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SPECIFIC ABSORPTION RATE TESTING FOR A MOBILE PHONE IN EUROPE

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ABSTRACT

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The topic for this thesis was commissioned by Verkotan Oy, a company working in the wireless industry providing testing and consulting services. The main objective was to plan and conduct accredited SAR testing for a mobile phone to be sold in Europe.

The work included clarifying the new regulations for LTE RF conducted power measurements and conducting them for all supported wireless technologies by the mobile phone, planning and conducting SAR testing, and writing test report.

The objectives given for this thesis were accomplished. The new regulations for LTE SAR testing were clarified and conducted according to IEC PAS 63083:2017. RF conducted power measurements were done for LTE, GSM/GPRS, WCDMA and WLAN technologies. Test plan was created after the RF conducted power measurements and SAR testing for the mobile phone was conducted according to it. Test report was written from the testing including all necessary information required to repeat the measurements. Any information regarding the mobile phone is not shown in this thesis because of non-disclosure agreement.

Keywords: SAR testing, mobile phone, LTE, Europe

PREFACE

I would like to thank Verkotan Oy for hiring me as an intern and providing a topic for this thesis.

Thanks to all my colleagues at Verkotan for providing a great working environment and special thanks for Miia Nurkkala, Kirsi Kyllönen and Sami Laukkanen at Verkotan for your help through this process.

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Oulu, 21.2.2019
Ilari Kinnunen

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VOCABULARY

DUT	Device Under Test
EMF	Electromagnetic Field
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
LTE	Long Term Evolution
MPR	Maximum Power Reduction
QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RF	Radio Frequency
SAR	Specific Absorption Rate
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

1 INTRODUCTION

This thesis was commissioned by Verkotan Oy, a company working in the wireless industry providing testing and consulting services.

The objective of this thesis was to plan and conduct accredited SAR testing for a mobile phone to be sold in Europe according to Radio Equipment Directive and harmonised standards referenced within it and to implement IEC PAS 63083:2017 to processes of Verkotan Oy. The focus in this thesis will be on LTE SAR testing since IEC PAS 63083:2017 has been released and it has new regulations for LTE SAR testing in Europe.

The work includes clarifying the new regulations for LTE RF conducted power measurements and conducting them for LTE, GSM/GPRS, WCDMA and WLAN technologies, as well as planning the SAR measurements in advance and completing them. The test report is written from SAR testing including the test results and all necessary information to repeat the measurements.

The regulations and test processes included in mobile phone SAR testing will be described in this document. Any information or results regarding the tested device are not shown in this thesis because of the non-disclosure agreement.

2 REGULATIONS FOR RADIO EQUIPMENT

2.1 Essential Requirements for Radio Equipment

Radio Equipment Directive 2014/53/EU has regulations for radio equipment that must be filled before they can enter the markets in Europe. There are three different essential requirements for a radio equipment set by Article 3 in Directive 2014/53/EU. SAR testing is included in the first part as “the protection of health and safety of persons and of domestic animals and the protection of property”. (1, p. L 153/72) The three essential requirements are shown below.

1. According to Directive 2014/53/EU, Article 3, radio equipment must be built in a way to ensure that it meets the following regulations:

“a) the protection of health and safety of persons and of domestic animals and the protection of property, including the objectives with respect to safety requirements set out in Directive 2014/35/EU, but with no voltage limit applying;

(b) an adequate level of electromagnetic compatibility as set out in Directive 2014/30/EU.” (1, p. L 153/72)

2. Radio equipment must also use and support the radio spectrum efficiently to avoid adverse interference (1, p. L 153/72).

3. The following essential requirements are needed for radio equipment of certain categories or classes according to Directive 2014/53/EU, Article 3:

- Radio equipment interworks with accessories, in particular with common chargers;
- Radio equipment interworks via networks with other radio equipment;
- Radio equipment can be connected to interfaces of the appropriate type throughout the Union;

- Radio equipment does not harm the network or its functioning nor misuse network resources, thereby causing an unacceptable degradation of service;
- Radio equipment incorporates safeguards to ensure that the personal data and privacy of the user and of the subscriber are protected;
- Radio equipment supports certain features ensuring protection from fraud;
- Radio equipment supports certain features ensuring access to emergency services;
- Radio equipment supports certain features in order to facilitate its use by users with a disability;
- Radio equipment supports certain features in order to ensure that software can only be loaded into the radio equipment where the compliance of the combination of the radio equipment and software has been demonstrated. (1, p. L 153/72-L 153/73)

2.2 Regulations for SAR testing

There are harmonised standards under the Radio Equipment Directive 2014/53/EU that have regulations for SAR testing. Directive 2014/53/EU references the standards EN 50360:2017 for products used next to the ear and EN 50566:2017 for products next to the body (1, p. C 326/114, C 326/115).

EN 50360:2017 refers to EN 62209-1:2016 and EN 50566:2017 to EN 62209-2:2010 that provide more precise regulations for SAR testing of devices used near head and body (2, p. 4; 3, p. 4).

Information from these standards and in addition from IEC PAS 63083:2017 were used to accomplish the SAR testing for a mobile phone. IEC PAS 63083:2017 is a publicly available specification published 2017-01 and it has new regulations for LTE SAR testing in Europe (4, p. 6). The LTE modes for RF conducted power measurements and test channels measured in SAR testing are selected using a different method than for other wireless technologies.

3 SPECIFIC ABSORPTION RATE

3.1 What is Specific Absorption Rate Testing?

Specific absorption rate (SAR) testing measures the amount of RF energy absorbed by a human or animal body (5). SAR testing concerns wireless devices that have radiating parts and intended use case within 20 cm of a body or head (6, p. 8). A device under test (DUT) must be configured to the maximum power state before SAR testing can be conducted to get the worst-case results. SAR testing only gives the worst-case RF exposure results and not the ones users usually get in normal circumstances. (5)

Exposure limits of SAR testing vary between different countries. Authorities such as Federal Communications Commission (FCC), European Union (EU) and Innovation, Science and Economic Development Canada (ISED) have regulations for SAR testing and SAR limits (7).

