Institutionen för systemteknik
Department of Electrical Engineering
Examensarbete

WCDMA User Equipment Output Power Calibration
Examensarbete utfört i Datatransmission
av
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Sammanfattning

To save time in Flextronics high volume production, the time for test and calibration of mobile telephones need to be as short and accurate as possible. In the wideband code division multiple access (WCDMA) case, the output power calibration is the most critical calibration concerning accuracy. The aim with this thesis was to find a faster calibration method than the one that exists today and still retain accuracy. The Third Generation Partnership Project (3GPP) outlines the requirements of the output power and they must be thoroughly considered when choosing calibration method. Measurement accuracy and the behavior of the transmitter chain parameters also must be considered. The output power in the WCDMA phone studied is controlled by seven parameters. The parameters are characterized in this thesis, and are found to be too hardware dependent to be predicted or to be seen as predictions from each other. Since no parameter predictions are possible it was stated that all parameters have to be measured, and a new way of measuring them in a faster way is proposed. The principle of the new measurement method is presented, and the implemented software is tested and evaluated. The new method mainly makes use of the spectrum analyzer zero span function. The evaluation shows that the new method is faster than the original and retains accuracy. The measurement uncertainties even seem to diminish, which implicates decreased temperature dependence due to faster measurement time.

Nyckelord

WCDMA, 3G, Output Power Calibration
WCDMA User Equipment Output Power Calibration

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Linköping, March 2003
Tea Folkeson
ABSTRACT

To save time in Flextronics high volume production, the time for test and calibration of mobile telephones need to be as short and accurate as possible. In the wideband code division multiple access (WCDMA) case, the output power calibration is the most critical calibration concerning accuracy. The aim with this thesis was to find a faster calibration method than the one that exists today and still retain accuracy.

The Third Generation Partnership Project (3GPP) outlines the requirements of the output power and they must be thoroughly considered when choosing calibration method. Measurement accuracy and the behavior of the transmitter chain parameters also must be considered.

The output power in the WCDMA phone studied is controlled by seven parameters. The parameters are characterized in this thesis, and are found to be too hardware dependent to be predicted or to be seen as predictions from each other.

Since no parameter predictions are possible it was stated that all parameters have to be measured, and a new way of measuring them in a faster way is proposed. The principle of the new measurement method is presented, and the implemented software is tested and evaluated. The new method mainly makes use of the spectrum analyzer zero span function.

The evaluation shows that the new method is faster than the original and retains accuracy. The measurement uncertainties even seem to diminish, which implicates decreased temperature dependence due to faster measurement time.
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1 ABBREVIATIONS

In telecommunications abbreviations are frequently used. For the purposes of the present document, the following abbreviations apply:

ACLR Adjacent Channel Leakage power Ratio
BS Base Station
CDMA Code Division Multiple Access
CN Core Network
CRT Cathode Ray Tube
DL Down Link (forward link)
DPCCH Dedicated Physical Control Channel
DPDCH Dedicated Physical Data Channel
DS Direct Sequence
DUT Device Under Test
ETSI European Telecommunications Standard Institute
FDD Frequency Division Duplex
GPIB General Purpose Interface Bus
IF Intermediate Frequency
IMT-2000 International Mobile Telephony at 2000 MHz
ITU International Telecommunication Union
Iu Interface between CN and UTRAN
PA Power Amplifier
QPSK Quadrature Phase Shift Keying
RF Radio Frequency
SF Spreading Factor
SIR Signal to Interference ratio
TDD Time Division Duplex
TFC Transport Format Combination
TFCI Transport Format Combination Indicator
TPC Transmit Power Control
UE User Equipment
UL Up Link (reverse link)
UMTS Universal Mobile Telecommunication System
UTRA UMTS Terrestrial Radio Access
UTRAN UMTS Terrestrial Radio Access Network
Uu Interface between UE and UTRAN
WCDMA Wideband Code Division Multiple Access
2  PROBLEM DEFINITION

To save time in Flextronics' high volume production, the time for test and calibration of user equipments (mobile phones) need to be as short and accurate as possible. In the wideband code division multiple access (WCDMA) case, the output power calibration is the most critical calibration concerning accuracy. Today's calibration method of the WCDMA phones works but it demands more time than desired.

The main target with this Master thesis was to examine if there is a way to shorten the output power calibration time for WCDMA phones. The calibration contains seven parameters that had to be characterized, both individually and by their impact on each other. The measurement equipment for radio frequency (RF) and its impact on the measured values also had to be concerned to maintain accuracy. Requirements from the Third Generation Partnership Project (3GPP) also had to be fulfilled. If a new faster method was found it was supposed to be software implemented and evaluated.
3 THEORY

In this chapter only a fraction of all the techniques and terms used in third-generation (3G) systems is described. For further reading References [7] and [9] are recommended.

3.1 THIRD GENERATION PARTNERSHIP PROJECT – 3GPP

Third Generation Partnership Project is a forum for WCDMA standardization. It became essential as similar technologies were being standardized around the world, and all parties wanted to have collaborative systems. The 3GPP forum provides today several technical specifications and reports for the 3G system. To be able to have the collaborative systems desired new, 3G equipment is developed by applying 3GPP specifications.

3.2 UNIVERSAL MOBILE TELECOMMUNICATION SYSTEM - UMTS

The main driver for deployment of 3G mobile radio networks is the demand for networks providing both high-rate data services like packet data services, and better spectrum efficiency. Two main 3G standards have been developed, one in Europe and one in the United States. The European Telecommunications Standard Institute (ETSI) is developing the UMTS standard for 3G in Europe and the International Communication Union (ITU) is developing the International Mobile Telephony at 2000 MHz (IMT-2000) standard for 3G in the U.S. This report will further on only describe the UMTS standard since this is the standard for the User Equipment (UE) used in the measurement part in this report.

