Mobile Handset Performance (Voice)

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Chapter 1

1 INTRODUCTION

The Commission for Communications Regulation ("ComReg") is responsible for regulating the electronic communications sector in Ireland in accordance with European Union and Irish law. ComReg also manages Ireland's radio frequency spectrum ("spectrum")[1] and national numbering resources.

Goal 8 of ComReg's Electronic Communications Strategy Statement[2] sets out that ComReg will aim to "understand evolving consumer needs, preferences, behaviours and perceptions". In this regard ComReg has initiated a number of work streams, in pursuit of this goal ComReg has, to date, published the following reports:

- Meeting Consumer's Connectivity Needs[3] – an overview of challenges to connectivity and actions Irish operators can take to optimise connectivity.
- Effect of Building Materials on Indoor Mobile Performance[4] - a report on the impact of certain building materials on mobile coverage inside buildings.
- Mobile Handset Performance – reports on measurements of antenna performance of mobile handsets when making voice calls and receiving or streaming data. Four reports have been published to date – two on voice call performance[5,7] and two on data performance.[6,8]

ComReg's first antenna performance reports, for voice[5] and data[6], were based on tests of 71 models of mobile handsets available on the Irish market in June 2017. Since then ComReg has also measured and published the antenna performance results for voice[7] and data[8] of 32 of the newest models of mobile handsets, which were available on the Irish market between June 2017 and August 2018.

This report presents the transmit performance results, when making voice calls, of a further 33 new models of mobile handsets that were available on the Irish market between September 2018 and July 2019.

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[1] Radio Spectrum Management Statement: ComReg document 18/118 - https://www.comreg.ie/publication/radio-spectrum-management-strategy-statement-2019-to-2021-design-version/
[2] ComReg document 19/52 - https://www.comreg.ie/publication/ecs-strategy-statement-2019-2021-english-language-version
[3] ComReg document 18/103b - https://www.comreg.ie/publication/meeting-consumers-connectivity-needs/
[4] ComReg document 18/73 - https://www.comreg.ie/publication/the-effect-of-building-materials-on-indoor-mobile-performance/
[5] ComReg document 18/05 - https://www.comreg.ie/publication/mobile-handset-performance-voice/
ComReg document 18/78 - https://www.comreg.ie/publication/mobile-handset-performance-voice-the-effect-of-building-materials-on-indoor-mobile-performance/
[6] ComReg document 18/82 - https://www.comreg.ie/publication/mobile-handset-performance-data/
[7] ComReg 18/109 – https://www.comreg.ie/publication/mobile-handset-performance-voice-technical-report/
[8] ComReg 19/67 – https://www.comreg.ie/publication/mobile-handset-performance-data-2

As set out in its Radio Spectrum Management Strategy Statement[9], ComReg will continue to measure the performance of all new models of mobile handsets that become available on the Irish market, for voice and data, and will publish future reports containing the results of these measurements.

1.1 FACTORS AFFECTING MOBILE USER EXPERIENCE

A number of factors affect the quality of the mobile service that a user experiences at any given location - see Figure 1 below. While most of these factors vary over time and by location, the one factor that is relatively constant, from the mobile user's perspective is the mobile handset.

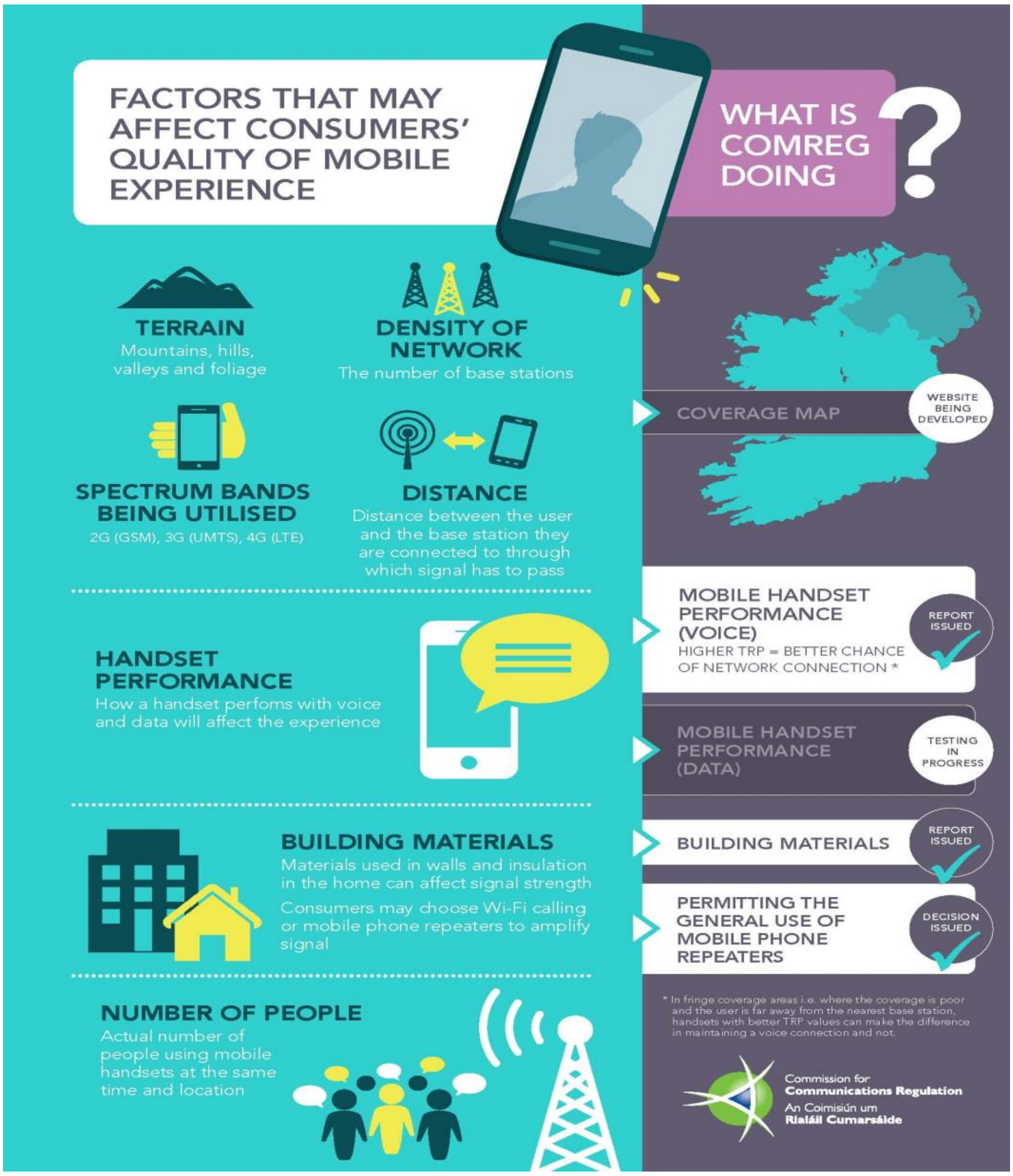

Figure 1: Some factors that affect end-user experience of mobile networks

[9] See footnote 1 above.

ComReg's objective is to gain a greater understanding of factors that affect the experience of users of mobile services, in making voice calls or in streaming data. Towards that objective, ComReg has independently acquired mobile handsets available on the Irish market from various sources and has measured their antenna performances in a manner that replicates mobile user experience. Furthermore, it should be noted that ComReg measured the antenna performance of each mobile handset as a complete device, and that no modifications were made to the device, or to test the antenna in isolation.

1.1.1 Radio frequency spectrum and antennas

All forms of wireless electronic communications use the same medium – radio spectrum. Every radio wave has a unique frequency (measured in Hertz or Hz) and wavelength (measured in metres) which for free space when multiplied by one another always equal the speed of light. Therefore, the higher the frequency the shorter the wavelength, and vice versa. Further, a radio wave with a longer wavelength (lower frequency) can travel further through free space than a radio wave with a shorter wavelength (higher frequency) before the strength of the wave becomes so diminished that it can no longer be received.