Liquid is used to simulate the human body or head tissue. SAR is measured from the simulating liquid. (5) Peak spatial-average SAR is reported as W/kg and it is an average of either 1g or 10 g tissue volume. The SAR limit in Europe is 2.0 W/kg average measured from 10 g tissue volume. (8, p. 509)

SAR testing is done to ensure that the power transmitted by a wireless device does not exceed the SAR limits. The SAR limits are set by experts of different fields to be far below the RF exposure level that would have adverse health effects. (5)

3.2 SAR Requirements

Whole-body SAR between 1-4 W/kg increases the body temperature less than 1°C for resting humans during 30 minutes of EMF exposure according to an experimental evidence. Data acquired from animal experiments refer to similar results. Workers and volunteers agree with laboratory results that an increased body temperature of 1°C can cause adverse biological effects. (8, p. 507)

Whole-body SAR values over 4 W/kg can result in an excessive amount of tissue heating due to changes in thermoregulatory capacity of the body causing harmful effects. The limit for irreversible effects caused by EMF exposure in normal situations is more than 4 W/kg even for the most sensitive tissues. According to ICNIPR guidelines, “Many laboratory studies with rodent and nonhuman primate models have demonstrated the broad range of tissue damage resulting from either partial-body or whole-body heating producing temperature rises in excess of 1–2°C.” (8, p. 507)

There has not been a convincing evidence on studies that humans exposed to typical levels of EMF exposure result in adverse reproductive effects or an increased risk of cancer (8, p. 507).

3.2.1 Occupational and General Public Exposure

The occupational and general public exposure groups are defined in ICNIRP guidelines as follows:

“The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of potential risk and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals.” (8, p. 508)

The general public population is usually unaware of the exposure to EMF and because of that they are not able to protect themselves from the exposure. For this reason, the exposure limit for general public is stricter. (8, p. 508)

3.2.2 Basic Restrictions

The amount of information about biological and health effects for humans or experimental animal caused by EMF exposure is limited and thus it is challenging to set up a safe limit for the whole frequency range and modulations. Two different general variables were taken into account when deciding the safety factors for high-frequency fields according to ICNIRP guidelines:

- “Effects of EMF exposure under severe environmental conditions (high temperature, etc.) and/or high activity levels; and
- the potentially higher thermal sensitivity in certain population groups, such as the frail and/or elderly, infants and young children, and people with diseases or taking medications that compromise thermal tolerance.” (8, p. 508)

The purpose of basic restrictions for frequencies between 100 kHz and 10 GHz is according to ICNIRP guidelines to “prevent whole-body heat stress and excessive localized tissue heating” (8, p. 508).

The occupational exposure limit is based on studies and the whole-body average SAR limit is set at 0.4 W/kg, including a safe margin for exposure affecting conditions. These conditions are, for example, the high ambient temperature, humidity or physical level activity. (8, p. 507) The general public exposure limit has additional safety factor of 5, and the whole-body average SAR limit is set to 0.08 W/kg (8, p. 509).

The localized SAR general public exposure limit for head and trunk was used in mobile phone SAR testing and it is 2.0 W/kg averaged over 10 g tissue volume (8, p. 509).

The localized SAR limit is based on animal experiments. The local SAR exposure of 100 W/kg has been noticed to have adverse effects on rabbits’ eyes. The safety factor of 50 was given for the general public exposure limit of local SAR setting the limit to 2 W/kg averaged over 10 g of tissue volume. The local SAR averaging over 10 g tissue volume is based on the approximate weight of the human eye that is 10 g. (9, p. 8)

Whole-body SAR and local SAR significantly decreases when the separation distance between the radiating device and the head or body is increased (8, p. 497). Basic restrictions set for the whole-body average SAR and the localized SAR for head and trunk can be seen from the Figure 1 shown below (8, p. 508).

Table 4. Basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz.[a]

Exposure characteristics	Frequency range	Current density for head and trunk ($mA\ m^{-2}$) (rms)	Whole-body average SAR ($W\ kg^{-1}$)	Localized SAR (head and trunk) ($W\ kg^{-1}$)	Localized SAR (limbs) ($W\ kg^{-1}$)
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	$40/f$	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	$f/100$	—	—	—
	100 kHz–10 MHz	$f/100$	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	$8/f$	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	$f/500$	—	—	—
	100 kHz–10 MHz	$f/500$	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:
1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 $mJ\ kg^{-1}$ for workers and 2$mJ\ kg^{-1}$ for the general public, averaged over 10 g tissue.

FIGURE 1. Basic restrictions (8, p. 509)

3.3 System Checks

System checks are part of SAR testing and they are done to make sure the test set-up used in SAR measurements is working properly at the test frequencies used. The repeatability of the test system is also measured at system checks. The factors affecting the results of the system check according to EN 62209-1:2016 are "incorrect liquid parameters, test system component failures, test system component drift, operator errors in measurement set-up and measurement parameter settings and other possible adverse conditions that may introduce measurement errors, for example RF interference." (10, p. 135)

The system check must be done with the same equipment and liquid used in SAR testing and within 24 hours or before starting SAR testing. The system check frequency must be within 100MHz from mid-band frequency of the tested device with frequencies above 1GHz. When using frequencies below 1GHz, the system check frequency must be within 10% of the mid-band frequency of the tested device. (10, p. 136)

A half-wave dipole and a flat phantom are needed to perform the system check (10, p. 136). The dipole is placed under the phantom at the separation distance of 15 mm for the frequency range of 300MHz-1GHz. For the frequency range of 1GHz-6GHz, the separation distance is 10 mm. There is a tolerance of ±0.2 mm in the separation distance. (10, p. 140)

An example of the test set-up for system check can be seen from the Figure 2 below.

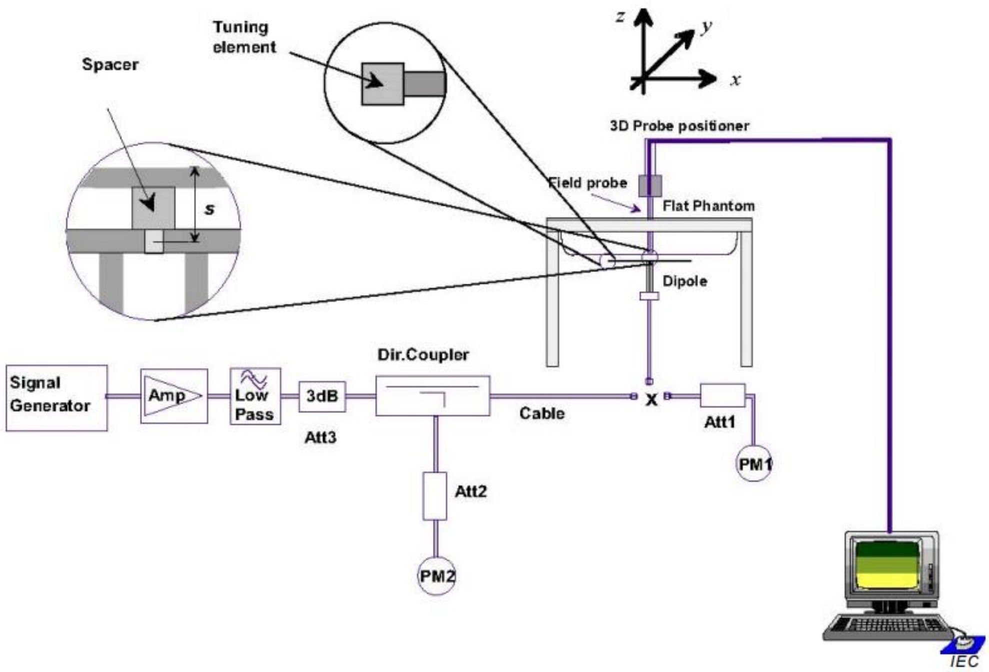

FIGURE 2. Test set-up for system check (10, p. 137)