Some of the main targets for UMTS networks are:

- High spectrum efficiency.
- Up to 2 Mbit/s data rates for limited coverage and low mobility and up to 144 Kbit/s rural outdoors.
- High flexibility to introduce new (and yet unknown) data services.
Figure 1 shows the UMTS reference architecture. The Core Network (CN) offers gateways and switching services to other communication networks, like the GSM network. $I_u$ is the interface between the CN and the UMTS Terrestrial Radio Access Network (UTRAN.) UTRAN is a radio access network that provides for example handover and radio resource administration. The base stations (BS) are a part of the UTRAN. $U_u$ is the interface between the UTRAN and the UE. The UE represents the mobile subscriber, it is the interface to the user and it provides the radio link to the BS.

*Figure 1: UMTS Reference architecture*
3.3 CDMA - WCDMA

Code division multiple access (CDMA) is after investigations the best multiple access schedule for the 3G air interface. In CDMA each user is assigned a unique code sequence that is used to code the data before transmission. The receiver is able to decode the data since it knows which code a certain user used. Since the codes are unique, and with almost zero cross-correlation the users can simultaneously transmit uninterrupted on the same frequency and at the same time. A popular simile is “The CDMA party.” Each person is seen as BS or UE and every one speaks and understands only one language, in pairs of two. The language is seen as the code sequence and the pitch of a voice is seen as the noise level. In reality the person representing the BS speaks and understands several languages at the same time.

Figure 2: The CDMA party

The CDMA technique is an old technique, and it has for example been used for military systems in the US. The main reason for using CDMA in military systems is the high tolerance to external jamming.
The most successful CDMA technique for 3G applications is the direct spread CDMA (DS-CDMA) technique. In this technique the data to be coded \( b(t) \) is multiplied by a wide-band digital code \( c(t) \). The digital code represents the code sequence to be used at the particular time \( t \). The ratio between the bit rate of \( c(t) \) and the bit rate of \( b(t) \) is called spreading factor (SF). The modulated signal is \( m(t) \).

*Figure 3: CDMA spreading operation. \( T_b = \text{symbol}, T_c = \text{chip} \).*

The spreading operation spreads the original narrow band signal to a wideband signal. There is no way to separate the spread original signals, but to de-spread them.

One multiple access scheme proposed by the standardisation groups is WCDMA. The WCDMA uses a DS-CDMA in which all users transmit in the same frequency channel. The reason why the technique is called wideband is that the SF can be very large in WCDMA systems.
In WCDMA the information bits are sent over a physical data channel and the control bits are sent over a separate control channel. The modulation in WCDMA is quadrature phase shift keying (QPSK.) The information sent over the channel is divided into frames, each frame length is 10 ms and each frame consists of 15 time slots. The chip rate in WCDMA is 3.84 Mchips/s and the channel bandwidth is 5 MHz.

3.4 UPLINK AND DOWNLINK

The link from UE to BS is called uplink (UL) and the link from BS to UE is called downlink (DL.) See Figure 4. The UL and DL consist of a number of logical and physical channels of which only some will be mentioned. On the DL, the channel of importance concerning output power is the Dedicated Physical Control Channel (DPCCH) where Transmit Power Control (TPC) bits are sent. The TPC bits inform the UE whether to rise or lower its power. The UL use a Dedicated Physical Data Channel (DPDCH) and a DPCCH to transmit the data. For further reading about the UL and DL Reference [2] is recommended.

*Figure 4: Uplink and Downlink.*
3.5 **FREQUENCY BANDS**

One multiplexing method used on the UL and DL in WCDMA is Frequency Division Duplex (FDD). In this mode different frequency bands are used to separate the UL and DL traffic. A physical channel is in this case defined by a certain code and a certain frequency.

Another multiplexing method is Time Division Duplex (TDD). In this mode only one frequency band is needed to carry both UL and DL traffic. The TDD mode is most suitable for small cells and will probably be more applied in the future. This thesis will only describe the FDD mode.

UMTS Terrestrial Radio Access (UTRA) / FDD is designed to operate in the following bands and with the following transmitter-receiver (TX-RX) frequency separation:

**Table 1: UTRA FDD frequency bands**

<table>
<thead>
<tr>
<th>Operating Band</th>
<th>UL Frequencies</th>
<th>DL frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UE transmit</td>
<td>UE receive</td>
</tr>
<tr>
<td>I</td>
<td>1920 - 1980 MHz</td>
<td>2110 - 2170 MHz</td>
</tr>
<tr>
<td>II</td>
<td>1850 - 1910 MHz</td>
<td>1930 - 1990 MHz</td>
</tr>
<tr>
<td>III</td>
<td>1710 - 1785 MHz</td>
<td>1805 - 1880 MHz</td>
</tr>
</tbody>
</table>

**Table 2: UTRA/FDD TX-RX frequency separation**

<table>
<thead>
<tr>
<th>Operating Band</th>
<th>TX-RX frequency separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>190 MHz</td>
</tr>
<tr>
<td>II</td>
<td>80 MHz</td>
</tr>
<tr>
<td>III</td>
<td>95 MHz</td>
</tr>
</tbody>
</table>

In Europe band I is used. Both fix and variable TX-RX frequency separation is supported by UTRA/FDD.
3.6 POWER CONTROL

One of the most important characteristics of WCDMA is that power is the common shared resource. The radio resource management allocates power to each user, and ensures that the maximum interference is not exceeded. The fact, that a single UE transmitting too much power can block the complete radio cell, due to interference in-between UEs, outlines the great importance of controlling the power. The different power settings in the UE are found during calibration of the UE in production.