Accordingly, due to their relatively long wavelength, radio waves in lower-frequency spectrum bands are better suited to providing mobile coverage over larger geographic areas and at relatively lower cost, because fewer masts and base stations are required. The mobile communications networks used in Ireland operate in a variety of frequency bands ranging from as low as 800 MHz up to several GHz. The "*sub-1 GHz bands"* are commonly referred to as "*coverage bands*" because of their long-range propagation characteristics.

"*Capacity bands*", on the other hand, lie in the various frequency bands above 1 GHz. Radio waves in these higher-frequency bands can travel over comparatively shorter distances before the signal becomes too weak to be received. Capacity bands are therefore used in more populous urban and suburban areas, where substantial network capacity is required.

In common with practices elsewhere, Irish Mobile Network Operators ("MNOs") utilise a mixture of coverage and capacity bands to provide service to consumers.

The reliance upon multiple spectrum bands means that mobile handsets contain multiple antennas that are capable of effectively transmitting and receiving signals in those same bands. An antenna is an integral physical component of every mobile handset; indeed, every piece of radio equipment that is capable of transmitting or receiving a wireless signal requires an antenna in order to do so. A transmitting antenna converts an electric current into a radio frequency ("RF") electromagnetic field and, at the other end, a receiving antenna intercepts the RF field and converts it back to an electric current. The quality and performance of the antenna will therefore have a fundamental impact on the quality and performance of the radio equipment to which it connects.

Further, just as the propagation losses[10] of radio waves change with frequency, the physical characteristics of antennas also affect radio performance. In particular, there is no standard "*one size fits all*" antenna. Instead there is a fundamental relationship between the length of a radio wave and the size of the antenna needed to effectively generate (or, at the opposite end, to intercept) that radio wave. An antenna typically needs to be at least one-tenth the size of the wavelength it receives. Antennas of approximately one half the size of the received wavelength tend to perform best.

Propagation losses of radio waves and of the antennas required to generate and detect radio waves, must be taken into account in the design and manufacture of mobile handsets. Mobile handsets contain multiple antennas, with each antenna designed to transmit and receive radio signals in a specific spectrum band and (for the reasons outlined above) the antennas must also be of a certain physical size in order to operate effectively.

Antennas were clearly visible in most first generation ("1G") and second generation ("2G") mobile handsets (which could be used for voice calls and later also for texting, but not for data). The antennas in many such handsets either protruded permanently from the top corner or could be extended telescopically. Third generation ("3G") networks capable of providing mobile data services were later rolled out and were followed by the current generation of fourth generation ("4G") networks that are capable of providing faster mobile data services. Mobile handset technology has evolved in tandem with network technology and has led to the widespread adoption of 3G and 4G "*smartphones*".

Smartphones are far more functionally advanced than their 1G and 2G predecessors (commonly referred to as "*feature phones*[11]"). Modern smartphones pack ever more computing power, battery capacity, data storage, display area, cameras and other technologies into increasingly thin plastic, glass, or metal cases. Their design and appearance is also an important factor for consumers and is one of the areas in which smartphone manufacturers compete. All of this means that a smartphone's multiple antennas, which are essential components, must compete with all other system components for the amount of available space within the casing. As a result, antennas in many modern smartphones can be small[12],[13] (relative to their optimum size) and easily obscured.[14]

[10] All frequencies propagate in the same manner in free space. The propagation losses are frequency dependent.
[11] The term "Feature Phones" in this context refers to those low-cost mobile handsets designed solely for voice calling and SMS/text messaging.
[12] For small size antennas, there is always a trade-off among antenna radiation quality factor(Q), BW and efficiency (η) (C. P. Huang, 1999; Dalia Nashaat et al, 2003)
The rule of thumb is: $\frac{BW\eta}{V} = Constant$
Where BW is antenna bandwidth, n is the antenna efficiency and V is the antenna volume. This shows that as volume decreases bandwidth and/or efficiency must also decrease
[13] Trade-off between antenna efficiency & Q-factor – M. Gustafsson, 2018
[14] Radio signals when faced with obstructions in their propagation to the antenna hinders the line of sight from a transmitter tower to the antenna which can have an adverse effect on quality of reception.

If an antenna within a mobile handset is obscured then that will affect the antenna's ability to generate and detect the very radio waves that are fundamental to the handset's performance. This will ultimately affect the experience of the user of the mobile handset in making or receiving voice calls or in downloading or uploading data.

1.2 METRICS TO MEASURE MOBILE HANDSET PERFORMANCE

A mobile handset must connect to the nearest base station in order to access a mobile network. The connection from handset to base station is the "uplink" (handset transmits / base station receives) and the connection from base station to handset is the "downlink" (base station transmits / handset receives). The weaker of these two links will determine the quality of the connection between the mobile handset and the mobile network.

Research indicates[15],[16] that the strength of the uplink tends to determine the limits of coverage for voice calls, while for data, the mobile handset spends most its time on the network consuming data from remote servers which means the downlink is the more critical connection. Two conclusions can thus be drawn:

(i). A mobile handset's *transmit performance* (i.e. its ability to generate radio waves) has the greater impact on the quality and consistency of mobile *voice* services.

(ii). A mobile handset's *receive performance* (i.e. its ability to detect radio waves) has the greater impact on the quality and consistency of mobile *data* services.

This report deals exclusively with item (i) above, transmit performance determined by measuring and integrating the Effective Isotropic Radiated Power transmitted by an antenna over a three-dimensional sphere including both vertical and horizontal polarization, this is referred to as the Total Radiated Power ("TRP")[17].

[15] Aalborg University Report Mobile Phone Antenna Performance 2016 ("TIS and TRP Measurements", pp. 16) - https://vbn.aau.dk/ws/portalfiles/portal/240065248/Mobile_Phone_Antenna_Performance_2016.pdf

[16] Aalborg University Report Mobile Phone Antenna Performance 2018 - https://vbn.aau.dk/ws/portalfiles/portal/292015653/MobilephoneTest2018Dec19.pdf

[17] The radiated RF performance of the Equipment under Test (EUT) is measured by sampling the radiated transmit power of the mobile at various locations surrounding the device. A three-dimensional characterization of the 'transmit' performance of the EUT is pieced together by analysing the data from the spatially distributed measurements. All of the measured power values will be integrated to give a single figure of merit referred to as Total Radiated Power (TRP). CTIA (Oct 2018) *Test Plan for Wireless Device Over-the-Air Performance*, version 3.8.1.

1.2.1 Industry-recommended values for TRP

The Cellular Telephone Industries Association ("CTIA")[18], an international industry trade group which represents the wireless communications industry including cellular, and the 3rd Generation Partnership Program ("3GPP")[19] have published standardised procedures for Over-the-Air ("OTA") measurement of TRP for mobile handsets. Annex: 2 contains an overview of those standardised measurement procedures.

Using these standardised measurement procedures, 3GPP and the GSM Association ("GSMA")[20] has also published its performance values[21] to be used as guidelines for acceptable and achievable performance of antennas in Mobile Handsets, across the 2G ("GSM") and 3G ("UMTS") bands. Table 4 in section 2.3 sets out the Recommendations values of GSMA.

[18] Website - https://www.ctia.org/

[19] The 3GPP is a collaboration between groups of telecommunications associations, known as the Organizational Partners. See http://www.3gpp.org/

[20] The GSM Association (commonly referred to as 'the GSMA') is a trade body that represents the interests of mobile network operators worldwide. See http://www.gsma.com/

[21] GSM Association, Official Document TS.24 - Operator Acceptance Values for Device Antenna Performance 2019 https://www.gsma.com/newsroom/wp-content/uploads//TS.24-v4.0.pdf

Chapter 2

2 TRP MEASUREMENT METHODOLOGY & RESULTS

This chapter provides an overview of the methodology used to measure the TRP performance of the 33 new mobile handsets. It then presents the results and a summary of the measurements.

2.1 OVERVIEW OF TRP TEST METHODOLOGY

This section provides an overview of the methodology used, and the relevant frequency bands and technologies.

