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Evaluation of a Near Field Scanner For Active Measurements of Mobile Phones

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Abstract

The radio performance measurements of terminal antennas require expensive investments and they are often performed in anechoic chambers. Now a days measurement techniques using wheeler cap, reverberation chamber, etc have become popular. But these methods are used for measurements either during the design or production or in-network testing phases but not for all. Hence EMSCAN, a Canadian company, has come up with a device called Lab express near field scanner to counter this problem.

In this thesis an attempt is made to study the EMSCAN near field scanner by looking into architecture and design aspects of this device. Moreover, the capability of the device to measure the radio performance of the terminal antennas in terms of radiation pattern and total radiated power (TRP) is also studied and anlaysed.The analysis of the TRP and radiation pattern measurements of the terminal antennas is done by comparing the EMSCAN measurement results of 10 commercially available mobile phones with that of CTIA approved Satimo SG24 chamber.

The TRP and radiation pattern measurements are done for GSM 900 MHz and DCS 1800 MHZ low bands i.e.975 and 512 respectively. Furthermore, the dependency of the measured TRP on the positioning of the mobile phone on EMSCAN is tested by measuring the TRP and the radiated power of a single mobile phone.

The measurement results after comparison suggest that there is a correlation of around 79% at 1800 MHz and 49% at GSM 900 MHz among the two methods. This leads to the conclusion that EMSCAN scanner cannot replace the anechoic chambers for estimating the radio performance of terminal antennas. The results obtained by measuring the mobile phone in 8 different positions suggest that there is no significant difference in the TRP measured. There is a difference of 1.25dB was observed between the maximum and minimum TRP measured in two different positions on the near field scanner.

The results obtained by both the methods are verified by computing the TRP and radiation pattern in Matlab.The Matlab results agrees more with the EMSCAN results than Satimo SG 24 chamber results.

ACKNOWLEDGEMENTS

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Abbreviations

3D	Three Dimensional
3G	Third Generations
3GPP	Third Generation Partnership Project
AMTU	Active Measurement Test Unit
AR	Axial Ratio
BS	Base Station
CDF	Cumulative Distribution Function
CTIA	Cellular Telecommunications and Internet Association
DCS	Digital Cellular System
EIRP	Effective Isotropic Radiated Power
EMCO	Electro Mechanics Company
ERP	Effective Radiated Power
DUT	Device Under Test
GSM	Global System for Mobile Communications
HP	Hewlett Packard
IEEE	Institution of Electrical and Electronics Engineers
PAC	Probe Array Controller
RF	Radio Frequency
R&S	Rohde and Schwarz
RX	Receive
SG	Star Gate

TRP   Total Radiated Power

TX   Transmit

UE   User Equipment

UMTS   Universal Mobile Telecommunications System

1 Introduction

1.1 Background

Mobile communication demands highly reliable and efficient mobile phones. The overall performance of the mobile phone depends on its antenna. The performance of 3G networks is very sensitive to the mobile phones performance in both the up- and the downlinks. Basically, mobile phone with poor performance may reduce the coverage and/or the capacity of the whole network, [1], [2]. Furthermore, the antenna is an essential component of the mobile phone and largely determines the overt the- air performance of the handheld device. Therefore simple yet reliable test methods are required to ensure antenna performance. Currently, cellular phones (all except UMTS phones) destined for the market which is stringent performance tests specified by the mobile phone-based Cellular Telecommunications and Internet Association (CTIA) [3]. An international standard is being developed within the 3GPP Standardization body, [4] where a test procedure for mobile phone including the antenna has been presented. This standard procedure is based on work performed by members of European COST Action 273 SWG2.2.

Measurements are very important to gain better understanding of the actual radio performance of the mobile phones. Due to rapid growth of mobile communication industry in recent years there is a need of fast and accurate radio performance measurements. Currently methods using wheeler cap, reverberation chambers, etc are used to estimate the radio performance of terminal antennas. But due to time and accuracy issues none of these methods received global consensus to be accepted as a single method for measuring the radio performance during in-network, design and production phases of the mobile phone. Hence, a near field scanner is developed by EMSCAN, a Canadian company, to serve this purpose.

