Mobile Handset Performance (Data)

Reference: ComReg 19/67

Date: 25/06/2019

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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") and national numbering resources.[1]

As part of its spectrum management function, and in line with Goal 8 of the Electronic Communications Strategy Statement which is to "understand evolving consumer needs, preferences, behaviours and perceptions", ComReg during its 2016–2018 work period initiated a number of work streams. On foot of those work streams ComReg has, to date, published the following reports:

- Meeting Consumer's Connectivity Needs[2] – an overview of challenges to connectivity and actions Irish operators can take to optimise connectivity.

- Effect of Building Materials on Indoor Mobile Performance[3] - 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 or receiving calls and streaming data. Three reports have been published to date – two on voice call performance[4] and one on data performance.[5]

This report sets out results of the most recent measurement of mobile handset performance, for data. Performance was measured based on Total Isotropic Sensitivity ("TIS") which is a measurement of a mobile handset's ability to detect a weak signal and maintain connection with a base station.

ComReg's first antenna performance reports, for voice and data, were based on tests of 71 makes and models of mobile handsets available on the Irish market in June 2017. ComReg has since also measured 32 of the newest makes and models of mobile handsets. The antenna performances for voice for those 32 handsets were published in (Doc 18/109)[6]. This report sets out the antenna performances for data for the same 32 handsets.

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[1] ComReg document 18/118 - https://www.comreg.ie/publication/radio-spectrum-management-strategy-statement-2019-to-2021-design-version/

[2] ComReg document 18/103b - https://www.comreg.ie/publication/meeting-consumers-connectivity-needs/

[3] ComReg document 18/73 - https://www.comreg.ie/publication/the-effect-of-building-materials-on-indoor-mobile-performance/

[4] 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/

[5] ComReg document 18/82 - https://www.comreg.ie/publication/mobile-handset-performance-data/

[6] ComReg 18/109 - https://www.comreg.ie/publication/mobile-handset-performance-voice-technical-report/

As set out in its Radio Spectrum Management Strategy Statement for 2019 to 2021[1], ComReg will continue to measure the performance of all new makes and models of mobile handsets that become available on the Irish market, for voice and data, and will publish future reports containing the results of those measurement.

1.1   FACTORS AFFECTING MOBILE USER EXPERIENCE

A number of factors will affect the quality of the mobile service that a user will experience 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: Factors affecting end-user experience of mobile networks

ComReg's objective is to gain a greater understanding of factors that affect the experience of users of mobile services, in making or receiving voice calls or in streaming data. Towards that objective, ComReg has acquired mobile handsets available on the Irish market from various sources and has measured their antenna performances a manner that replicates mobile user experience (including that ComReg measured the performance of each mobile handset as a complete device).

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 ("FS") 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 must 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 characteristics of radio waves change with frequency, the physical characteristics of antennas affect their 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 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.

The propagation characteristics 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 must 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. 3G networks capable of providing mobile data services were later rolled out and were followed by the current generation of 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*[7]"). 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[8] (relative to their optimum size) and easily obscured.[9]

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.

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[7] The term "Feature Phones" in this context refers to those low-cost mobile handsets designed solely for voice calling and SMS/text messaging.

[8] 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

[9] 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.

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[10] 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 no. (ii) Above – receive performance determined by measuring the Effective Isotropic Sensitivity received by an antenna over a three-dimensional sphere – this is referred to as the **Total Isotropic Sensitivity** ("TIS").

1.2.1 Industry-recommended values for TIS

The Cellular Telephone Industries Association ("CTIA")[11], an international industry trade group which represents the wireless communications industry including cellular, and the 3rd Generation Partnership Program ("3GPP")[12] have published standardised procedures for Over-the-Air ("OTA") measurement of TIS for mobile handsets. Annex: 2 contains an overview of those standardised measurement procedures.

Using these standardised measurement procedures, 3GPP and the GSM Association ("GSMA")[13] has also published its performance values to be used as guidelines for acceptable and achievable performance of antennas in Mobile Handsets, across the 3G and 4G bands. Table 4 in section 2.3 sets out the Recommendations values of GSMA.

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[10] 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

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

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

[13] 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/

Chapter 2

2 TIS MEASUREMENT METHODOLOGY & RESULTS

This chapter provides an overview of the methodology used to measure TIS performance of the 32 mobile handsets that were previously measured for TRP. It then presents the results and a summary of the measurements.

2.1 OVERVIEW OF TIS TEST METHODOLOGY

This section provides an overview of the 32 mobile handsets that were measured for TIS performance, including frequency bands and technologies, and the measurement methodology.

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. The TIS performance for each mobile handset was measured using the mid-channel frequency only, so as to reduce the total number of measurements. Measurements were done using LTE and UMTS technologies only.