2.1.1 Mobile Frequency Bands and Technologies

Table 1 sets out the technologies and frequency bands currently used in Ireland to operate mobile networks and provide mobile services in 2G ("GSM") and 3G ("UMTS"). The TRP performance for each mobile handset was measured using a mid-channel frequency, so as to reduce the total number of measurements. Measurements were conducted using GSM and UMTS technologies only.[22]

Table 1: Mobile Technologies and Channel Frequencies

Technology		Bands (MHz)	Channel Frequency (MHz)		
			LOW	MID	HIGH
GSM		900	925.2	942.6	959.8
		1800	1805.2	1842.6	1879.8
UMTS	Band 1	2100	2112.4	2140	2167.6
	Band 8	900	927.4	942.6	957.6

[22] GSM & UMTS were used as these are the technologies used for phone calls. LTE is data based and calls can be made by VoLTE, this is IP packet based and also considered data.

2.1.2 Mobile Handsets

In its initial reports, ComReg measured and published the voice[5] and data[6] performance results for 71 mobile handsets available on the Irish market in June 2017. ComReg subsequently measured and published the voice[7] and data[8] performance results for another 32 different models of mobile handsets, on the Irish market in August 2018.

As part of ongoing testing, ComReg has acquired new models of 33 mobile handsets that became available to the market between September 2018 and July 2019. The results of their antenna's transmitting performance are presented in section 2.2. All of the 33 mobile handsets tested are listed in Annex 1.

ComReg acquired one unit of each mobile handset, on the assumption that all mobile handsets are mass-produced to identical specifications and are subject to a strict quality control process. As such, one would not expect there to be any substantial difference between the TRP measurements for two or more new models of the same mobile handset[23].

[23] ComReg understands and appreciates that mobile handset manufacturers adopt stringent quality control procedures during the manufacturing process, in an effort to minimise the number of defective handsets that reach the open market. ComReg is not privy to the exact percentage rates of defective handsets that do reach the open market and therefore cannot quantify or estimate the number of defective handsets that are purchased by end-users. However, if any manufacturer should have reason to believe that ComReg has acquired and tested a defective or unrepresentative sample of a handset, the manufacturer may inform ComReg of its concerns and ComReg, upon being thus informed, will acquire and test a second sample of the same make and model of handset.

2.1.3 TRP Measurement Methodology

All measurements were taken in a controlled radio frequency (“RF”) environment and in accordance with methodologies set by the Cellular Telephone Industries Association (“CTIA”)[24]. In carrying out the measurements, ComReg also took account of previous work in this same area conducted by Aalborg University[15] and, separately, by the UK electronic communications regulator, Ofcom.[25] Further, the methodology was also independently reviewed by Queen’s University Belfast.[26]

A radio-isolated anechoic chamber[27] was constructed and tested, and a programmable handset measurement system was installed in the chamber and connected to a simulated mobile network base station and measurement equipment that installed outside the chamber (see Figure 2 and 9).

The simulated base station and measurement equipment transmit and receive signals from the mobile handset, at different directions and two polarizations. The system then, reports the resulting measurements of the tested mobile handset in terms of a Total Radiated Power (“TRP”)[17], and a 3D graphic representation of the power radiation pattern. The TRP performance is determined by measuring and integrating the Effective Isotropic Radiated Power (“EIRP”)[28] transmitted by the antenna of a mobile handset, over a three-dimensional sphere and vertical-horizontal polarizations.

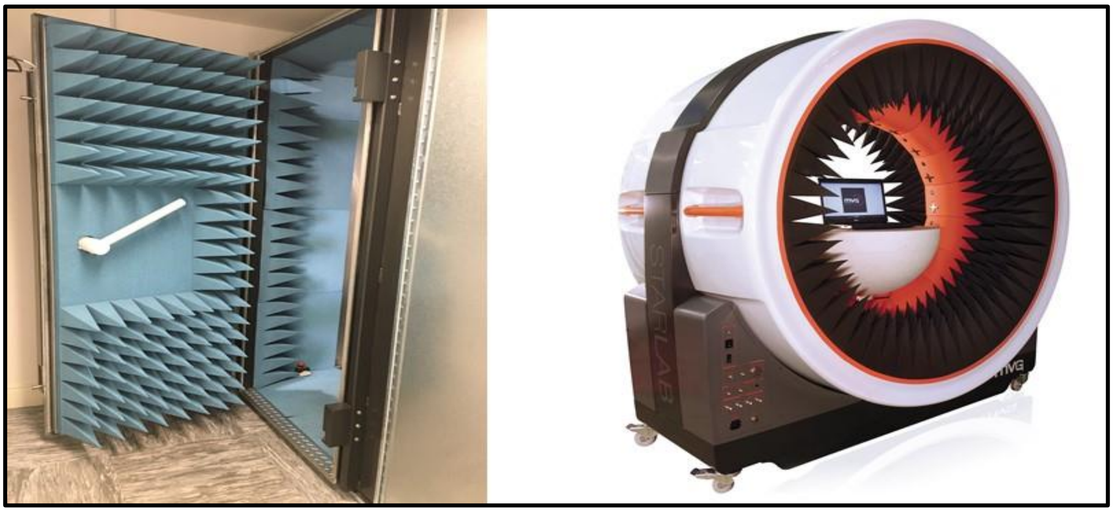

Figure 2: MVG StarLab Measurement System on the right was placed inside the Anechoic Chamber on the left for TRP and TIS Measurement[29]

[24] CTIA Test plan for wireless device over the air performance.
[25] A report for OFCOM, the UK Communication Regulator, mobile handset testing - https://www.ofcom.org.uk/__data/assets/pdf_file/0015/72231/mobile_handset_testing_1v01.pdf
[26] Website - https://www.qub.ac.uk/ecit/
[27] An anechoic chamber (an-echoic meaning "non-reflective, non-echoing, echo-free") is a room designed to completely absorb reflections of either sound or electromagnetic waves.
[28] It’s the absolute transmitted (Tx) power measured in a given direction (θ,).
[29] Annex: 2 and 3 describe, in greater detail, the measurement methodology and applicable standards and the equipment used.

The TRP performance of each mobile handset was measured using two scenarios which simulate the manner in which people typically use their mobile handsets in everyday life – i.e. when making voice calls. Each mobile handset was positioned in a "phantom" right hand beside the right side of the head[30]. The test was then repeated with the same handset positioned in a phantom left hand beside the left side of the head.

TRP measurements were taken for each of these two scenarios (see Figure 3):

- Handset Beside Head Hand Right ("BHHR"); and
- Handset Beside Head Hand Left ("BHHL").

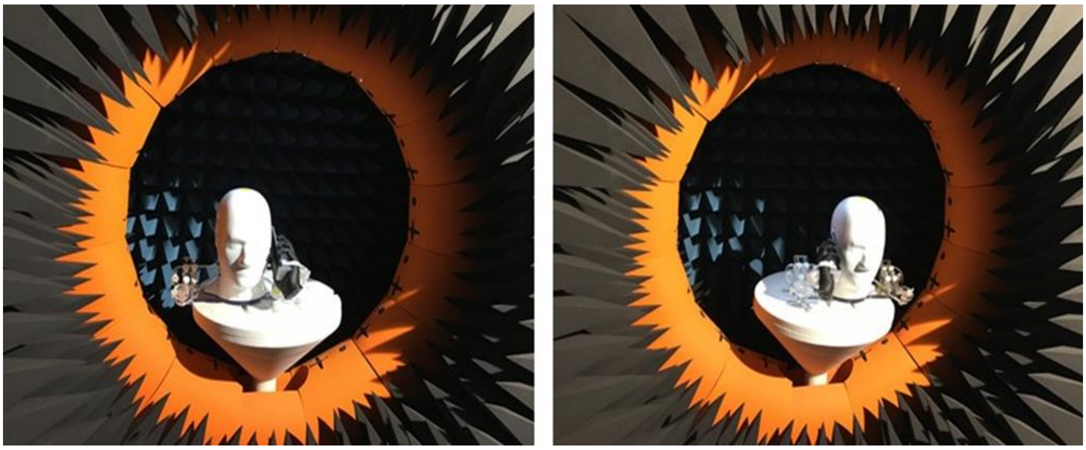

Figure 3: Handset Positioning for BHHL (left) and BHHR (right) scenarios

As set out by CTIA[31] test plan, in order to represent real world usage of mobile handset, an appropriate standard phantom hand shall be employed when testing. In the set of tests conducted by ComReg, various phantom hands were used - i.e. A phantom PDA hand[32] and Ultra-wide PDA[33] ("UWPDA") phantom hand[34]. The selection of the appropriate phantom hand was based on the width of the mobile handset. Annex 1 sets out the type of hand used for each mobile handset that was tested. Identical test procedures were used for all handsets.