The main task of this thesis is to study the EMSCAN [5] near field scanner by looking into architecture and design aspects of this device. Moreover, the capability of this device to measure the radio performance of the terminal antennas in terms of radiation pattern and total radiated power (TRP) is also studied and anlaysed.The analysis of the TRP and radiation pattern measurements of the terminal antennas is done by comparing the EMSCAN measurement results of 10 commercially available mobile phones with that of CTIA approved Satimo SG24 chamber. [6]. Furthermore the dependency of the measured TRP on the positioning of the mobile phone on near field scanner is tested by measuring the TRP and the radiated power of a single mobile phone . Totally 10 GSM mobile phones operating at 900 and 1800 MHz were measured and the results are subsequently analyzed.

1.2   Objective

The objective of the thesis is

- To study the near field scanner measurement system from EMSCAN
- To evaluate it's capability to measure efficiently the radio performance of the GSM mobile phones in terms of TRP and Radiation Pattern. This is done by comparing the EMSCAN results with the results from CTIA (Cellular Telecommunications and Internet Association) [2] approved SatimoSG24 Chamber.

1.3   Outline of the report

Chapter 1 gives a short introduction to the thesis. A problem statement is mentioned and an outline of report is presented.

Chapter 2 discusses the theoretical background for antenna theory. Some parameters related to antennas like radiation pattern, gain, directivity, EIRP etc are explained.

Chapter 3 contains a descriptive study of architecture of the near field EMSCAN. Advantages and disadvantages of this system are presented in this chapter. Also some measurements were taken on EMSCAN and are compared with the measurements by SatimoSG24.

Chapter 4 deals with Satimo SG 24 system. An in depth analysis of functionality and different measurements taken by this system are mentioned.

Chapter 5 measurements and results EMSCAN, SatimoSG24 and comparison both of the systems EMSCAN and SatimoSG24 also verification the results in Matlab.

Chapter 6 preliminary conclusion.It summarizes the comparison done in earlier sections about the two near field measurement systems.

At the end of the thesis report some suggestions are made to extend this work and these suggestions are grouped under title "future work". The thesis ends with the references used during the thesis work.

2 Theory

Antenna is defined according to IEEE Standard Definitions of Terms for Antennas, IEEE Std 145-1983." That part of a transmitting or receiving system which is designed to radiate or receive electromagnetic waves"

There are many parameters for antenna which determined it is behaviour and performance, some of these important antenna parameters are discussed below: [7]

2.1 Radiation pattern

One of the basic properties of an antenna performance is its radiation pattern, which is defined as [8] "a mathematical function or graphical representation of the radiation properties of the antenna as a function of space coordinates".

Evaluation of a radiation pattern is often consists of various parts of radiation lobes, such as Major lobe which is representing   the direction of maximum radiation intensity, minors lobes is representing undesired radiation and the back lobes is representing   the opposite direction of the major lobe s. One of the most important parameter for efficiency estimate is the ratio of power density in the minor lobe to that of the major lobe as shown in figure1. [8]
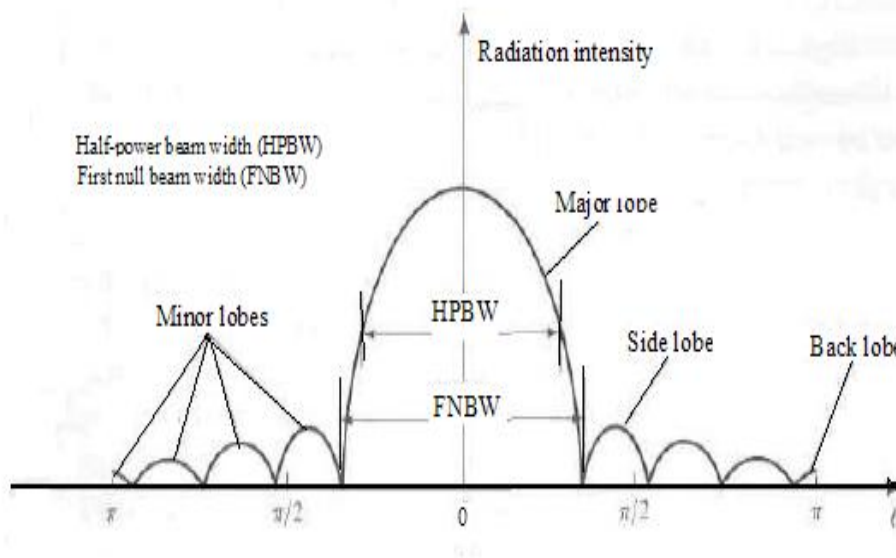
Figure 1 radiation lobes and beam widths of an antenna. [8]

Another common parameter which is often evaluated is the Half-power beam width (HPBW). According to [7]

The half-power beam width is "In a radiation pattern cut containing the direction of the maximum of a lobe, the angle between the two directions in which the radiation intensity is one-half the maximum value" normally the HPBW is referred to 3 dB beam width.