Table 1: Mobile Technologies and Channel Frequencies

Technology		Bands (MHz)	Channel Frequency (MHz)		
			LOW	MID	HIGH
UMTS	Band 1	2100	2112.4	2140	2167.6
	Band 8	900	927.4	942.6	957.6
LTE	Band 3	1800	2115	2140	2165
	Band 20	800	796	806	816

2.1.2 Mobile Handsets

In its first reports, ComReg published the voice and data performance results for 71 mobile handsets available on the Irish market in June 2017. ComReg subsequently measured 32 newer makes and models of mobile handsets, on the Irish market in August 2018. Details of these 32 handsets are in Annex 1. The TRP (Voice) performances of the 32 mobile handsets were published in (Doc 18/109).[6] This report presents the TIS performances (Data) for the same 32 mobile handsets - see section 2.2.

ComReg acquired one sample of each handset on the assumption that all mobile handsets are mass-produced to identical specifications and are subject to strict quality control processes. As such, one would not expect there to be any substantial difference between the TIS measurements for two or more new models of the same mobile handset[14].

2.1.3 TIS 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"). In carrying out the measurements, ComReg also took account of previous work in this same area conducted by Aalborg University[10] and, separately, by the UK electronic communications regulator, Ofcom.[15] The methodology was also independently reviewed by Queen's University Belfast.[16]

A radio-isolated anechoic chamber[17] was constructed and tested and a programmable handset measurement system was installed in the chamber along with a simulated mobile network base station and measurement equipment (see Figure 2 and 9).

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[14] 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.
[15] 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
[16] Website - https://www.qub.ac.uk/ecit/
[17] 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.

The simulated base station and measurement equipment transmit and receive signals from the mobile handset. The resulting measurements show the Total Isotropic Sensitivity (TIS performance) and a representation of the handset's sensitivity pattern.
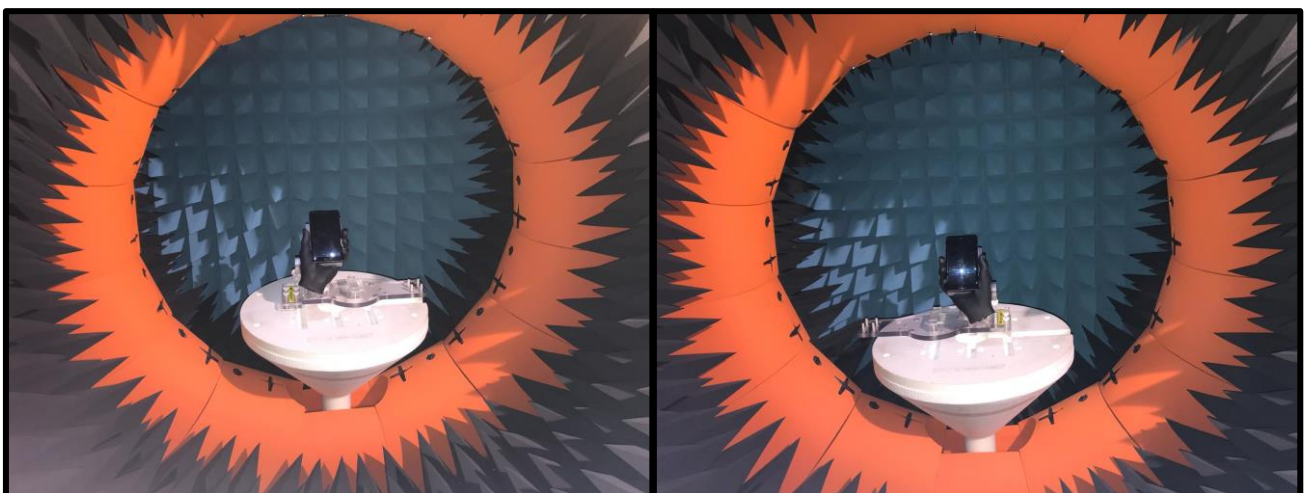
Figure 2: MVG StarLab Measurement System on the right was placed inside the Anechoic Chamber on the left for TRP and TIS Measurement[18]

The TIS 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 browsing. Each mobile handset was positioned in a "phantom" right hand (see Figure 3)[19]. The test was then repeated with the same handset positioned in a phantom left hand. TIS measurements were taken for each of these two scenarios:

- Handset being held with only right hand ("HR"); and
- Handset being held with only left hand ("HL").

Figure 3: Handset Positioning for HL (left) and HR (right) scenarios

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[18] Annex: 2 and 3 describe, in greater detail, the measurement methodology and applicable standards and the equipment used.

[19] 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.

As set out by CTIA[20] 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[21] and UWPDA[22] (Ultra-wide PDA) phantom hand.[23] 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.

