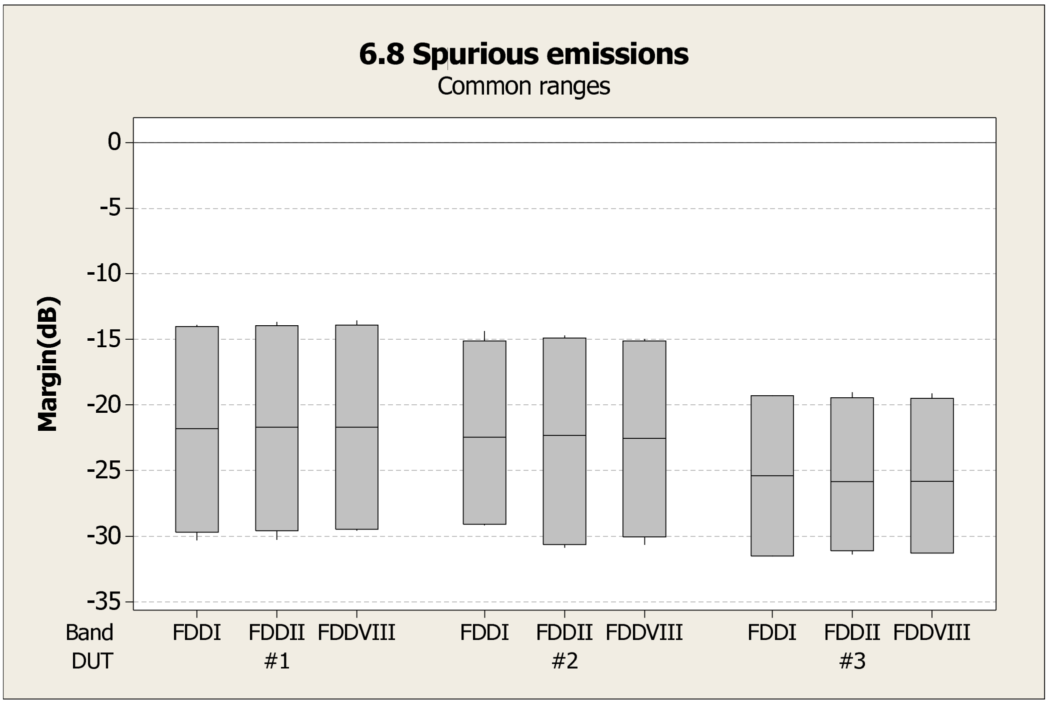

Figure 25: Results of test case Spurious emissions(6.8) expressed as margins to test limit.

6 Application of Analysis to Test Planning

Test planning is here selection of test cases to be included in a test round. This kind of planning is generally only needed for tests done for R&D purpose. The actual regulatory and organisational requirements define the necessary tests, so optimising those test sets in this way is not possible. When planning a test set the most valuable resource is time spent on a test system. Using every available test case is obviously the most thorough choice, but usually testing resources are limited. This leads to the need to limit the number of test cases in a test round. To use test time effectively it is important to know the duration of each individual test case. If a test case takes a long time to run and it provides little information, it should not be prioritised over shorter tests providing more information.

The approach taken here is to use the measured and analysed data presented in previous chapters as a basis for test planning. This is simply done so that if a test case shows differences between the tested devices it is selected to the test set. Test times of the individual test cases were considered during the selection. The durations of the test cases to be included were reasonable so there were no need to rule tests out because of too long test time. It should be noted that the selected test cases might leave some critical tests out, based only on the fact that the test gave similar result for all the devices tested. That is why this set of test cases should only be used as a starting point and the main focus of the test round should be on comparing or tracking performance differences between device models or versions. This kind of comparison test set could be used when tracking performance of a device during the design process or to find out the weak and strong areas of a new design compared to a known implementation.

A different approach for the receiver tests is also presented because using the standard test method did not make comparisons possible as all the DUTs tested gave the same results. This is discussed in chapter 6.3.