The power control is made to keep the quality of the connections and to minimize interference between channels, see chapter 5.2. Transmit Power Control (TPC) bits are sent both UL and DL to control the power. The following group of functions is used when controlling the UL power, see also Figure 5. The same closed-loop power control is used for DL power control but will not be further described in this report.

3.6.1 UL OPEN LOOP POWER CONTROL

The UL Open Loop Power Control sets the initial power of the UE, before the first TPC is sent on the DL, i.e. at random access. The estimated power has UE measurements and system parameters as input. The function is located both in the UE and in the UTRAN. When the first DPCCH is established the UE shall start the UL Inner Loop Power Control.

3.6.2 UL OUTER LOOP POWER CONTROL

The UL Outer Loop Power Control, located in the UTRAN, sets the target quality value for the UL Inner Loop Power Control, which also is located in UTRAN. This power control is mainly used for a long-term quality control of the radio channel. It takes quality estimates of the transport channel as input.
3.6.3 **UL INNER LOOP POWER CONTROL**

The UL Inner Loop Power Control sets the power of the UL dedicated physical channels. This power control receives its quality target from quality estimates of the UL dedicated physical control channel and from the UL Outer Loop Power Control. I.e. the BS takes estimates of the received Signal to Interference Ratio (SIR) and compares it to a target SIR. If the measured SIR is higher than the target SIR, the BS commands the UE to decrease its power. If the SIR is too low the UE will be commanded to increase its power. The BS sends TPC bits on the DL telling the UE whether to step up or down in power. The function is located both in the UE and in the UTRAN. This UL inner loop power control is used to modify the power 1500 times per second (i.e. once every time slot.) The output power is changed in steps of 1, 2 or 3dB. One of the most negative issues of CDMA systems in total is probably the need of fast and accurate TPC.
Figure 5: CDMA Power Control

CDMA Power Control

Open Loop Power Control

System Parameters  UE measurements

Compute initial power

Transmit access preamble

Increase power by 1dB

Access acknowledged

Yes

DPCCH established

Outer Loop Power Control

Target control

Increase power target

Decrease power target

Inner Loop Power Control

Yes

Measured power > target

Decrease power

No

Keep power

Yes

Measured power = target

Increase power

No

Decrease power

Increase power
4 MEASUREMENT ACCURACY

The importance of accurate measurements and reliable measurement equipment is not to be forgotten when it concerns the output power. If the calibration method accumulates possible faults done during the measurement part, it makes the measurement part even more important.

Different types of measurement equipment have got different favorable intervals, which is why several instruments will be used during calibration instead of only one. Another reason for using several instruments is the time aspect. Some instruments perform the measurement much faster than others would do.

The choice of cables and attenuators is also important to guarantee correct measurements. It is important that all cables, devices and instruments have got the same characteristic impedance. If not, reflected waves will be traveling along the transmission lines. This phenomenon is called mismatch. The reflected wave will cause a pseudo wave together with the original wave, since the reflected wave can bounce between two couplings. There will of course be measurement uncertainties when measurements are performed on the pseudo wave. Attenuators mitigate the effect of the reflected wave. The cable length is also of importance since standing waves otherwise can arise and cause measurement uncertainties.

The mismatch problem can be seen as a lightwave analogy, see Figure 6. The travelling wave along a transmission line is seen as a lightwave. Imagine the incident light striking some optical component. Some of the light is reflected but most of the light continues through the lens. Suppose the lens had mirror surfaces, almost all light would be reflected and only some transmitted. The more light transmitted the better is the characteristic impedance relationship. In so-called Network Analysis the three signals (i.e. incident, reflected and transmitted) are accurately measured.

Figure 6: Mismatch lightwave analogy
4.1 SPECTRUM ANALYSIS

A spectrum analyzer is used in the measurement part of this thesis, and this chapter will further describe the components of it and their accuracy properties.

Figure 7: Spectrum Analyzer block diagram

Figure 7 shows the block diagram of a spectrum analyzer. The components of most interest will be described below.

RF ATTENUATOR – The RF attenuator is used to adjust the level of the incident signal upon the first mixer. A too high and/or broadband signal will otherwise cause mixer gain compression and distortion. The user can adjust the attenuation.

MIXER - The mixer is by definition a nonlinear device and converts a signal from one frequency to another. In this case it converts the RF input signal to an Intermediate Frequency (IF) signal that the analyzer can filter, amplify and detect for the purpose of displaying the signal on the display.

IF GAIN – The IF gain adjusts the amplitude of the signal on the display without affecting the signal level at the input mixer. The RF attenuator and the IF gain are tied together, they compensate for each other to keep the reference level constant.

IF FILTER – The IF filter is a band pass filter used as a window for detecting the IF signal. Its bandwidth is called the resolution bandwidth and can be changed by the user. The optimum resolution bandwidth is heavily dependent on the characteristics of the signal of interest.
DETECTOR – To be able to view the signal on the analyzer display the detector converts the IF signal to a base band or video signal.

VIDEO FILTER – The video filter is used to filter the signal from the detector. It determines the bandwidth of the video amplifier, and is used to smooth or average the trace that will be seen on the screen. The user can change the video bandwidth. The video filter is most useful when the signal is covered by noise, but is also useful to get a better view of the signal studied. A too narrow video bandwidth will reduce the resolution.

SWEEP GENERATOR AND LOCAL OSCILLATOR – The sweep generator deflects the beam horizontally across the analyzer display creating the frequency axis. It also tunes the local oscillator, which further tunes the analyzer. The user can adjust the sweep time.

4.1.1 REFERENCE LEVEL

To get as accurate measurement value as possible, the reference level should be set as close as possible to the expected signal level. Setting the reference level means that the spectrum analyzer adjusts mixers, filters and other components to fit the expected value to be measured.