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[20] CTIA Test Plan for Wireless Device Over-the-Air Performance version 3.8.2 - https://api.ctia.org/wp-content/uploads/2019/04/CTIA_OTA_Test_Plan_3_8_2.pdf

[21] PDA phantom hand is a type of phantom hand that fits mobile handsets with widths ranging from 56 mm to 72 mm.
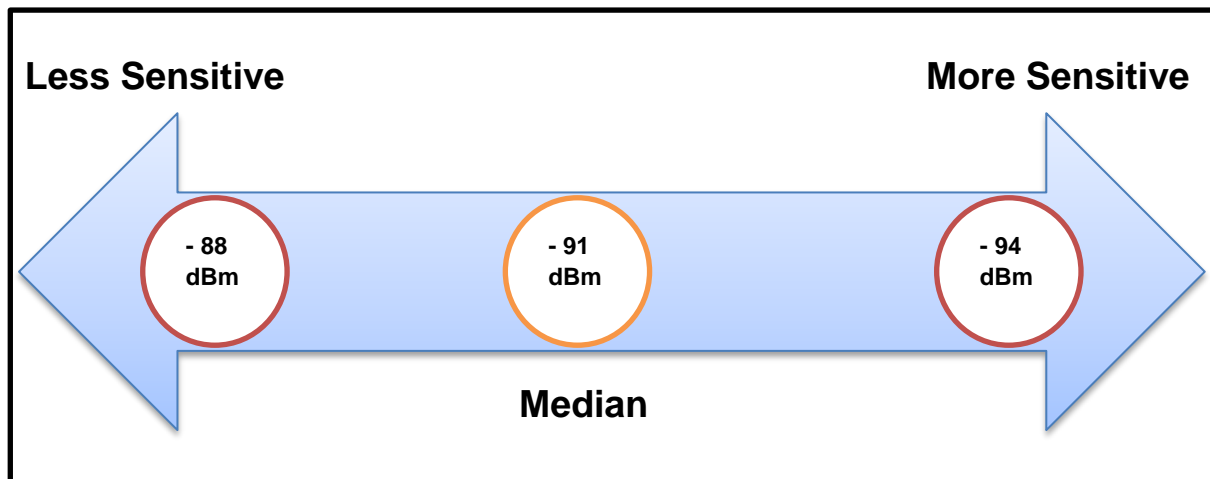
[22] UWPDA phantom hand is an ultra-wide PDA hand capable of holding handsets with widths ranging from 72 mm to 92 mm

[23] 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 3.8.2)

2.2 MEASUREMENT RESULTS

This section presents the TIS performance results of the 32 tested mobile handsets. TIS is a negative number which indicates the ability of a mobile handset to detect a weak power level signal. The more negative the TIS value the more sensitive the mobile handset - i.e. the more able to detect a weaker power level signal and maintain connection with a base station.

Figure 4: This figure shows that, a TIS measured value of -94 dBm is more negative than a TIS measured value of -88. (The more negative the TIS value the more sensitive the mobile handset**)**

Less Sensitive   **More Sensitive**

- 88 dBm   - 91 dBm   - 94 dBm

Median

The following tables list the measurements' results of the TIS performance for all 32 handsets in the UMTS and LTE bands. Measurements' results are presented in two scenarios; Hand Right (HR) and Hand Left (HL).

2.2.1 TIS Measurements for HR Scenario

Table 2 sets out the TIS measurements for the HR scenario (handset held in right hand) for all 32 handsets in the LTE 800[24], LTE 1800[25], UMTS 900[26] and UMTS 2100[27] **bands**. The handsets are listed in decreasing[28] (**i.e. from more sensitive measured TIS value to less sensitive measured TIS value**) order of TIS sensitivity measurements in the LTE - 800 band. Table 4 in section 2.3, sets out the Recommendations values of **GSMA**.

Table 2: TIS (dBm) for the HR scenario in the LTE-800 band in decreasing[28] order of sensitivity (from more sensitive measured TIS value to less sensitive measured TIS value)