6.1 Test Times

It is not possible directly influence the time it takes to perform individual test cases as the time is determined by a test system specific initialisation, call setup and then the measurement itself. Depending on the test case there may be multiple call setups and releases during the test. Test times of the included test cases are presented in table 2. The times are gathered from the tests performed for the thesis and they include the call setup and release. The durations have small variations between runs even with the same DUT but the values listed should be a good estimate as they are based on several iterations of the test cases. Total duration of each test case in the table is the amount of time required for the test case to be run in one frequency band including all the channel and environmental condition combinations.

The total time of a test set can be influenced by the selection of test cases and parameters which include frequency band, channel, voltage and temperature. The voltage and temperature are together addressed in test specification as environmental conditions and separated as normal and extreme conditions. The normal conditions include only the normal voltage and temperature so it means one run of a test case. The extreme conditions include both high and low voltage and high and low temperature which gives a total of four combinations. According to the specification[4] all the test cases are required to be performed in normal conditions and in addition a subset of them is to be performed in extreme conditions. The duration required for the temperature adjustment and stabilisation is not included in the test times table. Stabilisation is only required when DUT is tested in extreme temperatures as the normal conditions allow moderate variations in room temperature. Typical duration for the stabilisation is 45 minutes. By properly arranging the test cases the stabilisation is needed only twice during a full test set.

6.2 Test Set Recommendation

Based on the results presented in chapter 5 of this thesis the following test cases are recommended to be used as a starting point when creating a test set for comparing two or more devices. The durations are given for one band including all channels and environmental conditions excluding the set-up and stabilisation times required for temperature changes. Test durations can change according to UE release and features because of the applicability of test cases. The times given are for a release 6 UE supporting HSUPA which is typical for a present-day UE. In addition to descriptions below the recommended test cases are also presented in table 2.

The total duration of this test set is about 5.5 hours not including the stabilisations etc. The test time could be considerably shortened by running the tests only in normal conditions. This leaves out all temperature and voltage dependent phenomena and it should be carefully considered what effects this might have on the reliability of the conclusions. Another approach would be doing a study of the relations of the results of test cases and the environmental parameters to find out if reasonable test coverage could be achieved by selecting only part of the combinations.

Maximum output power

The test cases 5.2–5.2B cover the maximum output power requirements so that 5.2 is applicable for all devices and additionally one of 5.2A, 5.2AA or 5.2B is required depending on the release version of the UE. For modern high-end devices this means test cases 5.2 and 5.2B. The total duration of the test cases is, derived from table 2, 49.5 minutes. These test cases are recommended because they can reveal differences in the performance of the transmitter at the high end of the dynamic range.

Spectrum emission mask

The test cases 5.9–5.9B describe the requirements for spectrum emission mask. The requirement for release 6 UE is that all three test cases are run. The total duration of these is 15.5 minutes. The results of these test cases revealed clear differences between the DUTs.

Adjacent channel leakage ratio

Adjacent channel leakage ratio requirements are spread to test cases 5.10, 5.10A and 5.10B. They are included in the recommended test set because the results suggest possible risks due to some failing results. These test cases also showed different results between DUTs. The correlation between the three test cases seem to be quite low and therefore they all are included. The total duration is 2 hours 23 minutes. The seemingly long duration is a result of testing in extreme conditions. The effect of the condition parameters should be studied to find out if it is possible to shorten test time by selecting only part of the test cases and conditions.

Error vector magnitude and phase discontinuity

Error vector magnitude and phase discontinuity are measured in three test cases for release 6 UE: 5.13.1, 5.13.1AA and 5.13.3. The test cases are a good measure of transmitter properties and the data suggests some differences between the DUTs. The total time for the three test cases is 29 minutes.

PRACH preamble quality

The test case 5.13.4 shows some differences between the DUTs. Visually comparing the results of this test case to 5.13.1 EVM shows some correlation and it should be considered if either one should be left out from the test set to reduce the duration. However, this test case is included because it fills the criteria of showing differences between the devices. Test time is about 1.5 hours.