4.1.2 SWEEP

A sweep can be seen as a filter sweeping over the frequency range of interest. A too short sweeping time will affect the accuracy.

4.1.3 SPAN

The span is the frequency range selected from a center frequency. Zero span means measuring in the time domain. Then the spectrum analyzer functions as an oscilloscope except that only a narrow frequency band is studied at a time. The width of the frequency band is set by adjusting the bandwidth of the IF filter.
4.1.4 AMPLITUDE ACCURACY

The relative accuracy is always considerably more accurate for spectrum analyzers than the absolute accuracy. Therefore the aim is always to try to use the advantages of relative measurements. Figure 8 shows relative amplitude.

*Figure 8: Absolute and relative amplitude. The graph reproduces power in log scale versus frequency.*
5 REQUIREMENTS

3GPP states the requirements of the UE radio transmission. Some of the most important requirements for the output power calibration follow below. The transmitter characteristics are specified at the antenna connector of the UE. For further reading see Reference [1].

5.1 UE OUTPUT POWER

5.1.1 MAXIMUM OUTPUT POWER

The following Power Classes define the nominal maximum output power allowed in the different bands. The nominal power is defined as the broadband transmit power of the UE. The period of measurement shall be at least one time slot.

dBm is a measure of power relative 1mW. 0dBm = 1mW.

Table 3: UE Power Classes

<table>
<thead>
<tr>
<th>Operating Band</th>
<th>Power Class 1</th>
<th>Power Class 2</th>
<th>Power Class 3</th>
<th>Power Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power (dBm)</td>
<td>Tol (dB)</td>
<td>Power (dBm)</td>
<td>Tol (dB)</td>
</tr>
<tr>
<td>Band I</td>
<td>+33</td>
<td>+1/-3</td>
<td>+27</td>
<td>+1/-3</td>
</tr>
<tr>
<td>Band II</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Band III</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In Europe Band I, Power Class 3 is used.

5.1.2 MINIMUM OUTPUT POWER

The minimum output power required is defined as the mean power in one time slot, and shall be less than –50 dBm.

The dynamic range of the power settings is thus about 75 dB.
5.2 ADJACENT CHANNEL LEAKAGE RATIO

Adjacent channel leakage ratio (ACLR) determines how much of the transmitted power that is allowed to leak into the first and second adjacent channels, see Figure 9. It is important to consider ACLR since it will affect all wideband systems where the carriers are not far enough from each other. In WCDMA, spectrum efficiency is expected and therefore the carriers are located as close as possible to each other. Channel leakage raises the interference level in adjacent channels and can cause a reduced UL capacity.

**Figure 9: Adjacent Channel Leakage Ratio**

In the UL the adjacent channel performance is for example limited by the performance of the filters and the nonlinear power amplifier in the UE, which introduces adjacent channel leakage power. The higher the ACLR requirement, the more linearity is required from the UE power amplifier and the lower is the efficiency of the amplifier.
The minimum requirements on ACLR are according to 3GPP:
If the adjacent channel power is greater than –50dBm the ACLR shall be lower than the value specified in Table 4.

**Table 4: UE ACLR**

<table>
<thead>
<tr>
<th>Power Class</th>
<th>Adjacent channel frequency relative to assigned channel frequency</th>
<th>ACLR limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>+ 5 MHz or – 5 MHz</td>
<td>33 dB</td>
</tr>
<tr>
<td>3</td>
<td>+ 10 MHz or – 10 MHz</td>
<td>43 dB</td>
</tr>
<tr>
<td>4</td>
<td>+ 5 MHz or – 5 MHz</td>
<td>33 dB</td>
</tr>
<tr>
<td>4</td>
<td>+ 10 MHz or –10 MHz</td>
<td>43 dB</td>
</tr>
</tbody>
</table>

The ACLR requirements reflect what state of the art technologies can achieve today. These limits will be changed as the technology progress.

### 5.3 ERROR VECTOR MAGNITUDE - EVM

The EVM is a measure of the difference between the reference waveform and the measured waveform i.e. it is a measure of the modulation. The EVM is defined as the square root of the ratio of the mean error vector to the mean reference signal expressed in %. The measurement interval is one timeslot. For definitions see Figure 10. I mean In-phase and Q means quadrature. For more information see Reference [4].

**Figure 10: Error Vector Magnitude**
The EVM shall not exceed 17.5 % for the parameters specified in Table 5. I.e. the square root of the ratio of the mean error vector to the mean reference signal shall not exceed 17.5%.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE Output Power</td>
<td>dBm</td>
<td>≥ –20</td>
</tr>
<tr>
<td>Operating conditions</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Power control step size</td>
<td>dB</td>
<td>1</td>
</tr>
</tbody>
</table>

The EVM is not controlled in the calibration method but it could be a test in production.

5.4 UL INNER LOOP POWER CONTROL

The ability of the UE to adjust its output power in accordance to a TPC command received on the DL is the UL inner loop power control. In the time slot immediately after the TPC command can be derived the transmitter must be capable of changing the output power in steps of 1, 2 and 3 dB.

The minimum requirements for the transmitter output power step due to inner loop power control shall follow Table 6.