Figure.2 shows the two standard types of pattern cuts over the radiation sphere [9]. These cuts can be represented as azimuth (Φ) and elevation (θ). The azimuth (Φ) is an angle that is used to represent the horizontal plane of an antenna radiation pattern, and it ranges from 0 to 2π degrees. The elevation (θ) is an angle that used to represent the vertical plane of radiation pattern and it ranges from 0 to π degrees.
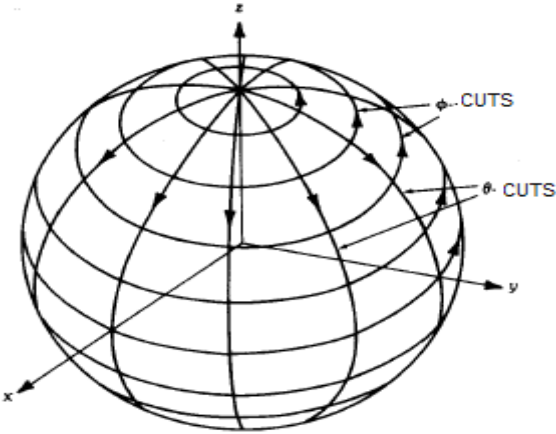
Figure 2 an illustration of θ and Φ- cuts over the radiation sphere.[9]

2.2 Field Regions

The Field radiation is defined according to [8] "The space surrounding an antenna is usually subdivided into three regions: the reactive near-field, the radiating near-field (Fresnell) and the far-field (Fraunhofer) regions. These regions are so designed to identify the field structure in each, but no abrupt changes in the field configurations are noted" as shown in figure 3 (a). Figure 3 (b) shows the change of an antenna amplitude pattern form from reactive near field toward the far field.[8]

(a) Field region of antenna   (b) changes of antenna amplitude pattern[10,8]
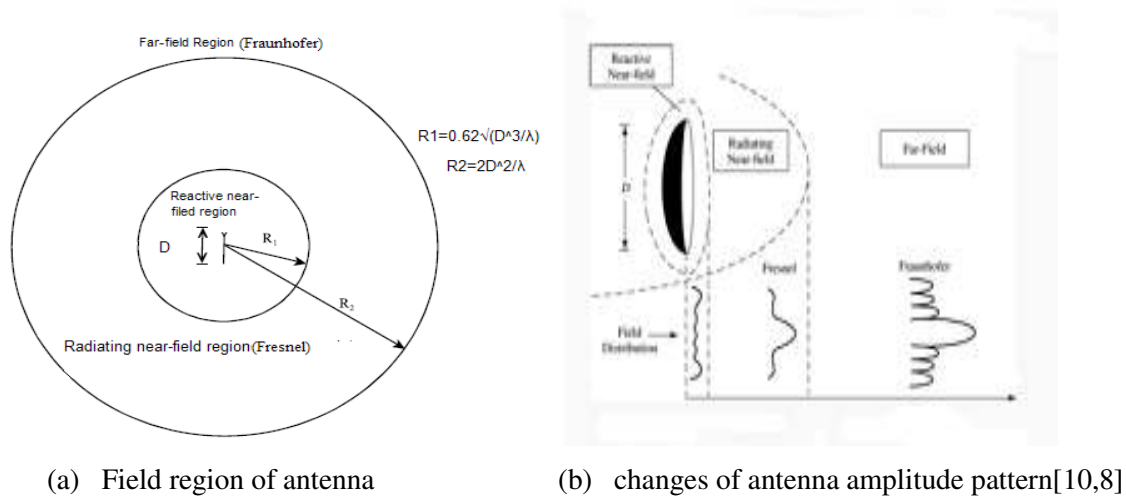
Figure 3 field regions of antenna and antenna amplitude pattern,[8,10]

2.3   Reactive near-field region

"That portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates" This is defined according to [8].