In the system check 1 g or 10 g peak spatial-average SAR is measured and the result is normalized to 1 W. If the input power used in the system check is 250mW, the peak spatial-average SAR is multiplied by 4 to get the result normalized to 1 W. The normalized result is compared to either numerical target SAR values found in the standard EN 62209-1:2016, Table D.1, or to dipoles calibration values. The system check is a pass if the result is within ±10% of the target values. (10, p. 138)

3.4 System Validations

System validation is done to verify the accuracy and performance of the measurement system with a comprehensive set of testing. It is required when the measurement system has a new part or when modifications have been made to the test system. System validation is needed for example when a new dipole is taken into use or when the old dipole has been calibrated. A probe with valid calibration needs to be used for system validation. (10, p. 139)

System validation starts with the same 1 g or 10 g peak spatial-average SAR measurement done in the system check. The peak spatial-average SAR needs to be within ±10% of either numerical target SAR values found at EN 62209-1:2016, Table D.1, or dipoles calibration values. System validation also has additional measurements to check the linearity of SAR values with e.g. different input powers and digital modulations. (10, p. 140-141)

4 RF CONDUCTED POWER MEASUREMENTS

RF conducted power measurements are done to determine the maximum power in each frequency band and operating mode and to select the worst-case test configuration for SAR testing (10, p. 25).

RF conducted power measurements of LTE technology in Europe have new regulations set by IEC PAS 63083:2017.

4.1 Measurement Set-up for RF Conducted Power Measurements

RF conducted power measurements were done with the Anritsu MT8820C radio communication analyzer using a calibrated RF cable with a 10dB attenuator for GSM/GPRS, WCDMA and LTE technologies. The loss of the RF cable including the attenuator and the cables attached to DUT were removed from the results afterwards. The test set-up for RF conducted measurements can be seen from Figure 3.

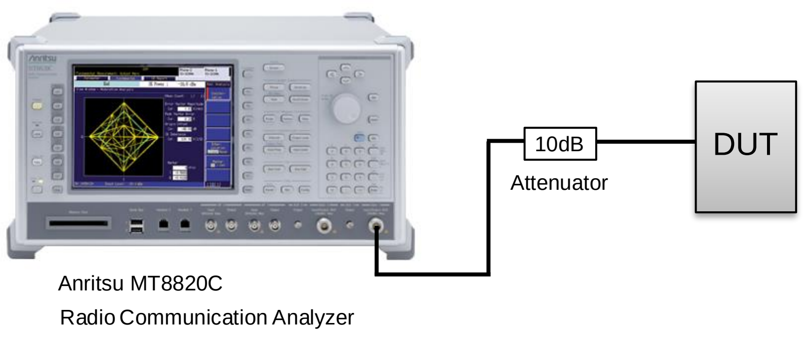

FIGURE 3. Test set-up for GSM/GPRS, WCDMA and LTE RF conducted power measurements (11)

RF conducted power from WLAN channels were measured without Anritsu radio communication analyzer. A software on the mobile phone was used to set the different configurations and channels because similar loopback modes are not available for WLAN 802.11 protocols that were used, for example, in LTE testing (12, p. 3). R&S NRP-Z81 power meter with 10dB attenuator was used to measure the RF conducted power of WLAN channels. Attenuation was taken into account in the final results.

4.2 LTE

Different LTE mode and SAR test configuration combinations can be hundreds because of complexity in the LTE technology. According to IEC PAS 63083:2017, the LTE mode consists of “Frequency band, channel bandwidth (from 1.4 MHz to 20 MHz), modulation (QPSK and 16- QAM), number of resource blocks allocated, offset of the resource blocks within the channel bandwidth as well as MPR.” (4, p. 7)

RF conducted power measurement can quickly identify the LTE mode having high power because the peak spatial-average SAR and the RF output power are related in the same test condition. The RF conducted power is not directly comparable to the peak spatial-average SAR because of three reasons mentioned in IEC PAS 63083:2017:

1. “RF conducted power is measured with a 50 Ohms load impedance;
2. The antenna impedance of a DUT is generally not 50 Ohms and varies over frequency
3. The antenna impedance can be affected by device position and phantom coupling conditions.” (4, p. 7)

From the IEC PAS 63083:2017, Annex A results can be seen that:

1. “QPSK modulation with 1 RB allocation usually produces the highest peak spatial-average SAR.
2. Peak spatial-average SAR has good correlation with the measured RF conducted output power.” (4, p. 7)

3. Highest SAR results are highly unlikely to be expected for LTE mode with conducted power less than 85% of maximum conducted power measured among all LTE modes in the frequency band (4, p. 7).

4.2.1 Generating the Tables for RF Conducted Power Measurements

IEC PAS 63083:2017 has regulations on what LTE modes need to be measured in RF conducted power measurements. The tables for each LTE frequency band used in Europe were generated according to these rules. The operation mode of QPSK-modulation and 1 RB allocation is measured at the highest bandwidth of every frequency band. When the number of channels within the frequency band is one, the 1 RB offset within the channel bandwidth is allocated at the centre. For the frequency band with 3 channels, the 1 RB offset within the channel bandwidth is allocated at 0, centre and max. (4, p. 7-8)

In addition, other LTE modes with the different channel bandwidth, modulation and number of RBs according to the Table 1 and Table 2 below need to be measured. Configurations of the Table 1 are used when MPR does not apply. In this case the RB offset for low and middle channels is set to 0 and for the high channel to max. MPR does not apply when the modulation used is QPSK and 1 RB is allocated. (4, p. 8)

TABLE 1. MPR does not apply (4, p. 19)