<table>
<thead>
<tr>
<th>TPC command</th>
<th>Transmitter power control range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 dB step size</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>+1</td>
<td>+0.5 dB</td>
</tr>
<tr>
<td>0</td>
<td>-0.5 dB</td>
</tr>
<tr>
<td>-1</td>
<td>-0.5 dB</td>
</tr>
</tbody>
</table>

The minimum requirements for the transmitter average output power step due to inner loop power control shall follow Table 7. In this case a TPC command group is a set of (10 or 7) equal TPC commands.
Table 7: Transmitter aggregate power control range

<table>
<thead>
<tr>
<th>TPC command group</th>
<th>Transmitter power control range after 10 equal TPC command groups</th>
<th>Transmitter power control range after 7 equal TPC command groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 dB step size</td>
<td>2 dB step size</td>
</tr>
<tr>
<td>+1</td>
<td>+8 dB</td>
<td>+12 dB</td>
</tr>
<tr>
<td>0</td>
<td>-1 dB</td>
<td>+1 dB</td>
</tr>
<tr>
<td>-1</td>
<td>-8 dB</td>
<td>-12 dB</td>
</tr>
</tbody>
</table>

The UE shall meet the above requirements for inner loop power control over the power range bounded by the Minimum output power as defined in chapter 5.1, and the Maximum output power supported by the UE defined in chapter 5.2.

The definition of the inner loop power step is the relative power difference between the mean power of the original timeslot and the mean power of the target timeslot.
6 SYSTEM DESCRIPTION

In this chapter the design of the system used for measurements is described. The system consists of a computer, a set of instruments and the Device Under Test (DUT). See Figure 11 and Figure 12. Due to secrecy the parameters will further in this document only be named A – G.

Parameters controlling the output power and their control range:
A = ON/OFF
B = 0-50
C = 0-3
D = 0-7
E = ON/OFF
F = 0-255
G = 0-255

Measurement points:
1 = Antenna connector
2 = Board (a soldering point)

*Figure 11: DUT with transmitter chain.*
The parameters in the transmitter chain are controlled by software. A software solution and different types of measurement equipment perform the measurements. Measurements are interpreted and processed by the computer and computer software. See Figure 12. A General Purpose Interface Bus (GPIB) is used to connect the instruments in parallel. The broken lines represent the RF area, and the attenuators are used for mitigating the mismatch problems. Before measuring a network analysis was made to be able to compensate for attenuation in cables, splitters and attenuators. For more information about network analysis see Reference [8].

*Figure 12: The system*
Chapter 7 Measurements

7  MEASUREMENTS

7.1  STRATEGY

The strategy for measurement was mostly based on already known theories of the transmitter chain, both concerning hardware and software. Documents describing hardware and software possibilities for the UE of interest and 3GPP specifications were carefully studied. Also the measurement accuracy issue was concerned when the way of measuring was prepared.

The system was first seen as one system under the influence of seven parameters. To characterize the parameters in this case they had to be measured one by one. They were then measured in certain combinations to see if they had any impact on each other. If one parameter directly depended on another parameter, the time to measure it during calibration could be reduced since it could be calculated from that other parameter. Therefore many different combinations had to be measured. Also the possibility to totally predict parameters was investigated. The measurements were in this case made on the antenna connector of the UE, and performed by a spectrum analyzer and power meter. See Figure 11 and 12.

Secondly, the system was divided into two sub systems where a measurement point was created in-between them. This board measurement was necessary to be able to understand the nonlinearities. A spectrum analyzer and RF-probe in this case performed the measurements. See Figures 11 and 12.

The strategy included measuring on several telephones to be sure of correct measurements, since temporary errors could be eliminated. A lot of time was spent on measurements. The error sources were not evident in the beginning but as time passed most of them were found. This was an interesting and educating part of the thesis. If time and access to telephones and measurement equipment had been infinite even more measurements would have been performed, since the more measurements performed, the better reliability.

Also the frequency dependence over different channels was measured to be able to compensate for channel variations during calibration of the UE. All other measurements were performed on mid-channel (1950 MHz) to avoid possible edge effects.
7.2 RESULTS OF ANTENNA CONNECTOR MEASUREMENTS

In this section a selection of antenna connector measurement results are shown. The measurement point referred is number 1 in Figure 11. Each measurement has been performed on 5 – 10 units. Each plot is to be seen as a representative example of the measurements performed. The frequency chosen represents always the mid-channel (1950 MHz) since possible edge effects otherwise could damage the measurements. Parameter A is set OFF in all measurements since this parameter only amplifies the signal and does not cause nonlinearities. The figures show the output power of the actual parameter. Due to secrecy the dynamics will not be shown.

**Parameter B: 0 – 50**

*Figure 13: Parameter B when parameter E is OFF*

When parameter B was measured all other parameters were set as proposed in earlier studies of the transmitter characteristics. Parameter B was linear when parameter E was set OFF and seemed to be nonlinear when E was set ON, see Figure 13,14. In the following measurements parameter B was set to 30 since this value is in the linear area, and parameter E was always set ON.
Parameter A: OFF  
Parameter B: 0-55  
Parameter C: 0  
Parameter D: 0  
Parameter E: ON  
Parameter F: 155  
Parameter G: 58  
Frequency: 1950 MHz

Parameter C: 0 - 3

Parameter C is nearly linear and has got small dynamic and was chosen to 0 in the following measurements.
**Parameter D: 0 - 7**

*Figure 16: Parameter D 1 - 7*

Parameter D is nonlinear but has got small dynamic and is in further measurements set to 0.

*Figure 17: Parameter D 0 - 7*


**Parameter F**: 0 – 255

*Figure 18: Parameter F*

![Parameter F graph](image)

<table>
<thead>
<tr>
<th>Parameter A</th>
<th>OFF</th>
<th>Parameter E</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter B</td>
<td>30</td>
<td>Parameter F</td>
<td>0 - 255</td>
</tr>
<tr>
<td>Parameter C</td>
<td>0</td>
<td>Parameter G</td>
<td>155</td>
</tr>
<tr>
<td>Parameter D</td>
<td>0</td>
<td>Frequency</td>
<td>1950 MHz</td>
</tr>
</tbody>
</table>

**Parameter G**: 0 – 255

*Figure 19: Parameter G*

![Parameter G graph](image)

<table>
<thead>
<tr>
<th>Parameter A</th>
<th>OFF</th>
<th>Parameter E</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter B</td>
<td>30</td>
<td>Parameter F</td>
<td>58</td>
</tr>
<tr>
<td>Parameter C</td>
<td>0</td>
<td>Parameter G</td>
<td>0 - 255</td>
</tr>
<tr>
<td>Parameter D</td>
<td>0</td>
<td>Frequency</td>
<td>1950 MHz</td>
</tr>
</tbody>
</table>
Both parameter F and G have got small linear intervals. Parameter F has got its linear interval around 58 and parameter G around 155. This is why 58 and 155 are the values set for the other measurements. Being outside these intervals can cause leakage and spurious emissions on the wideband signal. Spurioueses are disturbances on other frequencies.