$$R_1 = 0.62\sqrt{\frac{D^3}{\lambda}}$$

(2.1)

Where D is the maximum dimension of the antennas,

λ is wavelength of the antenna

R_1 is the reactive near-field region

2.4   Radiating near-field (Fresnel) region

"That region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna". This is defined according to [8].

$$0.62\sqrt{\frac{D^3}{\lambda}} \leq R2 \leq \frac{2D^2}{\lambda}$$

(2.2)

Where D is the maximum dimension of the antennas,

λ is wavelength of the antenna

R2 is the Radiating near-field region

2.5   *Far-field (Fraunhofer) region*

"That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna". This is defined according to [8].

$$R \leq \frac{2D^2}{\lambda}$$
(2.3)

Where *D* is the maximum dimension of the antennas,

λ is wavelength of the antenna

R is the far-field region

2.6   **Radiation Power Density**

One way to send information from one point to another is to use electromagnetic waves. Electromagnetic waves can carry information in free space or through a wave guide structure. The power which is related to its electromagnetic fields is defined by the Instantaneous Poynting vector [8].

Since the Poynting vector is power density and it can be written as follows [8]

$$\vec{W} = \vec{E} \times \vec{H}$$
(2.4)

Where,

W is the Instantaneous Poynting vector

E is the instantaneous electric field density

H is the instantaneous magnetic field density

The Radiation power density is as follows [8]

$$\vec{W} rad = \frac{1}{2} \mathrm{Re}[\vec{E} \times \vec{H}]$$
(2.5)

Where,

Wrad is the radiation power density

2.7   Radiation Intensity

Radiation Intensity in a given direction is defined as [8] "the power radiated from an antenna per unit solid angle" Mathematically form it can be written as follows [8]

$$U = r^2 \text{ x } Wrad \tag{2.6}$$

Where,

U is the radiation intensity

$Wrad$ is the radiation density

2.8   Directivity

The directivity of an antenna describes how the actual antenna directs the radiated intensity. Directivity of an antenna defined as [8] "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π."

Mathematically form as follows [8]

$$D = D = \frac{U}{Uo} = \frac{4\pi U}{Prad} \tag{2.7}$$

Where,

U is the radiation intensity

Uo is the radiation intensity of isotropic source

$Prad$ is the Total radiated power

The maximum directivity can be written in mathematically form as follows [8]

$$D = Do = \frac{Umax}{Uo} = \frac{4\pi Umax}{Prad} \tag{2.8}$$

Where,

Do is the maximum directivity

U_{max} is the maximum radiation intensity

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The directivity of an antenna is related to its gain [8].

$$G(\theta,\phi) = e_{cd}\, D(\theta,\phi) \tag{2.9}$$

Where e_{cd} is the antenna radiation efficiency (dimensionless)

Theoretically, if we consider that the gain of an antenna equal of its directivity, the e_{cd} antenna radiation efficiency is equal to 1, the antenna is perfect. Practically the value of antenna gain is less than the value of its directivity.

2.9   Gain

The gain of an antenna is defined according to [8] "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropic ally. The radiation intensity corresponding to the isotropic ally radiated power is equal to the power accepted (input) by the antenna divided by 4π ".

$$G(\theta,\phi) = 4\pi \frac{U(\Phi,\phi)}{P_{in}} \tag{2.10}$$

Where:

Pin is the power accepted by the antenna.

2.10   Effective Isotropic Radiated Power (EIRP)

One of the most important fundamental antenna parameter is   Effective Isotropic Radiated Power (EIRP). IEEE Standard Definitions of Terms for Antennas defines ", the gain of a transmitting antenna in a given direction multiplied by the net power accepted by the antenna from the connected transmitter". [7]

$$EIRP = P_{TX,}\ \text{x}\ G_{TX,} \tag{2.11}$$

Effective radiated power (ERP), "the relative gain in a given direction of a transmitting antenna with respect to the maximum directivity of a half-wave dipole multiplied by the net power accepted by the antenna from the connected transmitter". [7]

2.11 Polarization

 The polarization of a radiated wave according to [8]" that property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space, and the sense in which it is traced, as observed along the direction of propagation.". There are three types of polarization: linear polarization, circular polarization and elliptical polarization. Generally, the electric field vector of the electromagnetic wave is used to exhibit the polarization. The common case is the elliptical polarization that is represented by a field vector constantly changing the phase and magnitude. The circular polarization occurs when the magnitude of the field vector is fixed while the phase is constantly changing. The linear polarization occurs when the phase of the field vector is fixed.