Ch. B.W. [MHz]	**Modulation**	**RB**
1.4	QPSK	1
1.4	QPSK	5
3	QPSK	1
3	QPSK	4
5	QPSK	1
5	QPSK	8
10	QPSK	1
10	QPSK	12
15	QPSK	1
15	QPSK	16
20	QPSK	1
20	QPSK	18

In the Table 2 when MPR applies the RB offset for the low channel is set to max. For the middle channel the RB offset is set to 0 and max, and for the high channel the RB offset is set to 0. (4, p. 8)

TABLE 2. MPR applies (4, p. 19)

Ch. B.W. [MHz]	**Modulation**	**RB**
1.4	QPSK	6
1.4	16QAM	5
1.4	16QAM	6
3	QPSK	15
3	16QAM	4
3	16QAM	15
5	QPSK	25
5	16QAM	8
5	16QAM	25
10	QPSK	50
10	16QAM	12
10	16QAM	50
15	QPSK	75
15	16QAM	16
15	16QAM	75
20	QPSK	100
20	16QAM	18
20	16QAM	100

4.2.2 RF Conducted Power Measurements

The LTE mode tables for RF conducted power measurements were generated with Python script based on the IEC PAS 63083:2017 regulations with the help of an experienced programmer working in the company. The generated LTE mode tables of LTE bands 3, 7, 20 were compared to the Table E.1, Table E.2 and Table E.3 shown in IEC PAS 63083:2017, Annex E, to make sure the python script is working correctly. The LTE mode table generated for the LTE band 1 is available in the Appendix 1.

RF conducted power from the mobile phone was measured with LTE bands available in Europe that are supported by DUT. From the Figure 4 it can be seen the new required test configurations for the LTE Band 1. The new RB off-set configurations to be measured within the highest bandwidth are shown as red colour. The QPSK modulation and 1 RB allocation are used in these meas-urements. All RB offset configurations for QPSK modulation and 1 RB allocation are not needed to be measured with lower bandwidths because according to IEC PAS 63083:2017, “When the same RB offset has already been measured in the highest channel bandwidth, such RB offset configuration may be omitted”. (4, p. 8)

In the figure 4, the RB offset configurations omitted for bandwidths below 20 MHz are the low channel with the RB offset set to 0 and the high channel with the RB offset set to max (4, p. 8).

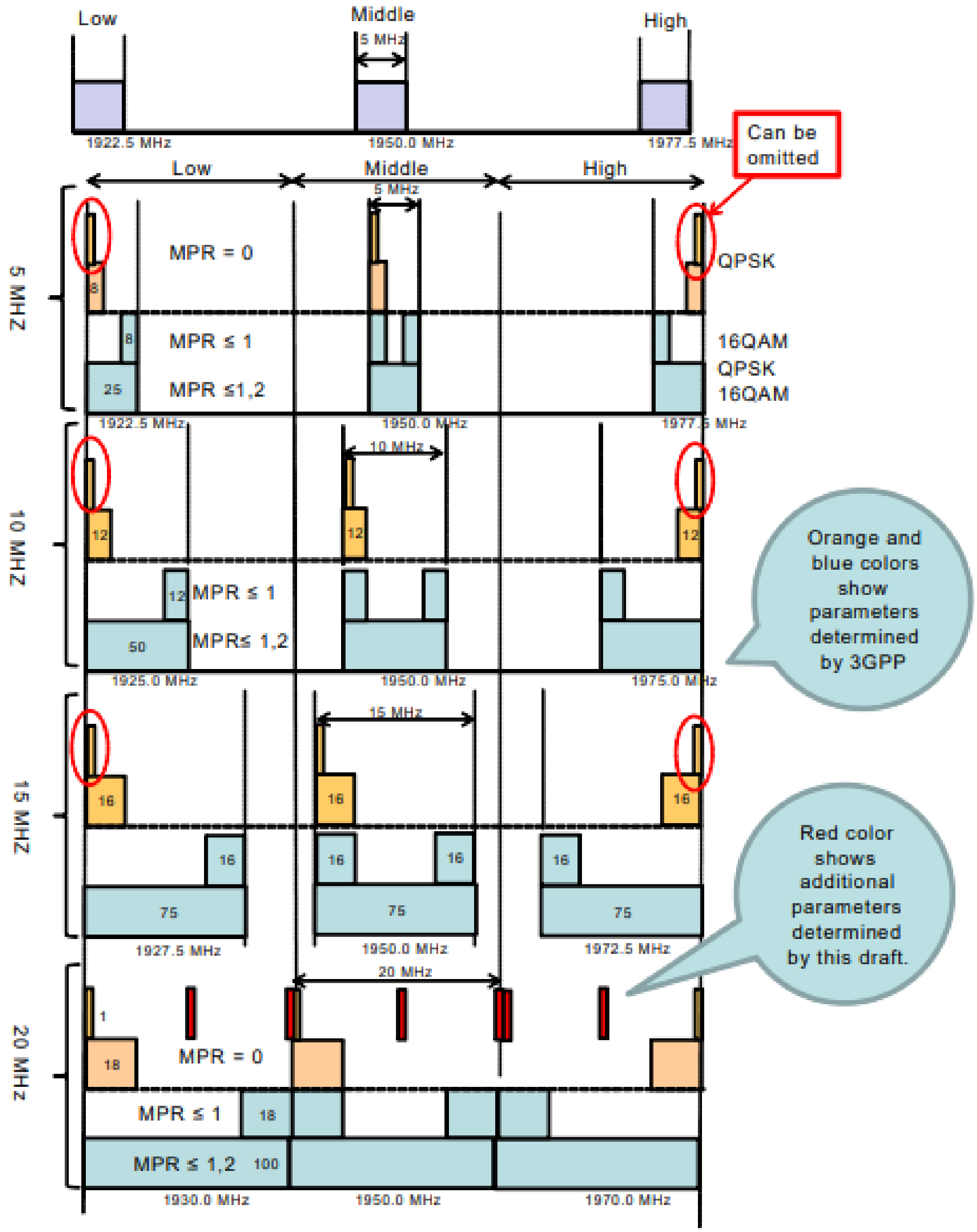

FIGURE 4. Measured and omitted RB offset configurations on the LTE band 1 (4, p. 9)

4.3 Other Wireless Technologies

There are no regulations in SAR standards for the RF conducted measurements for other wireless technologies than LTE. RF Conducted power measurements are done in the same way for GSM/GPRS and WCDMA. The only difference with GPRS technology is that the measured RF conducted power results are changed to time-averaged power and the SAR testing is conducted with the maximum time averaged power slot configuration (10, p. 25).