[30] Phantom hands are used to evaluate the effect of the human body on electromagnetic radiation and are manufactured from high-quality materials which stimulate the tissue and density of human hands and heads.
[31] CTIA Test Plan for Wireless Device Over-the-Air Performance version 3.8.1 - https://api.ctia.org/wp-content/uploads/2018/10/ctia-test-plan-for-wirelesss-device-over-the-air-performance-ver-3-8-1.pdf
[32] PDA phantom hand is a type of phantom hand that fits mobile handsets with widths ranging from 56 mm to 72 mm.
[33] UWPDA phantom hand is an ultra-wide PDA hand capable of holding handsets with widths ranging from 72 mm to 92 mm.
[34] Differences between requirements for devices wider and narrower than 72 mm reflect observed differences in OTA performance with different hand phantoms of up to 6 dB(CTIA version 3.8.1).

2.2 MEASUREMENT RESULTS

This section presents the TRP performance results of the antennas of the 33 mobile handsets tested. The higher the TRP value, the stronger the signal that can be received at the base station.

The following tables in section 2.2.1 and 2.2.2 list the measurement results of the TRP performance for all 33 handsets in the 2G and 3G bands. The Measurement results, are presented in two scenarios; Beside Head Hand Right (“BHHR”) and Beside Head Hand Left (“BHHL”); and sorted in decreasing order based on the GSM 900 band measurements.

2.2.1 TRP Measurements TRP for BHHR Scenario

Table 2 sets out the TRP measurements for the BHHR scenario (handset held in right hand beside right side of head) for all 33 handsets, in the GSM 900[35], GSM 1800[36], UMTS 900 and UMTS 2100[37] bands. Table 4 in section 2.3, sets out the Recommendations values of GSMA. The results are sorted in decreasing order based on GSM 900 band Measurements.

Table 2: TRP (dBm) results for the BHHR scenario
***F – Feature Phone, *S – Smart Phone**

Mobile Handset	GSM 900 (GSMA Recommendations = 20 dBm)	GSM 1800 (GSMA Recommendations = 21 dBm)	UMTS 900 (GSMA Recommendations = 11 dBm)	UMTS 2100 (GSMA Recommendations = 15 dBm)
Oneplus 7 Pro (S)	21.9	20.6	11.1	12.7
Samsung Galaxy J4+ (S)	21.5	22.0	10.1	12.6
Samsung Galaxy S10 (S)	20.8	23.2	10.5	11.0
Sony Xperia Xz3 (S)	20.6	19.7	11.7	14.7
Huawei P30 Pro (S)	20.6	19.8	11.3	9.2
Huawei P30 (S)	20.3	18.3	10.7	13.4
Cat B35 (F)	20.1	21.4	10.9	13.0
Samsung Galaxy S10+ (S)	20.0	20.8	11.2	9.9
Alcatel U5 (S)	20.0	19.4	9.9	12.6
Doro 8040 (S)	19.9	23.3	12.2	16.4
Alcatel One Touch Pixi3 (S)	19.9	19.3	10.9	13.1
Sony Xperia 1 (S)	19.7	21.2	15.3	17.7
Cat S61 (S)	19.7	17.4	11.0	12.4
Xiaomi Mi Mix 2s (S)	19.3	19.8	10.5	13.2
Huawei P30 Lite (S)	18.8	20.3	9.9	11.8
Xiaomi Mi Mix 3 (S)	18.34	15.68	9.36	11.15

[35] The “900 MHz band” means the 880 to 915 MHz band paired with the 925 to 960 MHz band as set out in Annex 3 to ComReg document 12/15
[36] The “1800 MHz band” means the 1710 to 1785 MHz band paired with the 1805 to 1880 MHz band as set out in Annex 3 to ComReg document 12/15
[37] The “2100 MHz band” means the 1920 to 1980 MHz band paired with the 2110 to 2170 MHz band

Mobile Handset	GSM 900 (GSMA Recommendations = 20 dBm)	GSM 1800 (GSMA Recommendations = 21 dBm)	UMTS 900 (GSMA Recommendations = 11 dBm)	UMTS 2100 (GSMA Recommendations = 15 dBm)
Huawei Psmart (S)	18.0	19.7	8.4	11.5
Huawei Mate 20 Lite (S)	17.9	17.6	8.0	10.1
Sony Xperia 10 (S)	17.7	17.9	10.0	13.5
Motorola Moto G7 (S)	17.6	18.1	6.6	11.5
Huawei Mate 20 (S)	17.6	16.5	8.9	10.9
Samsung A10 (S)	17.5	20.2	8.3	10.8
Huawei Y6 (2019) (S)	17.3	19.8	8.0	8.7
Nokia 9 Pureview (S)	17.3	19.6	7.1	11.7
Huawei Mate 20 Pro (S)	17.0	19.9	8.3	5.0
Apple Iphone Xr (S)	16.12	14.07	10.12	11.1
Apple Iphone Xs (S)	15.96	17.11	7.56	9.03
Huawei Mate20 X (S)	14.9	17.0	6.3	11.3
Apple Iphone Xs Max (S)	14.74	13.72	2.97	11.22
Motorola Moto G7+ (S)	13.2	24.0	8.5	13.0
Google Pixel 3 Xl (S)	12.5	16.4	8.1	10.7
Oneplus 5t (S)	12.4	21.1	3.6	12.0
Oneplus 6T (S)	11.86	18.95	3	10.95

2.2.2 TRP Measurements TRP for BHHL Scenario

Table 3 sets out the TRP measurements for the BHHL scenario (handset held in left hand beside the left side of the head) for all 33 handsets in the GSM 900, GSM 1800, UMTS 900 and UMTS 2100 bands. Table 4 in section 2.3 below, sets out the Recommendations values of GSMA. The results are sorted in decreasing order based on GSM 900 band Measurements.

Table 3: TRP (dBm) results for the BHHL scenario
***F – Feature Phone, *S – Smart Phone**

Mobile Handset	GSM 900 (GSMA Recommendations = 20 dBm)	GSM 1800 (GSMA Recommendations = 21 dBm)	UMTS 900 (GSMA Recommendations = 11 dBm)	UMTS 2100 (GSMA Recommendations = 15 dBm)
Samsung Galaxy S10 (S)	22.3	22.0	12.2	15.6
Oneplus 7 Pro (S)	21.6	18.0	11.0	12.2
Sony Xperia Xz3 (S)	21.2	21.0	12.5	12.0
Huawei P30 (S)	20.7	21.0	11.5	10.5
Huawei Mate20 X (S)	20.4	18.0	10.7	6.5
Cat B35 (F)	20.3	21.7	10.9	15.5
Huawei P30 Pro (S)	20.2	21.7	12.2	9.6
Samsung A10 (S)	20.1	20.3	10.2	11.3
Doro 8040 (S)	19.9	20.9	12.0	14.6
Samsung Galaxy J4+ (S)	19.6	18.8	9.0	11.4
Huawei P30 Lite (S)	19.6	18.7	10.9	10.8
Samsung Galaxy S10+ (S)	18.5	19.2	8.6	7.9
Sony Xperia 1 (S)	18.3	20.1	6.6	13.1
Huawei Mate 20 Lite (S)	18.3	15.6	8.7	8.7
Alcatel Onetouch Pixi3 (S)	18.3	19.5	9.8	14.8
Cat S61 (S)	18.0	19.8	8.9	12.3
Oneplus 6T (S)	17.9	20.1	9.2	12.5
Alcatel U5 (S)	17.8	22.7	15.2	7.6
Sony Xperia 10 (S)	17.7	18.0	10.0	15.1
Xiaomi Mi Mix 3 (S)	17.7	17.7	8.5	14.8
Motorola Moto G7 (S)	17.5	21.1	8.1	16.1
Huawei Y6 (2019) (S)	17.4	19.1	8.8	9.6
Nokia 9 Pureview (S)	17.2	21.0	7.5	13.3
Huawei Psmart (S)	17.0	19.3	7.7	11.0
Huawei Mate 20 Pro (S)	16.7	19.3	8.8	6.2
Huawei Mate 20 (S)	15.2	16.1	8.1	6.0
Xiaomi Mi Mix 2s (S)	15.1	19.0	7.1	13.6
Apple Iphone Xs Max (S)	15.0	17.5	5.6	13.8
Google Pixel 3 Xl (S)	14.8	16.5	8.2	12.5
Motorola Moto G7+ (S)	14.5	24.1	8.6	13.0