**Frequency dependence**

The frequency dependence is not caused by a certain parameter, but it must be measured for calibration purposes and is therefore measured over 13 channels. Figure 20 shows the channel dependence.

*Figure 20: Frequency dependence*
7.3 RESULTS OF BOARD MEASUREMENTS

In this section only a selection of board measurement results are represented. The measurement point referred is number 2 in Figure 11. Each measurement has been performed on 2 - 3 units.

Parameter A, C, D, E seemed to have the same characteristics as in the antenna connector measurement except a dynamic difference. Some parameters with a small dynamic range were very difficult to measure correctly since there was no real constructed measurement point. The measurement point was a soldering and the measurements were performed by an RF-probe, which introduces uncertainties. Parameter B, when E was set OFF, also had the same characteristics as in the antenna connector measurement case. The only difference was the dynamic difference. The characteristics of Parameter B, when E was set ON, was however different. The Parameter shows a linear behavior contrary to the nonlinear behavior in the first measurement.

**Parameter B**: 0 – 50

*Figure 21: Parameter B when parameter E is ON*

<table>
<thead>
<tr>
<th>Parameter A</th>
<th>OFF</th>
<th>Parameter E</th>
<th>ON</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter B</strong></td>
<td>0 - 50</td>
<td>Parameter F</td>
<td>-</td>
</tr>
<tr>
<td>Parameter C</td>
<td>0</td>
<td>Parameter G</td>
<td>-</td>
</tr>
<tr>
<td>Parameter D</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing Parameter B when E is ON](image-url)
7.4 CONCLUSIONS AFTER MEASUREMENTS

The measurements showed the characteristics of the parameters both measured on the antenna connector and on the board. Some parameters were quite linear and some were not. Subsystem I is mainly a linear system and Subsystem II is a nonlinear system, see Figure 11.

Parameter B seemed so linear that it could be possible to interpolate all needed values from only a few measured. This should of course save time since computer calculations compared to the performance of measurements are timesaving. This idea was rejected when the calculated values did not appear to be as close as needed to the actual values. This was a subjective judgement that was based on the 3GPP requirements demanded. The decision was also based on the fact that the normal measurement uncertainties were smaller than the margin of errors for the calculated values. Table 8 illustrates the margin of error for parameter B when every second value is the mean value of two adjacent. The idea was tried on several units; the one represented in the table is to be seen as an example. The margin of error is to be compared with the unavoidable measurement uncertainties presented in Table 9, Chapter 10.2.

Table 8: Margin of error when every second value is the mean value of two adjacent values

<table>
<thead>
<tr>
<th>Reconstructed Parameter B no.</th>
<th>Margin of error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>3.37</td>
</tr>
<tr>
<td>30</td>
<td>18.54</td>
</tr>
<tr>
<td>32</td>
<td>1.90</td>
</tr>
<tr>
<td>34</td>
<td>10.71</td>
</tr>
<tr>
<td>36</td>
<td>21.46</td>
</tr>
<tr>
<td>38</td>
<td>0.99</td>
</tr>
<tr>
<td>40</td>
<td>4.80</td>
</tr>
<tr>
<td>42</td>
<td>4.91</td>
</tr>
<tr>
<td>44</td>
<td>15.70</td>
</tr>
</tbody>
</table>

The board measurements later indicated that nonlinearity was added to parameter B when parameter E was set ON. The nonlinearities were caused by the last part of the transmitter chain, called Subsystem I in Figure 11.
This implicates that parameter B has to be measured in more than one combination to be able to fulfill the output power dynamic range required by 3GPP.

Parameter C and D have got such small dynamic range that the best idea seems to be to measure them. On the other hand the measurement uncertainties are obvious. See Table 9 in Chapter 10.2. If the parameters would be further characterized they could perhaps be pre-defined. But if a pre-definition should be of interest many more measurements would have to be carried out. Since there was not enough time to perform this characterization, the decision was to measure both parameters C and D. The decision to measure them was thus also a subjective judgment.

When it concerns parameters E and F, only a small interval actually has to be measured since only the operating range is of importance. Being outside the operating range can for example cause spuriouses. (Spurious emissions are disturbances on other frequencies e.g. mirror frequencies.) The choice of operating range was based on earlier studies and documentation of these two parameters.

No parameter gave enough information about another parameter that it did not need to be measured, and no parameter could be totally predicted. The parameters are hardware dependent and therefore hard to foretell. Measuring all of them is the best way to get an accurate calibration.

The conclusion was that all parameters actually had to be measured at least in one combination. When at least one combination is measured the other combinations desired can be computed.