RF conducted power from the mobile phone was measured from GSM/GPRS, WCDMA and WLAN frequency bands it supports in Europe.

5 TEST PLAN

A test plan for SAR testing was created according to the results of RF conducted power measurements of mobile phone. The test plan includes all test configurations measured in SAR testing making it easier to continue with SAR testing. The test configurations for LTE was selected using a different method than for GSM/GPRS, WCDMA and WLAN because of the new regulations.

5.1 LTE

All test positions are measured at all supported frequency bands with the channel and LTE mode having the highest RF conducted power. The measured channel can be either a low, middle or high channel. Other channels are measured with the LTE mode having the highest RF conducted power on each channel and on the test position having the highest reported SAR result. (4, p. 10)

For example, if the low channel of frequency band has the highest RF conducted power, all test positions are measured at that channel with the LTE mode having the highest RF conducted power. The middle channel is measured with the LTE mode having the highest RF conducted power in the middle channel and at the test position having the highest reported SAR result for the low channel. The high channel would be measured using the same method than the middle channel. All different LTE modes and test positions to be tested within all supported frequency bands were added to the test plan.

5.2 GSM/GPRS, WCDMA and WLAN

The operating mode having the highest RF conducted power was selected for SAR testing for each wireless technology and frequency band. SAR testing for GSM/GPRS, WCDMA and WLAN is always started from the middle channel and all test positions are measured at that channel. The test position having the highest reported SAR result is measured at low and high channels using the same operating mode than for the middle channel. All test configurations to be tested within all supported frequency bands were added to the test plan. (10, p. 34)

6 TEST PROCESS FOR SAR TESTING

6.1 SAR Test Set-up

The SAR test set-up consists of a PC, an DASY5-robot and a phantom. The robot has a measurement probe that is used to measure the SAR values from the tissue simulating liquid inside the phantom. DASY5 software is used on the PC to, for example, create the test configurations, install the different equipment and liquid used in measurements. The SAM phantom is used for mobile phone SAR testing because it is needed for the testing of the head test positions. It also has a flat part in the middle that is used in testing of the body test positions. The SAR test set-up can be seen in the Figure 5.

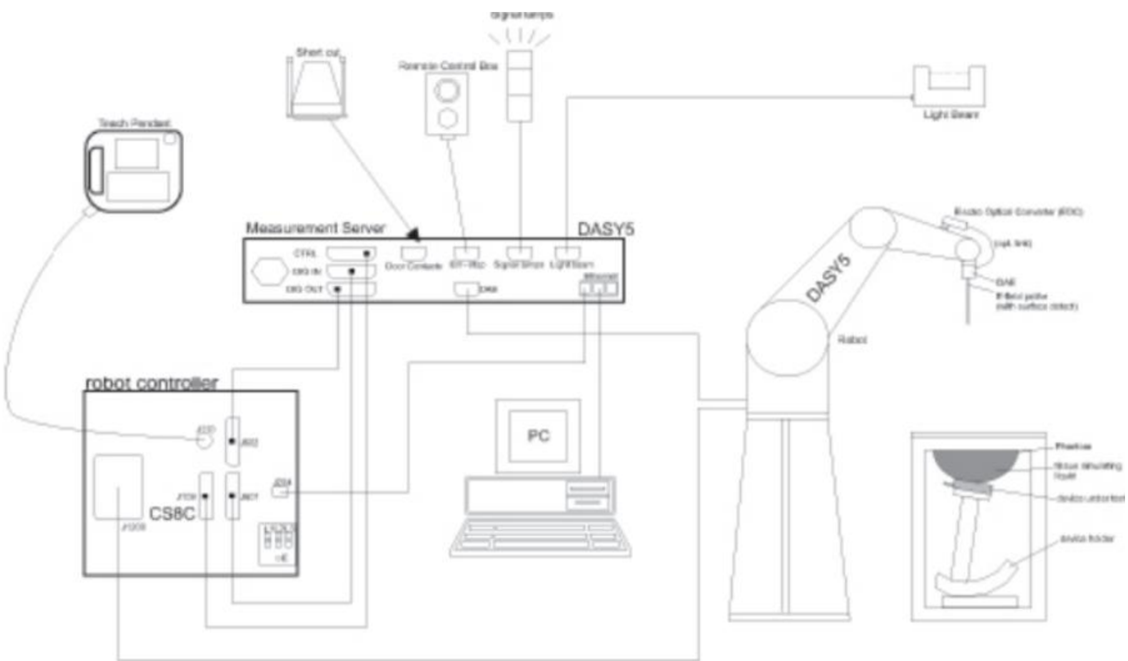

FIGURE 5. SAR test set-up (13, p. 11-1)

The RF signal was fed to the chamber from the Anritsu MT8820C radio communication analyzer through RF cables as shown in the Figure 6. This test set-up was used for SAR testing of GSM/GPRS, WCDMA and LTE. The antenna was used to make the connection between the radio communication analyzer and the mobile phone. The mobile phone was placed under the phantom in the SAR chamber and the DASY5-robot was used to measure the results.

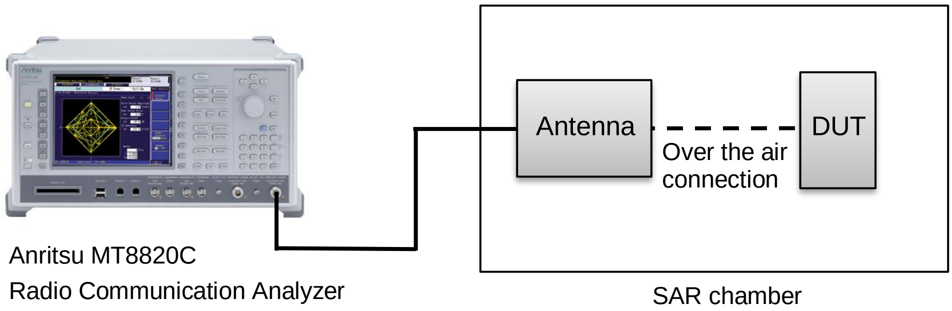

FIGURE 6. Connection from the Radio Communication Analyzer to DUT (11)

SAR testing of WLAN had some differences to testing of GSM/GPRS and WCDMA. WLAN transmission has random characteristics and needs to be configured before SAR testing. A software on a mobile phone was used to configure different WLAN test modes, for example setting the maximum output power and enabling continuous transmission. Similar loopback modes are not available for WLAN 802.11 protocols that were used, for example, in LTE testing. The Anritsu radio communication analyzer was not used because of this reason in SAR testing of WLAN. (12, p. 3)