Mobile Handset	GSM 900 (GSMA Recommendations = 20 dBm)	GSM 1800 (GSMA Recommendations = 21 dBm)	UMTS 900 (GSMA Recommendations = 11 dBm)	UMTS 2100 (GSMA Recommendations = 15 dBm)
Apple Iphone Xs (S)	12.4	16.6	4.7	13.2
Apple Iphone Xr (S)	11.8	13.6	3.8	9.6
Oneplus 5t (S)	10.4	16.0	2.1	8.8

2.3 MEASUREMENTS SUMMARY

This summary presents the overall average of the TRP[17] measurements in each band for BHHL and BHHR measurements scenarios. It also presents the difference between the highest and lowest measured TRP in each band.

The following points can be made regarding the TRP measurements obtained, for the 2G (GSM 900, GSM 1800) bands; and, 3G (UMTS 900, and UMTS 2100) bands:

2G (GSM 900) Band:

- For the BHHR scenario, average TRP was 17.9 dB and the difference between the highest and lowest TRP measurement was 10.1dB;
- For the BHHL scenario, average TRP was 17.7dB and the difference between the highest and lowest TRP measurement was 12.0dB;
- For some models the TRP measurements differed by 6.1dB between BHHL and BHHR scenarios.

2G (GSM 1800) Band:

- For the BHHR scenario, average TRP was 19.2dB and the difference between the highest and lowest TRP measurement was 10.3dB;
- For the BHHL scenario, average TRP was 19.2dB and the difference between the highest and lowest TRP measurement was 10.5dB;
- For some models the TRP measurements differed by 5.2dB between BHHL and BHHR scenarios.

3G (UMTS 900) Band:

- For the BHHR scenario, average TRP was 9.1dB and the difference between the highest and lowest TRP measurement was 12.3dB;
- For the BHHL scenario, average TRP was 9.0dB and the difference between the highest and lowest TRP measurement was 13.1dB;
- For some models the TRP measurements differed by 8.6dB between BHHL and BHHR scenarios.

3G (UMTS 2100) Band:

- For the BHHR scenario, average TRP was 11.8dB and the difference between the highest and lowest TRP measurement was 12.7dB;

- For the BHHL scenario, average TRP was 11.6dB and the difference between the highest and lowest TRP measurement was 10.0dB;
- For some models the TRP measurements differed by 5.0dB between BHHL and BHHR scenarios.

From the results of previous Mobile Handset Performance (Voice) reports, it can be seen that there is a reduction in the difference between the highest and lowest TRP measurements across the different bands with each report[38,39]. This is due to the lowest measured TRP values increasing as newer phones are released to market.

With regard to 2G, of the mobile handsets tested in the left side and the right side scenario measurements, the average results of the TRP performance is 11% below the recommended value of GSMA for GSM 900 band, and is 8.5% below the recommended value of GSMA for GSM 1800 band.

Table 4: GSMA[23] Operator Acceptance Values (TRP)

Technology (2G/3G)		Bands (MHz)	Acceptance Values for TRP (dBm)
			GSMA (BHH)
GSM		900	20
		1800	21
UMTS	Band 1	2100	15
	Band 8	900	11

In summary in the 2G (GSM 900) band, for both LHHR and RHHR measurement scenarios, the results of the transmit performance of the handsets tested, are as follows:

- 24 % of the handsets tested were found to have a TRP above 20 dBm;
- 58% of the handsets tested were found to have a TRP in the range of 15 to 20 dBm; and
- 18% of the handsets tested were found to have a TRP in the range of 10 to 15 dBm.

Specifically in the LHHR scenario:

[38] ComReg document 18/05 - https://www.comreg.ie/publication/mobile-handset-performance-voice/ (pg. 19)
[39] ComReg 18/109 – https://www.comreg.ie/publication/mobile-handset-performance-voice-technical-report/ (pg. 20)

- 9% of the handsets tested are at the value of 20 dBm; and
- 24% of the handsets tested are above 20dBm.

While, in the RHHR scenario:

- 18% of handsets tested were found to have a TRP 20 dBm; and
- 24 % of handsets tested were found to have a TRP above 20 dBm.

Similarly in 3G, of the mobile handsets tested in both the left and the right side scenarios, the average results of the TRP performance is:

- 17% below the recommended value of the GSMA for UMTS 900 band; and
- 22% below the recommended value of the GSMA for UMTS 2100 band.

Annex: 1 Mobile Handsets Tested

Mobile Handset	Hand Type
Samsung Galaxy S10	PDA Grip
Sony Xperia Xz3	Wide Grip
Samsung Galaxy S10+	Wide Grip
Oneplus 7 Pro	Wide Grip
Sony Xperia 1	Wide Grip
Samsung Galaxy J4+	Wide Grip
Xiaomi Mi Mix 2s	Wide Grip
Alcatel U5	PDA Grip
Motorola Moto G7+	Wide Grip
Huawei P30 Pro	Wide Grip
Motorola Moto G7	Wide Grip
Huawei Mate 20 Lite	Wide Grip
Huawei Mate 20 Pro	Wide Grip
Huawei P30	PDA Grip
Doro 8040	PDA Grip
Alcatel Onetouch Pixi3	PDA Grip
Huawei Psmart 2019	Wide Grip
Huawei Mate 20	Wide Grip
Cat B35	PDA Grip
Huawei Y6 (2019)	Wide Grip
Samsung A10	Wide Grip
Sony Xperia 10	PDA Grip
Cat S61	Wide Grip
Google Pixel 3 Xl	Wide Grip
Huawei P30 Lite	Wide Grip
Huawei Mate20 X	Wide Grip
Oneplus 5t	Wide Grip
Nokia 9 Pureview	Wide Grip
Oneplus 6T	Wide Grip
Xiaomi Mi Mix 3	Wide Grip
Apple Iphone Xr	Wide Grip
Apple Iphone Xs	PDA Grip
Apple Iphone Xs Max	Wide Grip

Annex: 2 Standards and Measurement Techniques

A 2.1 Determining the radio performance of mobile handsets is important and various organisations have worked on terminal antenna measurements in recent years. These include the Cellular Telephone Industries Association ("CTIA"), Cooperation in Science and Technology ("COST"), and 3rd Generation Partnership Project ("3GPP"). Below are brief descriptions of these organisations and the measurement techniques standardised over the years[40].

CTIA

A 2.2 The CTIA is an international industry trade group representing the wireless communications sectors, including cellular, and its test procedures are widely used and accepted by the mobile communications industry. The CTIA has defined a common set of industry-standard test procedures called OTA performance measurements[24,41] through which the Radiated RF Power and Receiver Performance measurements on wireless devices are evaluated. This CTIA test procedures define general requirements for equipment configuration, laboratory techniques, test methodologies, and evaluation criteria that must be met in order to ensure the accurate, repeatable, and uniform testing of wireless devices, to CTIA Certification standards.

A 2.3 The current CTIA certification includes most of the 3GPP technical specifications for UMTS mobile handsets. According to CTIA, two methods are standardized for measuring the performance of mobile handset antennas, executed both in free space and in the presence of the head, body and hand. The two methods are the conical cut method and the great circle cut method. These are 3D pattern measurement methods and, with modifications, they can be implemented in an anechoic chamber with either a spherical scanning or a dual axis measurement system, in accordance with 3GPP. The values measured (the "figures of merit") using the great circle cut method and conical cut method are TRP and TIS.