*F – Feature Phone, *S – Smart Phone

Mobile Handset	LTE 800 (GSMA Recommendations = -89.5 dBm)	LTE 1800 (GSMA Recommendations = -91 dBm)	UMTS 900 (GSMA Recommendations = -101 dBm)	UMTS 2100 (GSMA Recommendations = -103 dBm)
Samsung S9+ (S)	-94.8	-98.3	-108.5	-109.4
Samsung Galaxy S9 (S)	-94.1	-98.7	-107.0	-108.5
Huawei Honor 9 (S)	-94.0	-94.9	-108.0	-107.7
Huawei P20 (S)	-93.3	-97.1	-107.0	-109.4
Huawei Mate 10 Pro (S)	-93.0	-95.5	-107.7	-109.8
Samsung Galaxy J6 (S)	-93.0	-98.6	-105.8	-110.7
Samsung Galaxy A8 (S)	-92.8	-94.5	-106.9	-105.0
Sony Xperia XZ2 (S)	-92.7	-94.9	-107.4	-107.5
Samsung Galaxy J2 Pro (S)	-92.7	-96.7	-106.1	-109.0
HTC U11 (S)	-92.6	-97.6	-108.1	-109.1
Huawei Honor 9 Lite (S)	-92.5	-93.5	-106.4	-105.3
Huawei P20 Pro (S)	-92.4	-97.0	-106.7	-108.9
Apple iphone 8 (S)	-92.4	-96.3	-105.2	-106.9
Nokia 7 Plus (S)	-92.3	-95.3	-106.2	-106.1
Apple iphone X (S)	-92.2	-93.7	-103.0	-105.0
Sony Xperia XA2 (S)	-91.9	-92.8	-106.5	-106.4
Apple iphone 8+ (S)	-91.9	-95.8	-105.3	-106.5
LG V30 (S)	-91.8	-96.4	-107.0	-108.7
Huawei P smart (S)	-91.8	-93.9	-104.6	-106.1
Nokia 2 (S)	-91.6	-95.3	-106.1	-108.3
Nokia 8110 4G (F)	-91.5	-95.5	-106.6	-109.2
Google Pixel XL 2 (S)	-91.2	-94.8	-105.0	-107.3
Google Pixel 2 (S)	-91.0	-96.8	-106.6	-109.9
Nokia 3 (S)	-91.0	-94.6	-105.7	-109.6
Oneplus 5T (S)	-90.9	-93.6	-103.5	-106.3

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[24] The "800 MHz band" means the 791 to 821 MHz band paired with the 832 to 862 MHz band as set out in Annex 3 to ComReg Document 12/25

[25] 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 12/25

[26] 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 12/25

[27] The "2100 MHz band" means the 1920 to 1980 MHz band paired with the 2110 to 2170 MHz band

[28] The more negative the TIS value the more sensitive the mobile handset - i.e. it is able to detect a weaker power level signal and maintain a reliable connection with the base station.

Mobile Handset	LTE 800 (GSMA Recommendations = -89.5 dBm)	LTE 1800 (GSMA Recommendations = -91 dBm)	UMTS 900 (GSMA Recommendations = -101 dBm)	UMTS 2100 (GSMA Recommendations = -103 dBm)
Oneplus 6 (S)	-90.2	-95.0	-104.8	-106.6
HTC U12+ (S)	-89.6	-96.5	-105.2	-106.2
Huawei P20 Lite (S)	-89.2	-93.5	-103.9	-107.0
Sony Xperia XA2 Ultra (S)	-87.5	-91.1	-106.8	-108.2
Xioami Redmi Note 5 Global(S)	-87.2	-96.9	-102.9	-107.4
Samsung Galaxy A6 (S)	-87.1	-95.0	-106.6	-106.0
Xioami Mi Note 3 (S)	N/A	-98.0	-110.1	-111.5

2.2.2 TIS Measurements for HL Scenario

Table 3 sets out the TIS measurements for the HL scenario (handset held in left hand) for all 32 handsets in the LTE - 800[24], LTE- 1800[25], UMTS 900[26] and UMTS 2100[27] **bands**. The handsets are listed in decreasing[28] (**i.e. from more sensitive measured TIS value to less sensitive measured TIS value**) order of TIS sensitivity measurements in the LTE - 800 band. Table 4 in section 2.3 below, sets out the Recommendations values of **GSMA**.

Table 3: TIS (dBm) for the HL scenario in the LTE - 800 band in decreasing[28] order of sensitivity (from more sensitive measured TIS value to less sensitive measured TIS value**)**

*F – Feature Phone, *S – Smart Phone

Mobile Handset	LTE 800 (GSMA Recommendations = -89.5 dBm)	LTE 1800 (GSMA Recommendations = -91 dBm)	UMTS 900 (GSMA Recommendations = -101 dBm)	UMTS 2100 (GSMA Recommendations = -103 dBm)
Samsung Galaxy A6 (S)	-93.8	-95.8	-106.5	-106.4
Samsung Galaxy J6 (S)	-93.8	-98.0	-106.5	-110.7
Samsung S9+ (S)	-93.0	-99.0	-108.6	-109
Samsung Galaxy S9 (S)	-93.0	-99.0	-106.8	-109.4
Huawei Honor 9 (S)	-92.9	-95.9	-108.2	-108.9
Samsung Galaxy J2 Pro (S)	-92.8	-96.3	-105.5	-108.6
Samsung Galaxy A8 (S)	-92.2	-96.1	-107.3	-107.4
LG V30 (S)	-92.2	-95.7	-107.2	-107.7
Huawei Honor 9 Lite (S)	-91.9	-91.4	-107.0	-104.1
Nokia 7 Plus (S)	-91.9	-95.0	-104.1	-105.2
Nokia 3 (S)	-91.9	-93.6	-105.3	-109.5
Nokia 2 (S)	-91.8	-93.7	-106.5	-107.4
Sony Xperia XA2 (S)	-91.7	-91.9	-105.2	-105
Huawei P20 (S)	-91.5	-96.3	-105.9	-108.7
HTC U11 (S)	-91.4	-98.4	-106.9	-108.6
Apple iphone X (S)	-91.4	-94.1	-101.3	-103.5
Sony Xperia XZ2 (S)	-91.4	-96.1	-106.7	-107.7
Huawei Mate 10 Pro (S)	-91.3	-95.8	-107.7	-109.2
Huawei P smart (S)	-91.3	-91.6	-104.4	-104.9
Apple iphone 8 (S)	-91.3	-97.0	-104.5	-107
Nokia 8110 4G (F)	-91.2	-94.8	-106.4	-108.1
Apple iphone 8+ (S)	-90.8	-94.3	-100.7	-104.8
Huawei P20 Pro (S)	-90.5	-96.3	-106.2	-108.9
Oneplus 5T (S)	-89.7	-92.9	-102.4	-105.2
Huawei P20 Lite (S)	-89.7	-93.1	-103.9	-106.8
Google Pixel 2 (S)	-89.3	-96.7	-104.6	-108.3
Oneplus 6 (S)	-89.3	-95.0	-104.4	-105.9
HTC U12+ (S)	-89.0	-96.1	-101.0	-106.3
Google Pixel XL 2 (S)	-88.9	-93.4	-103.8	-106.9