Since in reality the polarization of the receiving antenna is never the same as the one of the transmitting antenna, a polarization mismatch appears, and it must be taken into account. There are two main factors also should be taken into consideration the polarization loss factor and axial ratio when performing antenna measurements.

2.12 Total Radiation Power (TRP)

The total radiated power is obtained by "integrating the Poynting Vector's real part over a closed surface completely enclosing the antenna". Mathematically the Poynting vector can be represented as follows [8].

$$P_{rad=}\oint_{s}\vec{W}_{rad.}\,d\vec{s} \tag{2.12}$$

Where:

$\vec{s}$ is the surface area

$\vec{W}_{rad}$ is the radiation intensity

The complex pointing vector is:

$$\vec{W}rad = \frac{1}{2}\text{Re}[\vec{E}\,\text{x}\,\overrightarrow{H*}\,] \tag{2.13}$$

$\vec{E}$ is the electric field vector

$\vec{H}=$ is the magnetic field vector

Since the magnetic field $\vec{H}$ can be represented as follows

$$\vec{H}=\frac{\vec{E}}{\eta o} \tag{2.14}$$

Where:

$\eta_{o\,=}\sqrt{\frac{\mu o}{\epsilon o}}\cong 120\pi\,\Omega$ is intrinsic impedance of free of the medium,

Using (2.13) into (2.12) thus the radiation intensity vector $\overrightarrow{W}rad$ can be written as follows:

$$\overrightarrow{W}rad = \frac{1}{2\eta o}|\vec{E}|^2 \tag{2.15}$$

The radiated power to the far field zone is given as follows [8]

$$P_{rad=}\oint_s \overrightarrow{W}_{rad}.d\vec{s} \quad = \quad \frac{1}{2\eta o} \int_\Omega |\vec{E}|^2 d\Omega \tag{2.16}$$

Where:

P*rad is* the total radiated power.

$d\Omega$ is the solid angle

2.13   Alternative definition of the Total Radiated Power (TRP)

The integration of total power that is radiated from the antenna under test (AUT) in all directions over the radiation sphere gives the Total radiated power [11]. The losses and the mismatch of an antenna should also be taken into consideration while computing the TRP. In general, anechoic chambers facility used to measure TRP.

The Total Radiated Power is defined as [11]

$$P_{TRP} = \frac{1}{4\pi} \oint (P_{tx}G_\theta(\Omega,,f) + P_{tx}G_\Phi(\Omega,,f)) d\Omega \tag{2.17}$$

Where:

Ω is the solid angle describe the direction

P_{tx} is the transmit power level of the (AUT)

f is antenna measured frequency.

$G_\theta(\Omega,,f)$ is transmitted antenna gain.

3 Near field system

3.1   EMSCAN system

3.1.1   System background

Currently, the near field scanners are capable of measuring the antenna properties like radiation pattern, gain, etc. An example of such near field scanner from EMSCAN is shown in figure 4. These scanners gather amplitude and phase data accurately and then compute the equivalent far field values using known and available transformations [5].

Figure 4 EMSCAN

An accurate estimate of the far-field is obtained if and only if the measurement distance between the probe and antenna under test is greater than or equal to one wavelength. By mechanical scanner the near field testing is performed with a single/multiple compensated probes which are capable of detecting the theta and phi polarizations. These measurements are not very quick and take some hours to complete full scan of the entire radiating surface. [5].In near filed measurements the factors like conducting planes, dielectric medium, array elements, etc can have lot of effect on the near field distribution of the source and subsequently on its far field properties also.

In the multi-axis Near-field measurement, the ground plan effects should be taken into account the measurement is done by keeping a distance of greater than one wavelength between the probe and the test antenna. [5] This distance is maintained in order to reduce the measurement sensitivity and also to limit the dynamic range. Because of high measurement time and physical size such systems are not suitable for high speed production test environment. Moreover such systems cannot be used in development labs where feedback and the optimum use of lab space is required.