6.2 Test Positions

6.2.1 Head Test Position

In head SAR testing, cheek and tilt positions are measured on the left and right side of the SAM phantom. In cheek position the mobile phone is placed under the phantom in a way that the middle part of the acoustic output touches the centre of ear. The mobile phone is then rotated in a way that the vertical centre line goes through the phone in the middle of it. The mobile phone is then lifted against the phantom so that the ear and cheek touch it. The definitions on how to place the mobile phone under the phantom for cheek position are explained fully in EN 62209-1:2016, 6.2.4.2. Cheek test position is shown in the Figure 7. (10, p. 28)

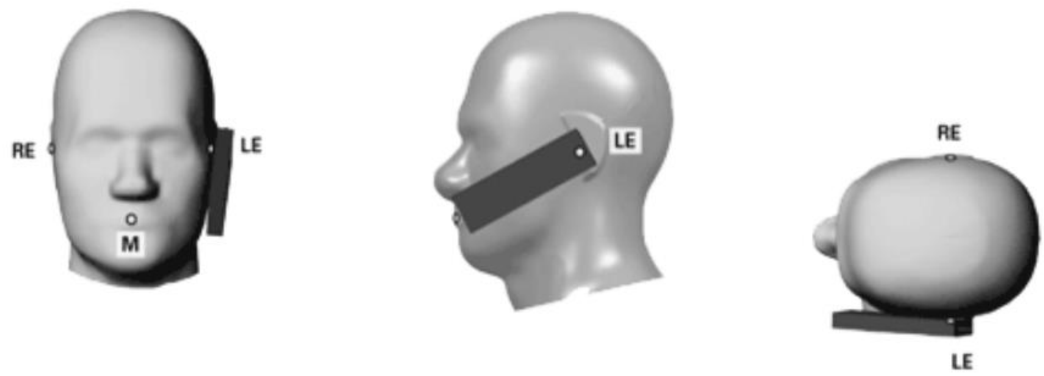

FIGURE 7. Cheek position (10, p. 30)

In tilt position, the angle is increased by 15 degrees and other changes are not made compared to cheek test position. The definitions how to place the mobile phone under the phantom for tilt position are explained fully in EN 62209-1:2016, 6.2.4.3. Tilt test position is shown in the Figure 8. (10, p. 32)

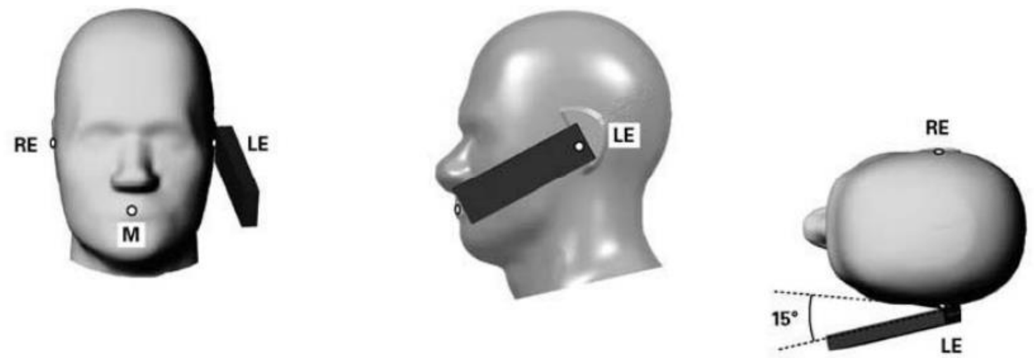

FIGURE 8. Tilt position (10, p. 32)

6.2.2 Body Test Position

In SAR testing of body test position, the back and front side of the mobile phone are measured in the middle of the flat part of the SAM phantom as shown in the Figure 9 (6, p. 24). The mobile phone is lifted until the separation distance of 5mm is reached between the mobile phone and the bottom of the phantom (3, p. 5).

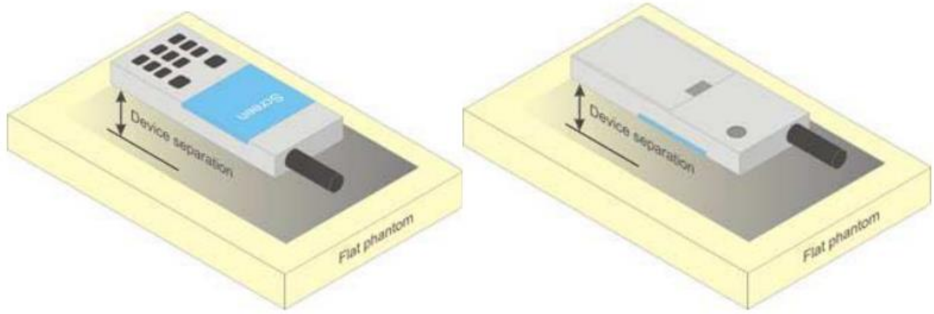

FIGURE 9. Front and back test position (6, p. 24)

6.3 SAR Testing for LTE Technology

SAR testing was carried out according to the test plan created. The measured SAR results were scaled with the formula $10^{((\text{Maximum power} - \text{Conducted power})/10)}$ to get the reported SAR result. This takes into account the difference between tune-up specifications and production variations given by the DUT manufacturer, and the actual measured conducted power of the device that was used in testing. (10, p. 25)

The reported SAR result was, according to the IEC PAS 63083:2017 Approach 1, multiplied by 1.35 and if the result was below the SAR limit of 2.0 W/kg, no more measurements were needed. The Approach 1 is the simplest way as it does not require more SAR testing. If the result is above the limit with this approach, IEC PAS 63083:2017 has two other approaches. (4, p. 11)

According to the Approach 2, all LTE modes that have RF conducted power equal to or over 85% from the maximum measured one in that frequency band, are measured at the test position where the SAR result surpasses the limit (4, p. 11).

According to the Approach 3, the LTE mode with the second highest RF conducted power in that frequency band is measured at the test position where the SAR result surpasses the limit. The reported SAR result is multiplied by 1.35 and if the result is below the 2.0 W/kg limit, no more measurements are needed.

If the result is over the limit, the same procedure is repeated until the results are below the required limit. (4, p. 11)

If the reported SAR result with any wireless technology is within 3dB of the SAR limit, all channels must be measured from that frequency band (10, p. 41).