Mobile Handset	LTE 800 (GSMA Recommendations = *-89.5* dBm)	LTE 1800 (GSMA Recommendations = *-91* dBm)	UMTS 900 (GSMA Recommendations = *-101* dBm)	UMTS 2100 (GSMA Recommendations = *-103* dBm)
Xioami Redmi Note 5 Global (S)	-87.7	-96.7	-102.8	-107.9
Sony Xperia XA2 Ultra (S)	-87.7	-88.9	-107.8	-106.2
Xioami Mi Note 3 (S)	N/A	-98.3	-109.5	-111

2.3 MEASUREMENTS SUMMARY[29]

This summary presents the overall average of the TIS measurements in each band for HL and HR measurements scenarios. It also presents the difference between the highest and lowest measured sensitivity in each band.

TIS is a negative number which indicates the ability of a mobile handset to detect a weak power level signal. The more negative the TIS value the more sensitive the mobile handset - i.e. the more able to detect a weaker power level signal and maintain connection with a base station. It should be noted that, **-94 dBm** would be a better receiving performance compared to **-88 dBm.**

This means, for example, that a measurement of -94 dBm is better than -89.5 dBm (the GSMA Recommendations) for the LTE 800 MHz band (the most widely used band for data). Similarly a value of -86.5 dBm does not meet the GSMA Recommendations of -89.5 for LTE 800 MHz band.

The following points can be made concerning the TIS measurements obtained by ComReg, for the LTE 800, LTE 1800, UMTS 900 and UMTS 2100 bands:

- LTE 800 band (Band 20):
  - for the HR scenario, average TIS was -91.62 dBm and the difference between the highest and lowest TIS measurements was 7.72 dB;
  - for the HL scenario, average TIS was -91.17 dBm and the difference between the highest and lowest TIS measurements was 6.12 dB; and

- LTE 1800 band (Band 3):
  - for the HR scenario, average TIS was -95.57 dBm and the difference between the highest and lowest TIS measurements was 7.55 dB; and
  - for the HL scenario, average TIS was -95.22 dBm and the difference between the highest and lowest TIS measurements was 10.17 dB;

- UMTS 900 band (Band 8):
  - for the HR scenario, average TIS was -106.16 dB and the difference between the highest and lowest TRP measurements was 7.23 dB; and
  - for the HL scenario, average TIS was -105.49 dBm the difference between the highest and lowest TIS measurements was 8.81 dB;

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[29] ComReg Doc 18/84 - https://www.comreg.ie/publication/mobile-handset-testing-data-clarification/

- UMTS 2100 band (Band 1):

  o for the HR scenario, average TIS was -107.80 dBm and the difference between the highest and lowest TRP measurements was 6.47 dB; and

  o for the HL scenario, average TIS was -107.35 dBm the difference between the highest and lowest TIS measurements was 7.48 dB;

The overall average of the TIS measurements show that:

- The TIS performance of the tested mobile handsets varies slightly when held in the left hand and when held in right hand, as can be seen above there is small variation observed on average between HR scenario and HL scenario for all the bands.

- The overall average values shown above surpass the GSMA TIS Recommendations values set out in Table 4 below, across all the technologies and frequency bands.