3GPP[42] [40]

A 2.4 The 3rd Generation Partnership Project ("3GPP") brings together seven telecommunications standard development organizations - ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC.

[40] Over-The-Air Performance Estimation of Wireless Device Antennas - SATHYAVEER PRASAD;2013
[41] A CTIA approved antenna measurement system for over-the-air testing of wireless devices - B. Lawrence; ETS-LINDGREN, UK; 2004.
[42] 3GPP Scope and Objectives – 3GPP; 2007.

A 2.5 The original scope of 3GPP (1998) was to produce Technical Specifications and Technical Reports for a 3G Mobile System based on evolved GSM core networks and the radio access technologies that they support (i.e. Universal Terrestrial Radio Access ("UTRA") both Frequency Division Duplex ("FDD") and Time Division Duplex ("TDD") modes).

A 2.6 The scope was subsequently amended to include the maintenance and development of the Global System for Mobile communication ("GSM") Technical Specifications and Technical Reports including evolved radio access technologies (e.g. General Packet Radio Service ("GPRS") and Enhanced Data rates for GSM Evolution ("EDGE")). The term "3GPP specification" covers all GSM (including GPRS and EDGE), W-CDMA (including HSPA) and LTE (including LTE-Advanced and LTE-Advanced Pro) specifications. The following terms are also used to describe networks using the 3G specifications: UTRAN, UMTS (in Europe) and FOMA (in Japan).

A 2.7 The 3GPP technical specification groups that work with terminal testing and mobile terminal conformance testing are the GSM EDGE Radio Access Network Working Group 3 ("GERAN WG3") and the Radio Access Network Working Group 5 ("RAN WG5"), respectively. The Radio Access Network Working Group 4 ("RAN WG4") works with "radio performance and protocol aspects (system) - RF parameters and BS conformance." This group contributes to the standardisation of the figures of merit required for estimating the radio performance of mobile handset antennas.

A 2.8 The 3GPP standard procedure for measuring the radio performance of 3G, UMTS and GSM mobile handsets is based on the procedure proposed by COST 273 SWG 2.2. According to this, the standard procedure for measuring the radio performance of the transmitter and receiver must include the antenna and the effects of the user. In this context, two measurement procedures were standardised, the Spherical scanning system and Dual axis system.

A 2.9 Both procedures are based on the 3D pattern measurement method, proposed by COST 259[43] and COST 273[44], and are carried out in an anechoic chamber. Under the 3GPP standard, utilising a reverberation chamber is considered an alternative procedure for measuring the TRP of mobile handsets. The 3GPP has defined the reverberation chamber and anechoic chamber two-stage and multi-probe test methods as standard methods for MIMO over the Air testing.

A 2.10 The TRP and TIS are the standard figures of merit for estimating the radio performance of a mobile handset antenna, in an isotropic field distribution environment with a cross polarisation ratio of unity.

[43] COST Action 259 - Wireless Flexible Personalized Communications – COST; 1996
[44] COST Action 273 - Towards Mobile Broadband Multimedia Networks - COST; 2005

Measurement Techniques[45]

A 2.11 The performance of Handset under Test (“HUT”) can be determined by characterising the Far-Field (“FF”) radiation. There are two measurement systems capable of providing the Far Field radiation characteristics, directly or indirectly.

Direct Measurement Techniques[45]

A 2.12 Direct measurement techniques are based on the Far-Field measurement systems. In direct measurement techniques, the distance L between the probe and the HUT has to be great enough to consider that the HUT is in the plane wave region and this could be considered as a disadvantage of the direct measurement technique as it could require a large distance. The sub-categories of direct measurement techniques are outdoor FF range, indoor FF range, and compact range.

Indirect Measurement Techniques[45]

A 2.13 Indirect measurement techniques are based on Near-Field (“NF”) measurement systems. Once the Near-Field measurements are captured they can then be mathematically transformed to Far-Field radiation with NF/FF algorithms. Indirect measurement techniques can be split in three sub-categories- planar, cylindrical and spherical geometries.

A 2.14 The StarLab system is a Near Field multi-probe system which can be configured either in cylindrical or in spherical geometry as configured for this measurement study. Compared to FF the advantage of NF is the reduced distance between HUT and probes.

A 2.15 In spherical NF measurements, the electromagnetic field is sampled on a closed sphere surface surrounding the antenna under test during its rotation and then transformed to FF by Fourier transformation algorithms based on the Huygens principle. Spherical scanning measurement is suitable for mobile handset testing because it is accurate and cost efficient. Spherical scanning is used for Omni-directional antennas, semi-directive antennas or directive antennas.

Dual axis system

A 2.16 A dual axis system is a method where the mobile handset is placed on a positioner that is able to rotate around two different axes. The signal is transmitted/received by a fixed probe antenna.

[45] User Guide – StarLab - MVG; 2015

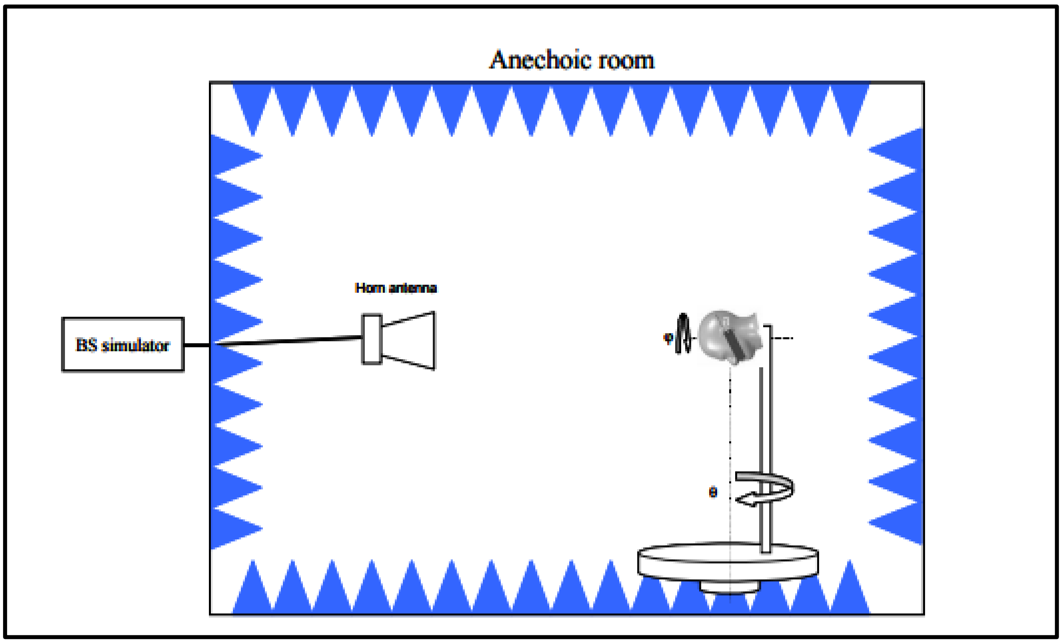

Figure 5: Dual axis system (for illustration purpose)

Spherical Scanning Measurement methods

A 2.17 A spherical scanner system is a method where the mobile handset is placed on a positioner that is capable of rotating horizontally. The probe antenna is then rotated physically along the vertical plane in order to get the 3D pattern of the mobile handset under test. Spherical Scanning systems can also use multi-probe antennas where these antennas can be placed along an arch in vertical plane and electronically switched in order to get the 3D pattern.