6.3.1 Power Drift

When the power drift in the SAR measurement exceeds ±5%, the power drift can be considered in the measurement results to provide more accurate SAR results (10, p. 38). The formula used to include the power drifts in reported SAR result is $10^{((\text{Maximum power} - (\text{Conducted power} - \text{Power drift}))/10)}$ where the power drift must be changed to positive.

6.4 SAR Testing for Other Wireless Technologies

SAR testing for other wireless technologies, including GSM/GPRS, WCDMA and WLAN, were performed according to the standards EN 62209-1:2016 and EN 62209-2:2010. SAR testing was conducted according to the test plan created earlier. The reported SAR result is calculated in the same way than for the LTE technology. Head and body test positions are the same for all wireless technologies. The different approaches used in LTE SAR testing and the earlier mentioned IEC PAS 63083:2017 are not used for other wireless technologies.

The Figure 10 shows the measurement process used in SAR testing of head test position for all wireless technologies except LTE. First, the wireless technology and the frequency band is chosen. The operating mode having the highest RF conducted power is selected for SAR measurements. SAR testing is started at the middle channel and all test positions including cheek and tilt on the left and right side of the phantom are measured. Low and high channels of the selected frequency band are measured at the test position having the highest reported SAR result and with the same operating mode as the middle channel. (10, p. 36)

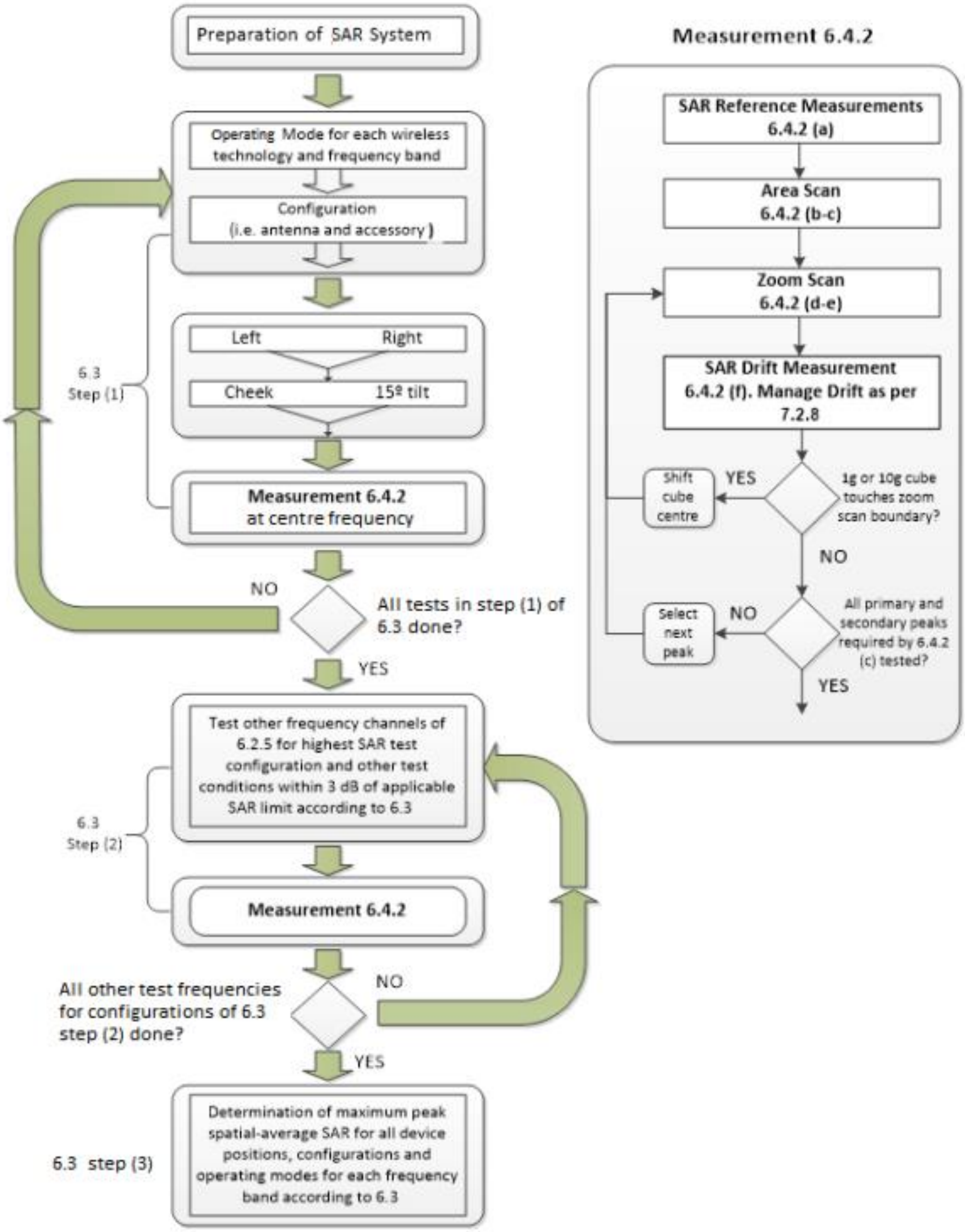

FIGURE 10. Measurement process (10, p. 36)

One SAR measurement consists of four different measurements. In the SAR reference measurement, the power from the DUT is measured. The area scan is done to measure the whole area covered by the DUT. The zoom scan is a more precise measurement that measures a small cube around the maximum SAR measured during the area scan. The last measurement is the SAR drift measurement, measuring the power from the DUT in the same way than the

SAR reference measurement. The SAR reference measurement and the SAR drift measurement are compared to see if the power has drifted during the measurement. The same procedure is done with all test positions and wireless technologies for mobile phone testing.

6.5 Simultaneous Transmission

Typically, it is possible for WLAN and one of the cellular technologies to be operated simultaneously (10, p. 41). For each different test position, the highest reported SAR result was selected from cellular technologies. The same was done for WLAN and the highest cellular reported SAR result and the highest WLAN reported SAR result were summed, assuming the antennas are co-located, to see if the simultaneous SAR is over the limit of 2.0 W/kg. If the simultaneous SAR was over the limit, two results were summed again using Combined Fast SAR of SEMCAD X software. The reason why the software is used is because the hot spots of the two summed measurements may not be exactly on top of each other so when the results are summed with the software, the simultaneous SAR result is can be smaller. The results after summed with Combined Fast SAR are either pass or fail.