Table 4: GSMA[30] Operator Acceptance Values for TIS

Technology (3G/4G)		Bands (MHz)	Acceptance Values for TIS (dBm)
			GSMA (Browsing)
UMTS	Band 1	2100	-103
	Band 8	900	-101
LTE	Band 3	1800	-91
	Band 20	800	-89.5

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

Annex: 1 **Mobile Handsets Tested**

Mobile Handset	Hand Type
Apple iPhone 8	PDA Grip
Apple iPhone 8+	Wide Grip
Apple iPhone X	PDA Grip
Google Pixel 2	PDA Grip
Google Pixel XL 2	Wide Grip
HTC U11	Wide Grip
HTC U12+	PDA Grip
Huawei P smart	Wide Grip
Huawei Honor 9	PDA Grip
Huawei Honor 9 Lite	PDA Grip
Huawei Mate 10 Pro	Wide Grip
Huawei P20	PDA Grip
Huawei P20 Lite	PDA Grip
Huawei P20 Pro	Wide Grip
LG V30	Wide Grip
Nokia 2	PDA Grip
Nokia 3	PDA Grip
Nokia 7 Plus	Wide Grip
Nokia 8110 4G	Mono Grip
Oneplus 5T	Wide Grip
Oneplus 6	Wide Grip
Samsung Galaxy A6	PDA Grip
Samsung Galaxy A8	Wide Grip
Samsung Galaxy J2 Pro	Wide Grip
Samsung Galaxy J6	PDA Grip
Samsung Galaxy S9	PDA Grip
Samsung S9+	Wide Grip
Sony Xperia XA2	PDA Grip
Sony Xperia XA2 Ultra	Wide Grip
Sony Xperia XZ2	PDA Grip
Xioami Mi Note 3	Wide Grip
Xioami Redmi Note 5 Global	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[31].

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[32] [33] 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.

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[31] Over-The-Air Performance Estimation of Wireless Device Antennas - SATHYAVEER PRASAD;2013

[32] CTIA Test plan for wireless device over the air performance.

[33] A CTIA approved antenna measurement system for over-the-air testing of wireless devices - B. Lawrence; ETS-LINDGREN, UK; 2004.

3GPP[34] [31]

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

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.

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[34] 3GPP Scope and Objectives – 3GPP; 2007.

A 2.9 Both procedures are based on the 3D pattern measurement method, proposed by COST 259[35] and COST 273[36], 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.

Measurement Techniques[37]

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[37]

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[37]

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.

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[35] COST Action 259 - Wireless Flexible Personalized Communications – COST; 1996
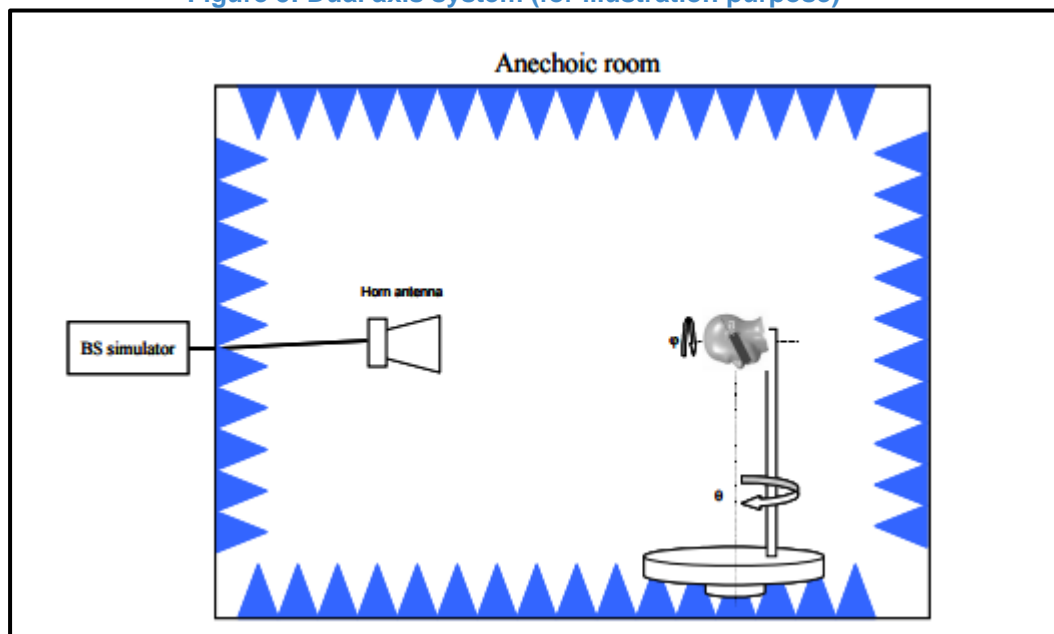[36] COST Action 273 - Towards Mobile Broadband Multimedia Networks - COST; 2005
[37] User Guide – StarLab - MVG; 2015