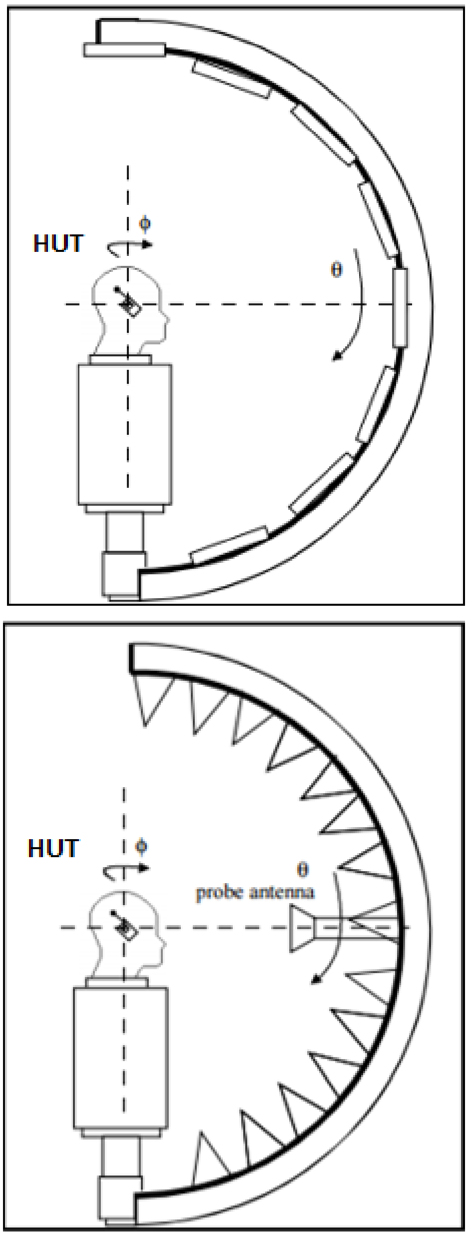

Figure 6: (a) Multi Probes (b) Single Probe (for illustration purpose)

A 2.18 The spherical scanning measurement is one of the indirect measurement techniques NF to determine FF radiation characteristics of antennas. Within the spherical scanning technique there are two acceptable methods of scanning the HUT to determine figures of merit such as TRP and TIS. These methods are the conical cut method and the great circle cut method.

A 2.19 **The conical cut method:** The handset under test rotates on its long axis and the measurement antenna is selected electrically above and below the level of the handset under test for each rotation.

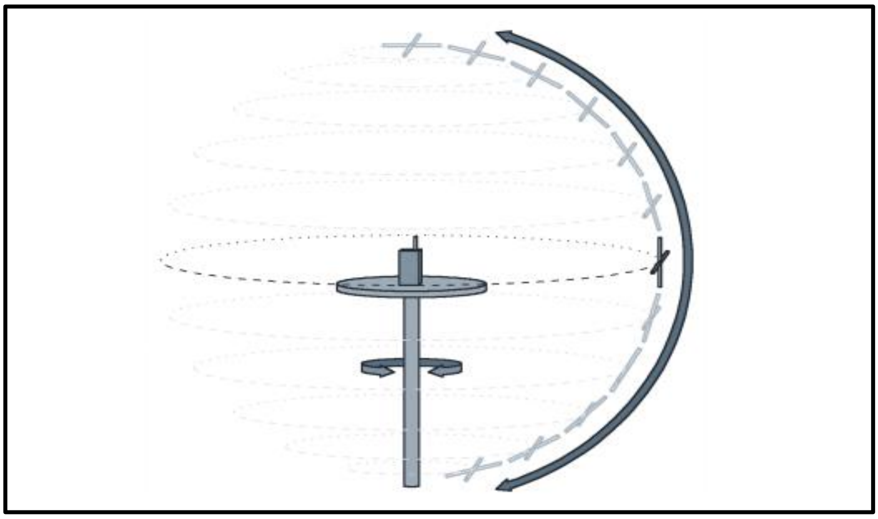

Figure 7: The conical cut method[46] (for illustration purpose)

A 2.20 **The great circle cut method:** for this method, the measurement antenna remains fixed and the handset under test is rotated about two axes in sequential order.

[46] Antenna Pattern Measurement: Concepts and Techniques - http://www.ets-lindgren.com/sites/etsauthor/WhitePapers/APM.pdf

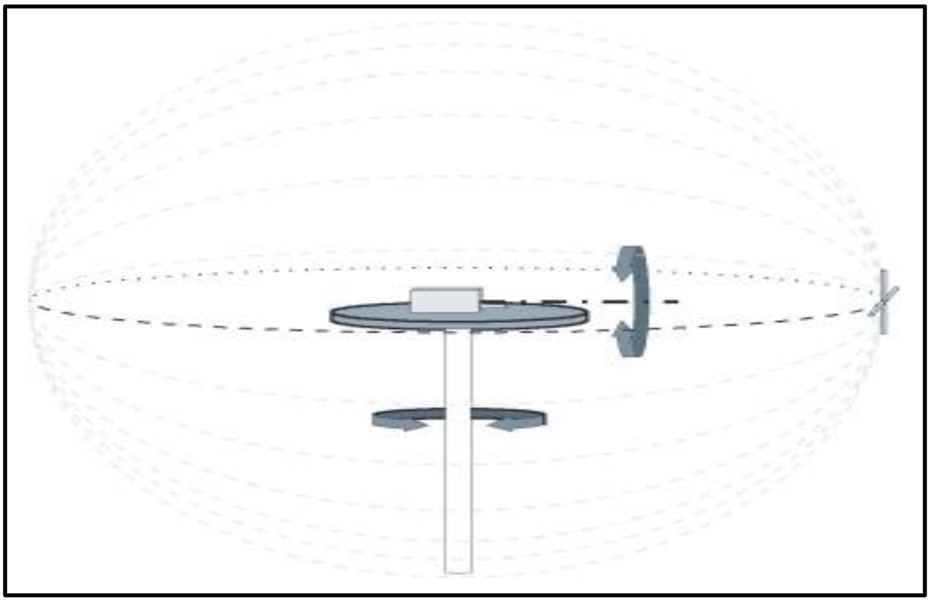

Figure 8: The great circle cut method (for illustration purpose)

The spherical scanning measurement is defined by both CTIA and 3GPP as the standard reference test method for measuring the performance of the HUT. The StarLab used for testing is based on the great circle cut method. In both methods, the angle of elevation in the long axis of HUT is the Theta (θ), and the azimuth angle of the HUT is the Phi (∅). At all times reference must be made to the maximum size of the handset under test so that the StarLab near to far field transformation integrity is adhered to, see Table 5

Table 5: Maximum diameter of HUT[47]

Frequency	NUMBER OF OVERSAMPLING				
(GHz)	x 1	x 2	x 3	x 5	x10
0.65	0.45	0.45	0.45	0.45	0.45
1	0.45	0.45	0.45	0.45	0.45
2	0.38	0.45	0.45	0.45	0.45
3	0.25	0.45	0.45	0.45	0.45
4	0.19	0.38	0.45	0.45	0.45
5	0.15	0.31	0.45	0.45	0.45

Table 6: System specifications[47]

PEAK GAIN ACCURACY	
0.65 GHz - 0.8 GHz	±1.5 dB
0.8 GHz - 1 GHz	±1.1 dB
1 GHz - 6 GHz	±0.8 dB

47 http://www.uwave.com.my/wp-content/uploads/2014/04/starlab_2014.pdf

Table 7: OTA performance measurement specifications[47]

ACCORDING TO CTIA SPECIFICATIONS	
TRP accuracy FS	<±1.9dB
TRP accuracy talk position	<±2.0dB
TRP repeatability	±0.3dB

Annex: 3 Test Setup and Equipment

A 3.1 The mobile handsets measured for TRP were placed in an anechoic chamber and the test equipment used is listed below and it was set up as illustrated in figure 9.