3.1.2 System Description

EMSCAN is a near field scanner that consists of array of antenna probe as shown in figure 5.This system is powered with a 6VDC power supply, the dimensions of scanner (array of probes) are about 22cm x 30cm x7cm and the user computer is connected via the USB cable. In order to measure performance of the mobile phone, it should be placed active mode (call) because the system has no built-in base station simulation (BSS. [12]
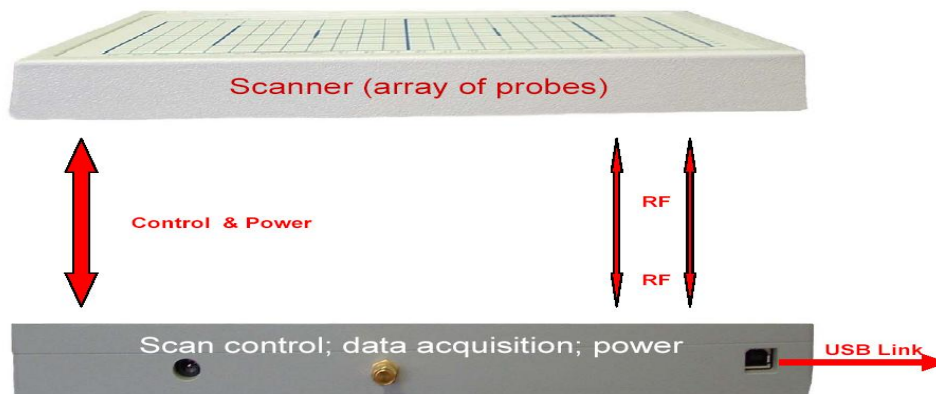
Figure 5 Construction of EMSCAN (Courtesy EMSCAN)

Features of the system:

- The system consists of a switched array of antenna elements that are embedded in a dielectric forming an array surface for detecting the electric- field (E), and magnetic-field (H) components from the device under test (DUT).[5]

- The DUT is placed on the scan surface .The scan surface is always parallel to the array surface and the separation distance of less than one half wavelength of the measured frequency is maintained.

- It also includes a processing engine which is connected to the switched antenna array. Figure 6 shows the processing of the measured near field data to obtain the far field estimate of the radio performance of the DUT. [5]The processing engine improves and corrects the individual probe level from the effects of the mutual coupling and the dynamic coupling which is generated from the individual probe elements and also the device under test. Because of this, the far-field transformation will also effected due to the limited size of scanner.

The processing engine consists of [5]

1. a controller and sampler channels,
2. a path correction channel , to adjust the path losses and delays,
3. Interpolation for a data translator,
4. amplitude and phase detector

5. Near field corrector, used to correct the probe level and reduce the antenna elements form the reflections and the dynamic coupling.

6. Near-field to far-field Transformation channel for converting the near field (H) data to far field patterns.
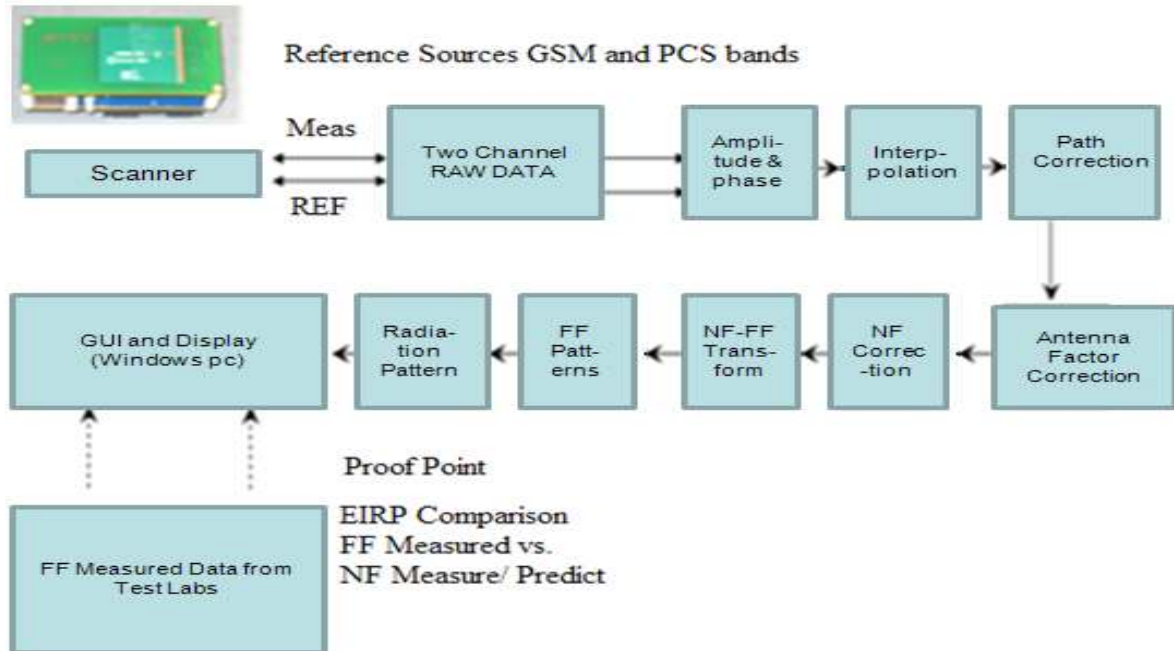
Figure 6 Processing engine.[5]