Finally the decision was to measure:

**Parameter A**: ON/OFF
**Parameter B**: 0 – 50 (parameter E = OFF)
**Parameter B**: 5 values in the nonlinear area (parameter E = ON)
**Parameter C**: 0 – 3
**Parameter D**: 0 – 7
**Parameter E**: ON/OFF
**Parameter F**: 58 (the same value is always applied)
**Parameter G**: 4 values in the linear area
**Channel dependence**: 13 channels

All other combinations are computed.
Today’s calibration method is divided into one measurement part and one calculation part. Keeping the present calculation part and changing the measurement part could save much implementation time. Therefore mainly the same measurements as in the present method were kept to facilitate the implementation. If there had been time to change the calculation part the proposition of measurements would have been slightly different. The difference could have been to measure some more values of parameter B and G, to probably get a more accurate calibration.
Chapter 8 The new method

8 THE NEW METHOD

8.1 NEW METHOD IDEA

Today's calibration method is divided into one measurement part and one calculation part. Since there was more time to gain by improving the measurement part, the work was concentrated on measurement improvements. The aim was to implement a new measurement part that perfectly supported the existing calculation part.

Because all parameters need to be measured as exactly as possible to fulfill the 3GPP requirements demanded, a fast way of measuring had to be designed.

The software supporting today's calibration method has an advantageous command when using a spectrum analyzer. The software solution supports several measurements per sweep. Since the time to initialize and sweep is considerable, it is evident that less initializations and sweeps should save time. Therefore the new method idea was to do more measurements per sweep than before.

What had to be considered was the measurement accuracy of the new method. The new way of measuring included measuring further away from the reference level and this means a decreased accuracy. This fact was stated when studying the data sheets of the instruments. Also the fact that every measurement is based on fewer measurement points would probably decrease accuracy even more.

Much time was spent preparing and implementing the new method. The parameter configuration had to be thoroughly considered to get the best result.

The channel dependence could not be measured using the new method due to the frequency dependence. The spectrum analyzer cannot handle more than one frequency setting simultaneously.

As in the present method, almost all measurements were to be relative measurements. The new method should include three absolute measurements to which all other measurements were to be related. These absolute measurements were not thoroughly verified but relied on.
8.2 IMPLEMENTATION OF NEW METHOD

The new method was software-implemented in a C++ environment.

Here follows an example of how the new measurement method appears on the spectrum analyzer. This example is not an example from the actual calibration.

Figure 22 shows an ordinary wideband signal seen in the frequency domain.

*Figure 22: WCDMA signal in frequency domain*
Figure 23 shows the same signal seen in zero span i.e. time domain.

**Figure 23: WCDMA signal in zero span**
Suppose four wideband signals, from the same device under test, with individual parameter settings (i.e. different output power) are to be measured in a considerably short period of time. To be able to measure them the power must be controlled very rapidly and a certain software solution must be applied. If this is possible the “sweep” will look like Figure 24. In this figure four different parameter settings are represented.

The figure can also represent the output power of a UE, which is instructed by TPC bits sent on the DL to decrease its power with 3dB in every frame (i.e. every 15th timeslot.)

*Figure 24: WCDMA signal in zero span with multiple output levels*

In the new calibration method this way of measuring the output power was used. Different parameter configuration was needed to fulfill to the accuracy and time aspects.

The values from the spectrum analyzer display are processed by the new computer software (i.e. separated and mean averaged.)

36
8.3 RESULTS AND EVALUATION OF NEW METHOD

8.3.1 TIME

The time for the measurement part was reduced by 75%. The time for the whole output power calibration method was reduced by 39%.

8.3.2 ACCURACY

The accuracy was retained, despite measuring further away from the reference level, and despite that the measurements were based on fewer measurement points. This fact was stated when comparing ordinary measurement uncertainties with the difference of the present and new way of measuring. The differences were in the same size as measurement uncertainties, and measurement uncertainties are unavoidable.

An ordinary verification of measurement uncertainties and new models is normally carried out on a large number of units and with a large number of tests per unit. The verification in this report is due to lack of time, not carried out on a statistically correct number of units or number of tests. The verification is however to be seen an indication of reliability.

Firstly the normal measurement uncertainties due to hardware, instruments and cables were carried out. Ten measurements performed by both the present and the new method was carried out on one unit. The temperature was kept stable. Some of the results are presented in column three and four in Table 9. The coefficient of variation is normally calculated as the standard deviation divided by arithmetical average but since the number of measurements is small it is calculated as the range divided by arithmetical average and it is presented in percent. See below.

\[
\text{Arithmetical average} = \frac{1}{n} \sum_{i=1}^{n} x_i \\
\text{Range} = x_{\text{max}} - x_{\text{min}} \\
\text{Coefficient of variation} = \frac{\text{Range}}{\text{Arithmetical average}}
\]
Since there are only few measurements the arithmetical average is adapted and applies $1/n$ instead of $1/(n-1)$.

All results discussed below are presented in Table 9.

Parameter B has got almost exactly the same coefficient of variation in both methods. This is because the measurements are performed in the same manner.

Parameter C and D seem to have a very high coefficient of variation. This is due to the fact that their dynamic range is small compared to the measurement uncertainties. Their coefficient of variation seem however to be smaller in the new measurement method. In the new method the measurement time is shorter and thereby the temperature dependence has decreased. The temperature dependence can explain the improvement of the coefficient of variation.

The new measurement method was verified by performing five measurements each on six units; the represented unit in Table 9 is just to be seen as an example. The fifth column represents the relative deviation of the new method, but expressed in percent. See below.

Relative deviation = $\frac{|\text{Average present method} - \text{Average new method}|}{\text{Average present method}}$

In this case the present method measurements were thus seen as references. Both methods rely on three absolute measurements. All other measurements are seen as relative measurements to the absolute ones. The absolute measurements were not thoroughly verified but relied on. A verification of an absolute measurement is always quite uncertain since the measurement equipment never can provide a totally reliable measurement.