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.
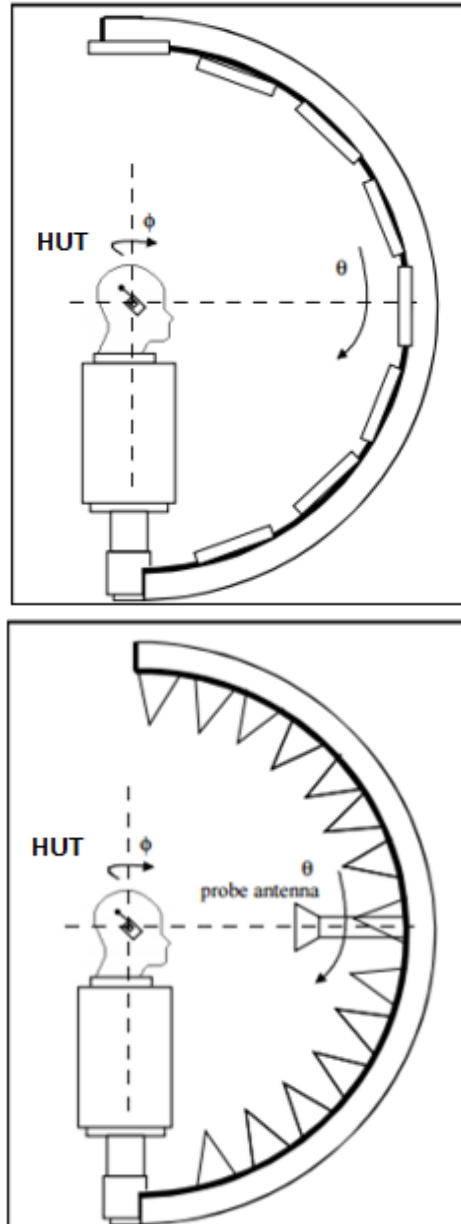
Figure 5: Dual axis system (for illustration purpose)

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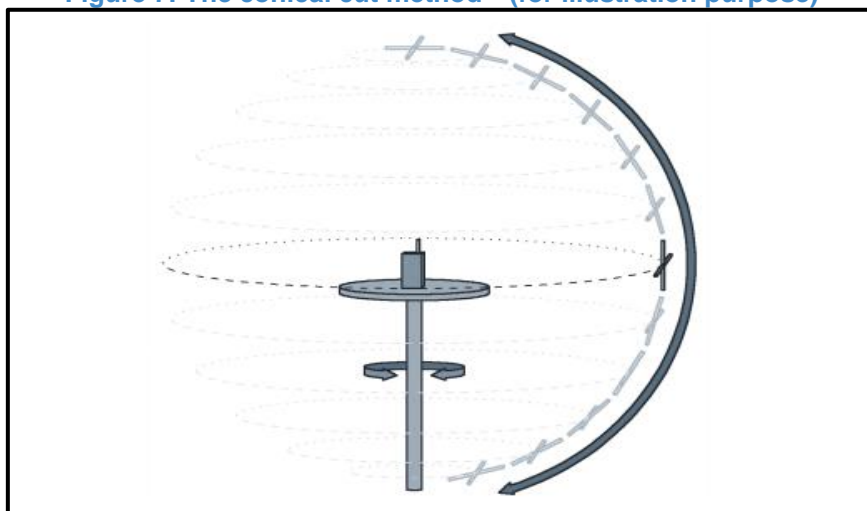
Figure 6: (a) Multi Probes (b) Single Probe (for illustration purpose)

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.
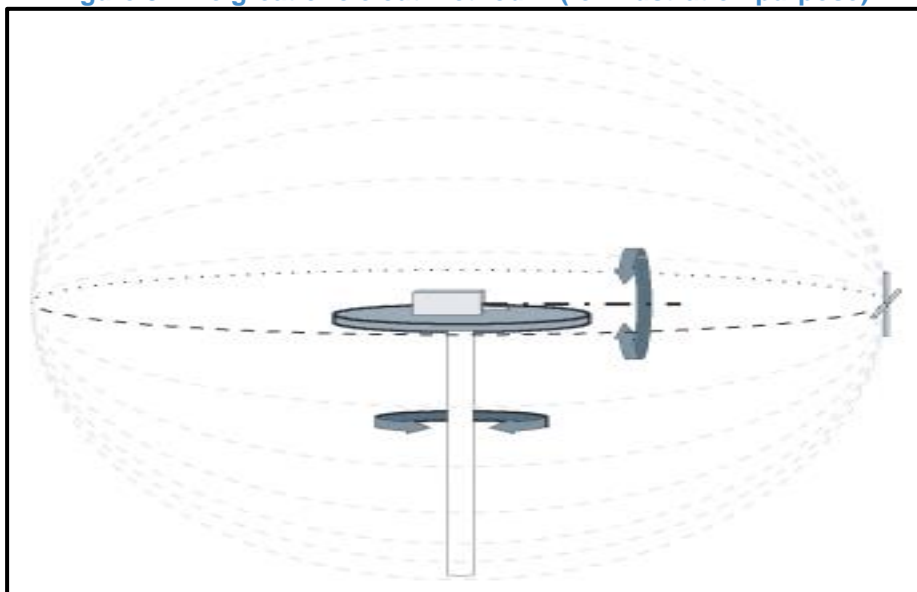
Figure 7: The conical cut method[38] (for illustration purpose)

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.