3.1.3   System Architectures

The Lab express scanner is made up of 384 half loop antennas arranged in a two dimensional manner. These antennas can act as of transmitters or receivers. The arrangement of these antennas is shown in figure 7(a).The array consists of 24 elements along x-axis and 16 along y-axis with each element (loop antenna) of dimensions 2mm length and 10mm depth. The inter element spacing is around 10mm.These dimensions of loop antenna area optimized to discriminate H and E-field intensities. The accuracy can be improved by using more antennas but these results in higher mutual coupling effects between antennas and feed structures [5].

The distance from the array surface to the scan plan is about 2cm with a range of about $1/88^{th}$ to $1/1.8^{th}$ of the wavelength and the distance (d) between the two parallel element as shown in Figure 7 (b) is about $1/176^{th}$ to $1/3.6^{th}$ of wavelength. The sensitivity of the Lab Express can be improved if the space between the arrays surfaces to the scan plan is reduced. In such a case the system will be in reactive near field and generally D/d is about 2.0 for the implementation of Lab Express.
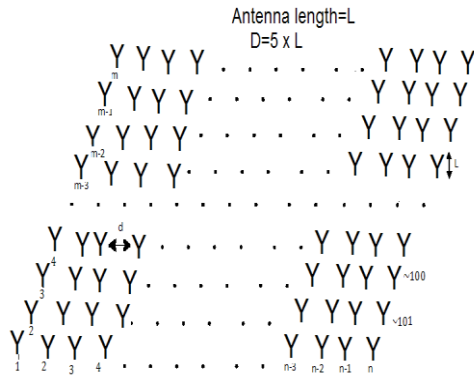
Fig (a)
Figure 7(a) 24 element array [5]
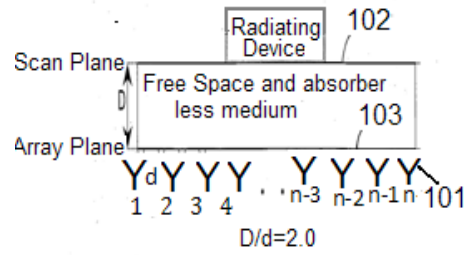
Fig (b)
(b) Placement of scan[5]

3.1.4 System Attributes:

- High speed measurement system.
- Characterize EIRP, Radiation power; near and far field radiation in less than 6 sec. include time to place the Mobil up on call.
- High repeatability ,the result varied by about +/- 3dB in case if the mobile was position in the same place
- Bandwidth (300MHz to 2.7 GHz) [12]
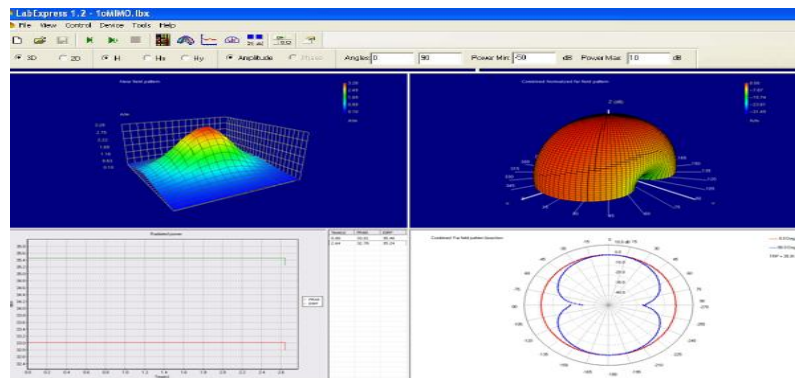
Figure 8 illustration of measurements results in EMSCAN

3.1.5 Setting up a scan

In order to estimate far field radiation patterns and radiated power of the antennas this is required techniques building upon the Lab Express. The system can simulate different structure models to estimate their near field equivalents.