As mentioned above the difference between the present and new way of measuring is in the same size as measurement uncertainties. The exception is parameter G. In this case the parameter configuration is changed. The change is to measure the parameter when parameter B is in its linear area. This is not the case in the present method. This ought to be better since the nonlinearities of parameter B are compensated for in the calculation part of the calibration method.
Table 9: Verification of measurement uncertainties and verification of the new method.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Difference between param no.</th>
<th>Coefficient of variation present method (%)</th>
<th>Coefficient of variation new method (%)</th>
<th>Relative deviation of new method (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter A</td>
<td>On/off</td>
<td>5,59</td>
<td>0,63</td>
<td>2,19</td>
</tr>
<tr>
<td>Parameter B</td>
<td>27 - 28</td>
<td>0,96</td>
<td>0,96</td>
<td>0,09</td>
</tr>
<tr>
<td></td>
<td>28 - 29</td>
<td>1,05</td>
<td>1,05</td>
<td>0,11</td>
</tr>
<tr>
<td></td>
<td>29 - 30</td>
<td>0</td>
<td>1,12</td>
<td>0,11</td>
</tr>
<tr>
<td></td>
<td>30 - 31</td>
<td>0,87</td>
<td>0,87</td>
<td>0,34</td>
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<td></td>
<td>31 - 32</td>
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<td>0,93</td>
<td>0,09</td>
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<td>34 - 35</td>
<td>1,07</td>
<td>1,07</td>
<td>0,21</td>
</tr>
<tr>
<td>Parameter C</td>
<td>0 - 1</td>
<td>33,15</td>
<td>5,95</td>
<td>7,18</td>
</tr>
<tr>
<td></td>
<td>1 - 2</td>
<td>33,52</td>
<td>5,75</td>
<td>2,79</td>
</tr>
<tr>
<td></td>
<td>2 - 3</td>
<td>23,53</td>
<td>11,56</td>
<td>1,76</td>
</tr>
<tr>
<td>Parameter D</td>
<td>1 - 2</td>
<td>130,43</td>
<td>34,48</td>
<td>26,09</td>
</tr>
<tr>
<td></td>
<td>2 - 3</td>
<td>321,43</td>
<td>66,66</td>
<td>7,14</td>
</tr>
<tr>
<td></td>
<td>3 - 4</td>
<td>142,86</td>
<td>14,49</td>
<td>64,29</td>
</tr>
<tr>
<td></td>
<td>4 - 5</td>
<td>44,25</td>
<td>9,17</td>
<td>3,54</td>
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<td></td>
<td>5 - 6</td>
<td>42,86</td>
<td>4,42</td>
<td>7,62</td>
</tr>
<tr>
<td></td>
<td>6 - 7</td>
<td>16,20</td>
<td>2,29</td>
<td>0,69</td>
</tr>
<tr>
<td>Parameter G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22,88</td>
<td>2,04</td>
<td></td>
<td>12,36</td>
</tr>
<tr>
<td></td>
<td>5,99</td>
<td>1,03</td>
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<td>15,93</td>
</tr>
<tr>
<td></td>
<td>11,78</td>
<td>2,17</td>
<td></td>
<td>22,39</td>
</tr>
</tbody>
</table>
As a complement to Table 9 the histograms of some values could be of interest. Figure 25 shows the histograms of Parameter D no. 1-3 measured with the present and new method respectively. The left column represents measurements performed by the present method, and the right column represents the same measurements performed by the new method. The histograms confirm the coefficients of variation.

Figure 25: Histograms of Parameter D no. 1-2, 2-3, 3-4 measured by both the present and new method. The x-axes are equally graded.
8.3.3 COMPARISON WITH CURRENT METHOD

In the new method only the measurement part of the calibration method is changed, the calculation part remains the same. The new method is as accurate as the old one, but the time saved in the measurement part is significant. The coefficients of variations are generally smaller in the new method, which implicates decreased temperature dependence.
9 CONCLUSION

The parameters in the WCDMA phone transmitter chain is too hardware dependent to be able to predict, or to be used as predictions of each other. Despite linearity interpolated values are not as exact as needed to retain accuracy. Therefore all parameters have to be measured in at least one combination. Thereafter other combinations can be calculated from the measured ones.

The new measurement method is based on the fact that all measurements made in today’s method still have to be done but in a new faster way.

The new method is a software solution and utilizes the spectrum analyzer zero span function. The parameter configuration is of great importance and was thoroughly considered in the new method.

The predicted problem was accuracy, but when comparing today’s method with the new this problem was canceled out. The measurement errors appeared to be in the same size as normal measurement uncertainties due to equipment, cables and mismatch. The coefficients of variations are generally smaller in the new method, which implicates decreased temperature dependence.

To conclude the new calibration measurement method is as accurate as the present but it demands less time. A more careful error handling could however be implemented.
PROPOSALS FOR FURTHER STUDY

One way to improve the measurement time even more is by including more measurements per sweep. But what still has to be considered in this case is the measurement accuracy. A proper inquiry into the accuracy issue could really open up the possibilities of the problem. Then both measuring far from the reference level and the fact that every measurement will be based on even fewer measurement points have to be considered. The dynamic range of the spectrum analyzer is also to be considered. But if the accuracy remains the time to be saved is significant.

Due to lack of time, the error handling in the new software solution was quite modest. If the new method is to be used in a real production line the error handling must be improved. In addition verification of possible measurement faults would have to be carried out on many more phones than performed in this report.

As mentioned in Chapter 10.2 parameter C and D could maybe be pre-defined if they were thoroughly characterized. In general, many more telephones should be measured on to be real certain of measurement uncertainties.

Two more time demanding proposals for further study would be to improve the existing calculation part and to look at other measurement equipment.
11 REFERENCES


[2] 3GPP 1999 “TS 25.211v3.1.1- Physical channels and mapping of transport channels onto physical channels (FDD)”

[3] 3GPP 2002 “TS 25.401 v5.3.0 - UTRAN Overall Description”


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