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

Figure 8: The great circle cut method [38] (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 ($\emptyset$). 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[39]

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[37]

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

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

Table 7: OTA performance measurement specifications[37]

ACCORDING TO CTIA SPECIFICATIONS	
TIS accuracy FS	<±2.0 dB
TIS accuracy talk position	<±2.1 dB
TIS repeatability	±0.5 dB

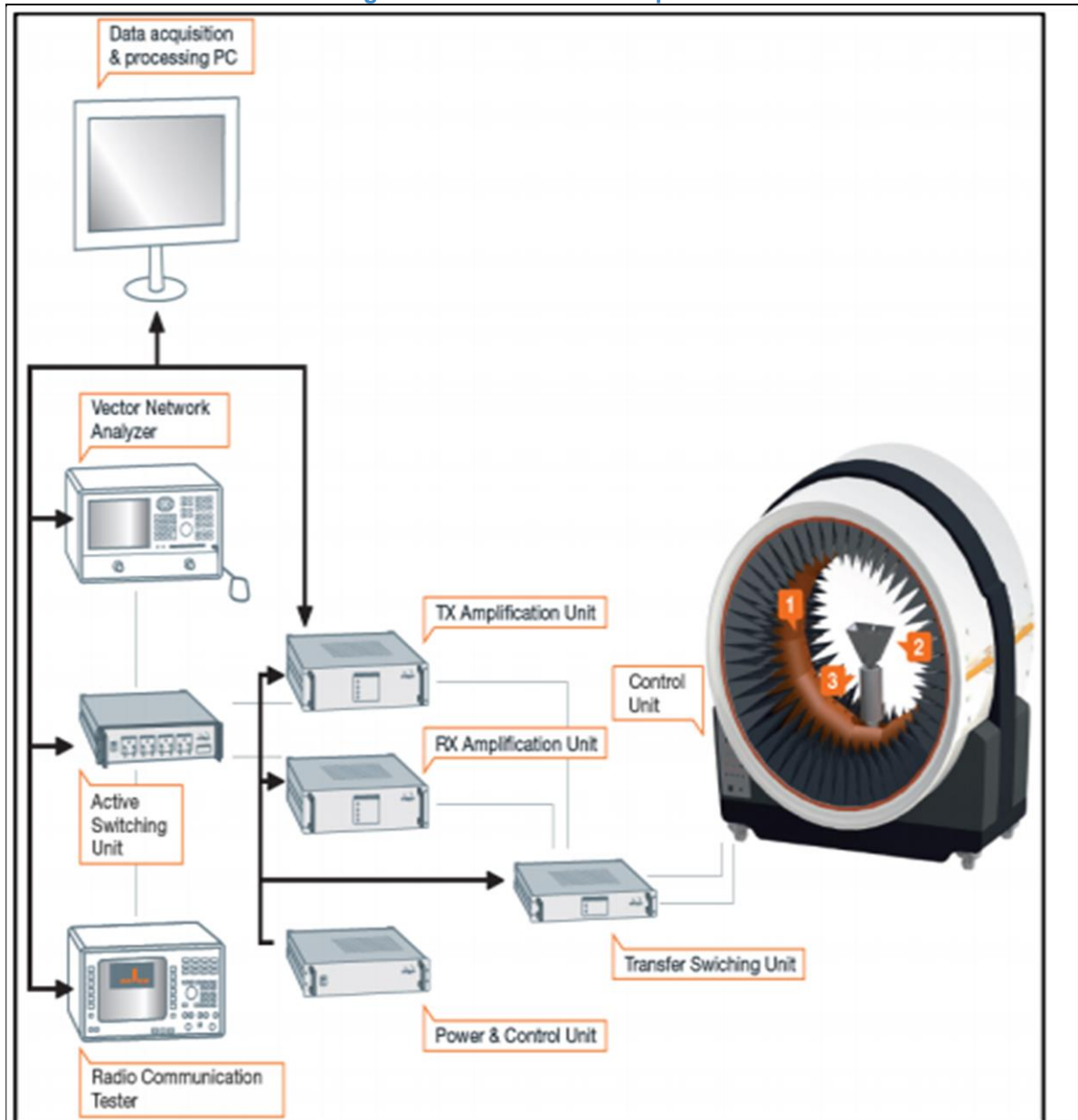**Table 7: OTA performance measurement specifications[37]**

Annex: 3 **Test Setup and Equipment**

A 3.1 The mobile handsets measured for TIS 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 8: Measurement Equipment

Equipment /Software used	Manufacturer	Model No/Version
Active Switching Unit	MVG	11017004-2248
Anechoic Chamber	Rainford EMC systems	-
CTIA 'Monoblock' phantom left hand	IndexSAR	IXB-050L
CTIA 'Monoblock' phantom right hand	IndexSAR	IXB-050R
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	1.9.3
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	2.0.0

Figure 9: StarLab Test Setup[37]

List of Abbreviations

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

Abbreviation	Explanation
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