6.3 Iterative Method for Receiver Tests

From the test results it can be seen that if these devices should be compared by receiver performance, the test cases should be run using conditions that are harder for the UE than is required in the specifications. A natural way to achieve this is to use iterative testing method where the worst test condition in which the UE passes the test limits is searched. The Anritsu test system used allows this iteration to be done in all required test cases. The iteration method is similar in all the test cases. A parameter is selected as the iteration variable and it is changed by the step size after each iteration. The direction of change is determined by BER measurement result so that when the BER is below the limit the conditions are toughened and vice versa. The used step size for level changes and the target BER can be chosen by the user. Also the minimum and maximum values of the variable are selectable. This is required in order to avoid levels that could be dangerous to the device under test and to limit the amount of iterations and hence test time. [22]

The method was tested to verify the functionality of the iterative method for the selected test cases and to test if there were any limitations by the test system. The test cases were run with a new DUT not used in the original test rounds so the results are not comparable. Only band FDDI in normal conditions was tested using center channel.

For test case 6.2 Reference sensitivity level the varied parameter is downlink transmission power. The step size used was 0.5dB and maximum span was set to 20dB. The requirement for this test case is -106.0dBm and the result was -109.5dBm.

For test case 6.3 Maximum input power the step size for input power was 1dB and the span was set to 20dB. This turned out to be too big value since the system did not support larger value than -20.0dBm/3.84MHz where system limit was reported. Requirement was -25.7dBm/3.84MHz.

Test case 6.4A Adjacent channel selectivity(Rel. 5 and later) includes measurements with interferers on both upper(+5MHz) and lower(-5MHz) adjacent channels separately. The test is also done with two power levels and thus separated to case 1(lower level) and case 2(higher level). Case 2 is done with 27dB greater downlink and interferer levels than case 1 when the specified levels are used. The iterated variable in this case is the interferer level. Span was set to 20dB and step size to 1dB. The results for case 1 were -42dBm for both upper and lower adjacent channels where the limit was -52dBm. For case 2 the results were -21dBm and -22dBm for upper and lower adjacent channels respectively the limit being -25dBm.

Test case 6.7 Intermodulation characteristics includes two interfering signals: the WCDMA simulating noise signal and a sinusoidal signal. Both signals have the same level which is specified at -46dBm. Two frequency combinations are tested: The first case includes sinusoidal interferer at -10MHz from the carrier with the simulated WCDMA signal lying at -20MHz. The second combination is the same but with positive offsets. The possible intermodulation results should appear on the carrier frequency. The iteration is performed altering the level of the two interferers in synchronous manner with step size of 1dB. Results were -38dBm for interferers below the carrier frequency and -39dBm for the interferers above the carrier.

Using this one DUT the method was proven useful for test cases 6.2, 6.4A and 6.7. Test case 6.3 did not give any additional information since test system limit was reached. A larger study with more devices should be made to find out if the results are useful in comparisons between devices. As emphasised before test time should be always considered when suggesting changes in testing. The effect on test times is of course dependent of the number of iterations required but as one measurement takes a second the real impact is reasonably small. Of the included tests the greatest difference was observed with test case 6.2 where the time was increased to 1 minute 26 seconds from 31 seconds. Relationally this is a great change but as all the tests in question are originally short using this method would not add the test time significantly.

Table 2: Test durations of the test cases discussed in this thesis. Test case numbering follows [4]. Measurement conditions and channels are also presented. Total duration includes all the channels and environment combinations required for each test. Test cases marked with 'X' are included in the recommended test set discussed in chapter 6.2