Table 9: Measurement Equipment

Equipment /Software used	Manufacturer	Model No/Version
Active Switching Unit	MVG	11017004-2248
Anechoic Chamber	Rainford EMC systems	-
CTIA ‘PDA’ phantom left hand	IndexSAR	IXB-053L
CTIA ‘PDA’ phantom right hand	IndexSAR	IXB-053R
CTIA ‘UWPDA’ phantom left hand	IndexSAR	IXB-056L
CTIA ‘UWPDA’ phantom right hand)	IndexSAR	IXB-056R
Handset alignment tool ‘A’	IndexSAR	IXJ-020
Handset alignment tool ‘B’	IndexSAR	IXJ-030
Head/Hand fixture to meet the requirements of CTIA Test Plan Satimo mounting for IndexSAR SAM head	IndexSAR	IXBH-061A
Radio Communications Tester	Anritsu	MT8820C
RX Amplification Unit	MVG	1101238-2247
SAM	IndexSAR	IXB-030
SatEnv	MVG	3.0.3.0b23
SPM	MVG	1.11.1
StarLab	MVG	SL V2_0.4-6/6-18 GHz
Transfer Switching Unit	MVG	1101248-2235
TX Amplification Unit	MVG	1101252-2239
Vector Network Analyser	Anritsu	MS46522B
Wave Studio	MVG	3.1.2

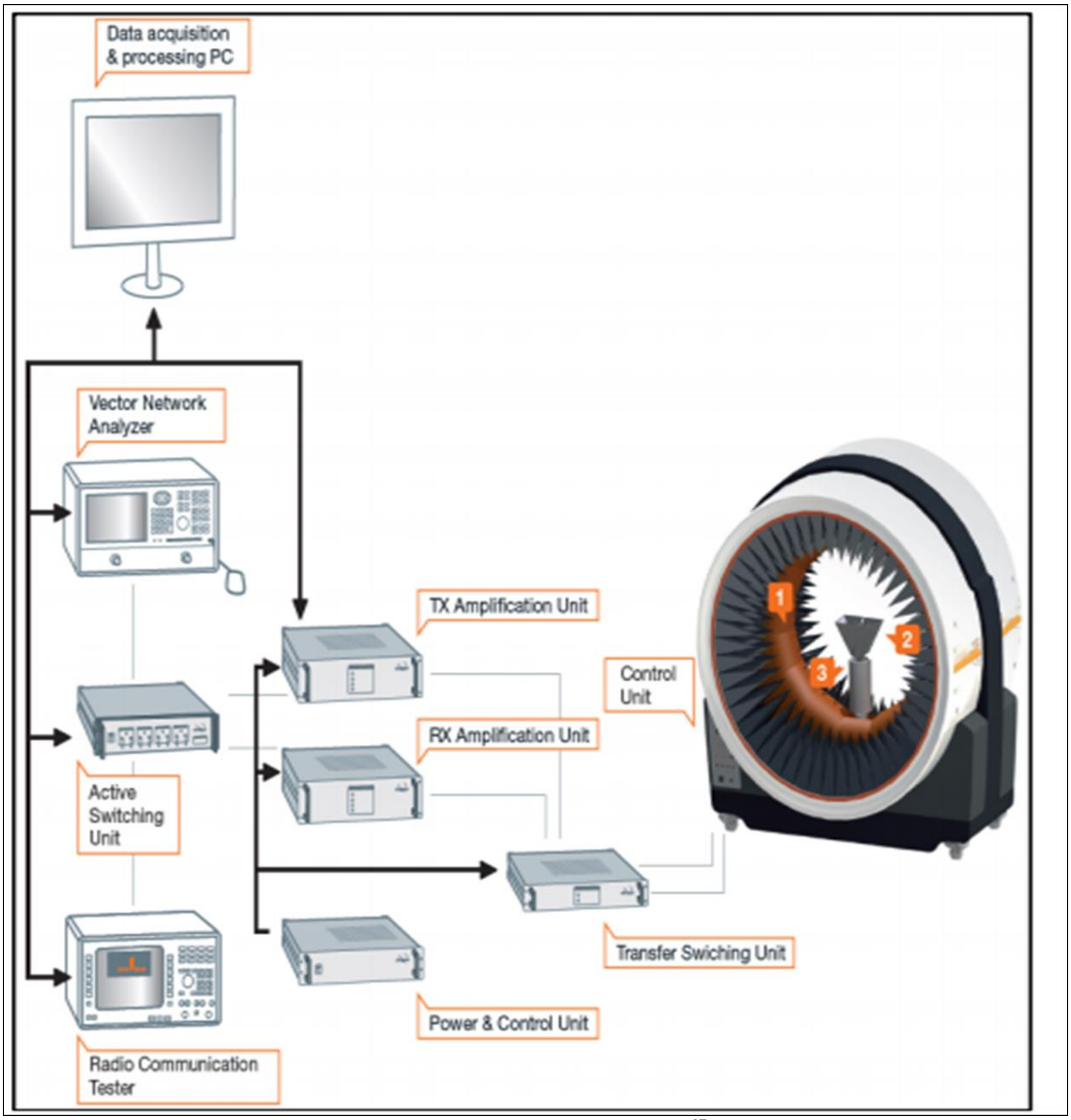

Figure 9: StarLab Test Setup[45]

List of Abbreviations

<table>
<tr><th>Abbreviation</th><th>Explanation</th></tr>
<tr><td>dB

dBm</td><td>Decibels
Decibels is a ratio which describes change in signal strength
<table>
<tr><th>Decibels</th><th>Change in signal factor</th></tr>
<tr><td>0 dB</td><td>= x 1</td></tr>
<tr><td>3 dB</td><td>= x 2</td></tr>
<tr><td>6 dB</td><td>= x 4</td></tr>
<tr><td>10 dB</td><td>= x 10</td></tr>
<tr><td>20 dB</td><td>= x 100</td></tr>
</table>
Abbreviation for Decibels relative to one milliwatt</td></tr>
<tr><td>2G</td><td>Second-Generation Cellular Technology</td></tr>
<tr><td>3D</td><td>Three-Dimensional Space</td></tr>
<tr><td>3G</td><td>Third-Generation Cellular Technology</td></tr>
<tr><td>3GPP</td><td>3rd Generation Partnership Project</td></tr>
<tr><td>4G</td><td>Fourth Generation Cellular Technology</td></tr>
<tr><td>EIRP</td><td>Effective Isotropic Radiated Power</td></tr>
<tr><td>COST</td><td>Co-operation in Science & Technology</td></tr>
<tr><td>CTIA</td><td>Cellular Telephone Industries Association</td></tr>
<tr><td>DL</td><td>Downlink</td></tr>
<tr><td>FDD</td><td>Frequency Division Duplexing</td></tr>
<tr><td>FF</td><td>Far-Field</td></tr>
<tr><td>FS</td><td>Free Space</td></tr>
<tr><td>GPRS</td><td>Global Packet Radio Service</td></tr>
<tr><td>GPRS/EDGE</td><td>General Packet Radio Service/Enhanced Data Rates for Global Evolution</td></tr>
<tr><td>GSM</td><td>Global System for Mobile Communications</td></tr>
<tr><td>GSMA</td><td>GSM Association</td></tr>
<tr><td>BHHL</td><td>Beside Head Hand Left</td></tr>
<tr><td>BHHR</td><td>Beside Head Hand Right</td></tr>
<tr><td>HSPA</td><td>High Speed Packet Access</td></tr>
<tr><td>HUT</td><td>Handset Under Test</td></tr>
<tr><td>LTE</td><td>Long Term Evolution</td></tr>
<tr><td>MNO</td><td>Mobile Network Operator</td></tr>
<tr><td>MVG</td><td>Microwave Vision Group</td></tr>
<tr><td>NF</td><td>Near-Field</td></tr>
<tr><td>OTA</td><td>Over-the-Air</td></tr>
<tr><td>PDA Grip</td><td>A dummy hand used to grip wider phones</td></tr>
<tr><td>RAN</td><td>Radio Access Network</td></tr>
<tr><td>RCA</td><td>Radio Communications Analyser</td></tr>
<tr><td>RF</td><td>Radio Frequency</td></tr>
<tr><td>RX</td><td>Receiving</td></tr>
<tr><td>SAM</td><td>Specific Anthropomorphic Mannequin</td></tr>
<tr><td>TDD</td><td>Time Division Duplexing</td></tr>
</table>

Abbreviation	Explanation
TIS	Total Isotropic Sensitivity
TRP	Total Radiated Power
TX	Transmitting
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VNA	Vector Network Analyser
W-CDMA	Wideband Code Division Multiple Access
Wide Grip	A dummy hand used with normal sized smartphones