6.6 Reporting

All test results are documented in test reports and the testing must be fully repeatable with the information included in test reports. This includes DUT configurations and test positions, system calibrations and measurement uncertainty limits. There are 5 different minimum requirements to be reported in test reports according to EN 62209-2:2010: General introduction, measurement system, uncertainty estimation, device and test details, and report summary. The ISO/IEC 17025:2005 standard has detailed guidelines of what information must be included in test reports. (6, p. 64-65)

7 CONCLUSIONS

The main objective was to plan and conduct accredited SAR testing for mobile phone to be sold in Europe and implement the new LTE regulations from IEC PAS 63083:2017 to processes of Verkotan Oy.

The work included clarifying the new regulations for LTE RF conducted power measurements according to the regulations of IEC PAS 63083:2017 and conducting them for LTE, GSM/GPRS, WCDMA and WLAN technologies, creating a test plan for SAR testing, conducting SAR testing for a mobile phone and writing the test report including the test results and all necessary information to repeat the measurements.

The mobile phone SAR testing was completed, and other objectives were accomplished as well. The new regulations for LTE RF conducted power measurements were clarified and conducted according to the regulations of IEC PAS 63083:2017. The new regulations were also implemented to the processes of Verkotan Oy. RF conducted power measurements were completed for other wireless technologies, including GSM/GPRS, WCDMA and WLAN. The test plan was created, and SAR testing for the mobile phone was conducted according to this plan for LTE, GSM/GPRS, WCDMA and WLAN technologies. The test report was written including the SAR test results and information required for repeatability.

IEC PAS 63083:2017 has new regulations regarding RF conducted power measurements and SAR testing of the LTE technology. New LTE modes were added to the RF conducted power measurements when compared to the old regulations. On RF conducted power measurements, some of the LTE modes located at the edge of the channel may be omitted if they have already been measured at the highest channel bandwidth. SAR testing for the LTE technology is started using the channel and LTE mode having the highest RF conducted power within the frequency band. Other channels are measured using the LTE mode having the highest RF conducted power on each one and at the test position having the highest reported SAR result.

Plenty of new information was learned regarding overall SAR testing knowledge during the thesis. This included the test positions for a mobile phone used in SAR testing and how to place the mobile phone under the phantom. RF conducted power measurements were a new task, including the set-up as well as conducting them. Wireless technologies, such as GSM/GPRS, WCDMA, WLAN and LTE, are more familiar and during the thesis, it was learned how they are tested. The new LTE regulations for SAR testing clarified during this thesis will help the company as it is easier to do more LTE SAR testing for devices to be sold in Europe in the future.

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APPENDIX 1

LTE Band	BW (MHz)	RBs	RB Start	Modulation	Channel Type	Channel	Frequency (MHz)
1	20	1	0	QPSK	LOW CH	18100	1930
1	20	1	49	QPSK	LOW CH	18100	1930
1	20	1	99	QPSK	LOW CH	18100	1930
1	20	18	0	QPSK	LOW CH	18100	1930
1	20	100	0	QPSK	LOW CH	18100	1930
1	20	18	82	16QAM	LOW CH	18100	1930
1	20	100	0	16QAM	LOW CH	18100	1930
1	20	1	0	QPSK	MID CH	18300	1950
1	20	1	49	QPSK	MID CH	18300	1950
1	20	1	99	QPSK	MID CH	18300	1950
1	20	18	0	QPSK	MID CH	18300	1950
1	20	100	0	QPSK	MID CH	18300	1950
1	20	18	0	16QAM	MID CH	18300	1950
1	20	18	82	16QAM	MID CH	18300	1950
1	20	100	0	16QAM	MID CH	18300	1950
1	20	1	0	QPSK	HIGH CH	18500	1970
1	20	1	49	QPSK	HIGH CH	18500	1970
1	20	1	99	QPSK	HIGH CH	18500	1970
1	20	18	82	QPSK	HIGH CH	18500	1970
1	20	100	0	QPSK	HIGH CH	18500	1970
1	20	18	0	16QAM	HIGH CH	18500	1970
1	20	100	0	16QAM	HIGH CH	18500	1970
1	15	16	0	QPSK	LOW CH	18075	1927.5
1	15	75	0	QPSK	LOW CH	18075	1927.5
1	15	16	59	16QAM	LOW CH	18075	1927.5
1	15	75	0	16QAM	LOW CH	18075	1927.5
1	15	1	0	QPSK	MID CH	18300	1950
1	15	16	0	QPSK	MID CH	18300	1950
1	15	75	0	QPSK	MID CH	18300	1950
1	15	16	0	16QAM	MID CH	18300	1950
1	15	16	59	16QAM	MID CH	18300	1950
1	15	75	0	16QAM	MID CH	18300	1950
1	15	16	59	QPSK	HIGH CH	18525	1972.5
1	15	75	0	QPSK	HIGH CH	18525	1972.5
1	15	16	0	16QAM	HIGH CH	18525	1972.5
1	15	75	0	16QAM	HIGH CH	18525	1972.5
1	10	12	0	QPSK	LOW CH	18050	1925
1	10	50	0	QPSK	LOW CH	18050	1925
1	10	12	38	16QAM	LOW CH	18050	1925
1	10	50	0	16QAM	LOW CH	18050	1925
1	10	1	0	QPSK	MID CH	18300	1950

1	10	12	0	QPSK	MID CH	18300	1950
1	10	50	0	QPSK	MID CH	18300	1950
1	10	12	0	16QAM	MID CH	18300	1950
1	10	12	38	16QAM	MID CH	18300	1950
1	10	50	0	16QAM	MID CH	18300	1950
1	10	12	38	QPSK	HIGH CH	18550	1975
1	10	50	0	QPSK	HIGH CH	18550	1975
1	10	12	0	16QAM	HIGH CH	18550	1975
1	10	50	0	16QAM	HIGH CH	18550	1975
1	5	8	0	QPSK	LOW CH	18025	1922.5
1	5	25	0	QPSK	LOW CH	18025	1922.5
1	5	8	17	16QAM	LOW CH	18025	1922.5
1	5	25	0	16QAM	LOW CH	18025	1922.5
1	5	1	0	QPSK	MID CH	18300	1950
1	5	8	0	QPSK	MID CH	18300	1950
1	5	25	0	QPSK	MID CH	18300	1950
1	5	8	0	16QAM	MID CH	18300	1950
1	5	8	17	16QAM	MID CH	18300	1950
1	5	25	0	16QAM	MID CH	18300	1950
1	5	8	17	QPSK	HIGH CH	18575	1977.5
1	5	25	0	QPSK	HIGH CH	18575	1977.5
1	5	8	0	16QAM	HIGH CH	18575	1977.5
1	5	25	0	16QAM	HIGH CH	18575	1977.5