TC n.o.	**Duration**	**Conditions**	**Channels**	**Total**	**Rec.**
5.2	00:00:18	NC+EC	L,M,H	00:04:30	X
5.2A	00:01:15	NC+EC	L,M,H	00:28:45	X
5.2AA	00:02:00	NC+EC	L,M,H	00:30:00	X
5.2B	00:03:00	NC+EC	L,M,H	00:45:00	X
5.3	00:00:21	NC+EC+V	L,M,H	00:06:18	
5.4.1	00:03:16	NC+EC	L,M,H	00:49:00	
5.4.2	00:01:42	NC	M	00:01:42	
5.4.3	00:00:20	NC+EC	L,M,H	00:05:00	
5.4.4	00:01:21	NC	M	00:01:21	
5.5.1	part of 5.5.2	NC+EC	L,M,H	part of 5.5.2	
5.5.2	00:01:59	NC+EC	L,M,H	00:29:45	
5.6	00:00:27	NC	M	00:00:27	
5.7	00:00:58	NC	M	00:00:58	
5.7A	00:03:47	NC	M	00:03:47	
5.8	00:00:16	NC	L,M,H	00:00:48	
5.9	00:00:21	NC	L,M,H	00:01:03	X
5.9A	00:01:00	NC	L,M,H	00:03:00	X
5.9B	00:03:50	NC	L,M,H	00:11:30	X
5.10	00:00:25	NC+EC	L,M,H	00:06:15	X
5.10A	00:01:16	NC+EC	L,M,H	00:19:00	X
5.10B	00:07:50	NC+EC	L,M,H	01:57:30	X
5.11	00:03:09	NC	L,M,H	00:09:27	
5.12	00:00:36	NC	M	00:00:36	
5.13.1	00:00:35	NC	L,M,H	00:01:45	X
5.13.1A	00:01:22	NC	L,M,H	00:04:06	X
5.13.1AA	00:02:59	NC	L,M,H	00:08:57	X
5.13.3	00:18:39	NC	M	00:18:39	X
5.13.4	00:05:53	NC+EC	L,M,H	01:28:15	X
6.2	00:00:31	NC+EC	L,M,H	00:07:45	
6.3	00:00:51	NC	M	00:00:51	
6.3A	00:00:30	NC	M	00:00:30	
6.4A	00:01:30	NC	M	00:01:30	
6.5	08:20:00	NC	M	08:20:00	
6.6	00:00:13	NC	M	00:00:13	
6.7	00:00:48	NC	M	00:00:48	
6.8	00:01:53	NC	L,M,H	00:05:39	

7 Conclusions

This thesis concentrates on result analysis of 3G RF conformance tests. Characteristic properties of WCDMA and UMTS are discussed in chapter 2. The test cases included in the scope are introduced in Chapter 3. In chapter 4 a normalisation scheme for presenting the results in a common scale and a graphical presentation, boxplot, for visualising the data are presented. The measurement equipment and the analysis results are discussed in chapter 5. Chapter 6 is used to propose a set of test cases that are shown to provide differences between devices. The chapter also includes a description of an alternative test method to gain additional value from receiver tests.

The visual analysis using boxplots was shown to give additional value out of conformance test results. Applying normalisation to the data and then representing the results as boxplots enables comparisons between devices. The use of this kind of analysis could save some valuable test time in the product development because the analysis enables discovering the performance differences between device models. The visualisations enable also observing the margins to the test limits, which can be used to identify risky areas between or inside test cases. An example of this is visible in figures 12 to 14 where the smaller offsets are clearly having the smallest margins.

In order to gain the best value out of the boxplots, the selection of parameters to be used to separate the boxes must be done carefully. Currently there are no better ways of doing this than by relying on the previously gathered information or by trial and error. The optimal result is probably obtained by a combination of these two.

By using the analysis results it was made possible to form a recommended test set to be used in benchmarking devices. This set consists of the test cases that were shown to provide different results between two or more of the tested devices. The selected test cases are marked with 'X' in table 2 and the reasoning behind each test is explained in chapter 6.2. The applied method does include a risk of leaving out useful test cases and probably use of larger set of different types of devices would be a good option to lower that risk.

The selection of environmental conditions and test cases together for research & development tests should be addressed in future studies. By selecting the test cases to be run only in some environmental conditions the total test times could be optimised. One approach for doing this would be to analyse a large set of devices to find out what conditions are the most difficult for each test case and then only test in those conditions.

The results of receiver bit error ratio measurements were identical for all the tested devices. All the tests resulted in zero BER. This gave a reason to study the possibilities of the used test system and as a result they were later run with a different test mode to test the functionality in practice and gain information about test duration. This iterative method was found out to be useful with some test cases but was only tested with one DUT so a comparative analysis between different devices was not done. This should be evaluated and studied more before this mode of testing can be recommended to be taken in systematical use.

It was found out that generating the graphics from test system output files in a way it was done is not feasible for everyday use. The time consumed by doing manual mechanical work is simply too long. However, the observations made in the thesis support the idea of developing tools to help performing the analysis tasks. With proper tools the analysis could be used in daily work as a value-adding reporting format. Starting the development of such tools from the test cases listed in the recommended test set would probably be the best approach and give the most added value.

References

[1] *Official Journal of the European Communities*, Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity

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