The DUT should be placed as close to the center as is possible. The DUT should be switched on and set to transmit in a constant power mode i.e. within the sensitivity range of the EMSCAN. The EMSCAN is sensitive and depended on DUT being used; generally, the dynamic range for source power is between +30 dBm and 0 dBm.

Scan can be run when the DUT is placed on the scanner in a transmitting mode listed below. The base station simulator (BSS) is set to transmit in a constant frequency mode. The BSS is set to have modulation such as Amplitude Modulation or Phase Modulation but should not have frequency modulation unless the peak frequency deviation is less than ± 1.4 MHz.

The basic procedures required to perform a scan of a device under test (DUT):

1. Connect the Transmitting monopole antenna with base station simulator (R&D CMU200).
2. Fix the monopole antenna in a free space such that there is no effect from the user.
3. Set the frequency of the Base station simulator (R&D CMU200) accorded to the frequency range of mobile phone.
4. Connect the USB cable into the USB part on the EMSCAN and USB port on the user computer.
5. Set the phone up on a call and positioned the phone on face up on the EMSCAN.
6. Repeat the same procedure with positioned the phone on face down. As shown in figure 9.
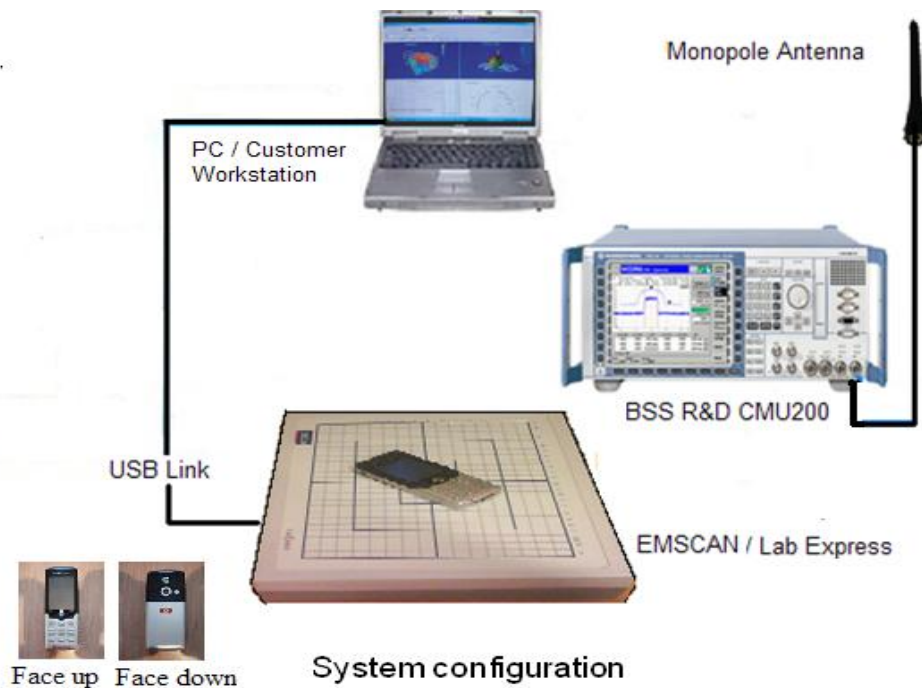
Figure 9 EMSCAN measurement system[12]

3.2   Satimo SG24 anechoic chamber

3.2.1 Introduction

This measurement system is a real time spherical near field antenna testing system. It consists of an anechoic chamber with an array of antenna probes encircling a rotation table, as shown in figure 10. This system works on capability of detecting the signal from each probe by perturbing its electromagnetic wave properties. According to [13,14] the disturbing of the probes results in generation of a frequency modulated component in the output signal and this component is directly proportional to the amplitude and phase of the field incident at the probe. The measurements are done by sequentially modulating each probe. Once the near field measurement data is obtained, this is transformed to far field radiation pattern using spherical wave expansion numerical techniques [13, 14].
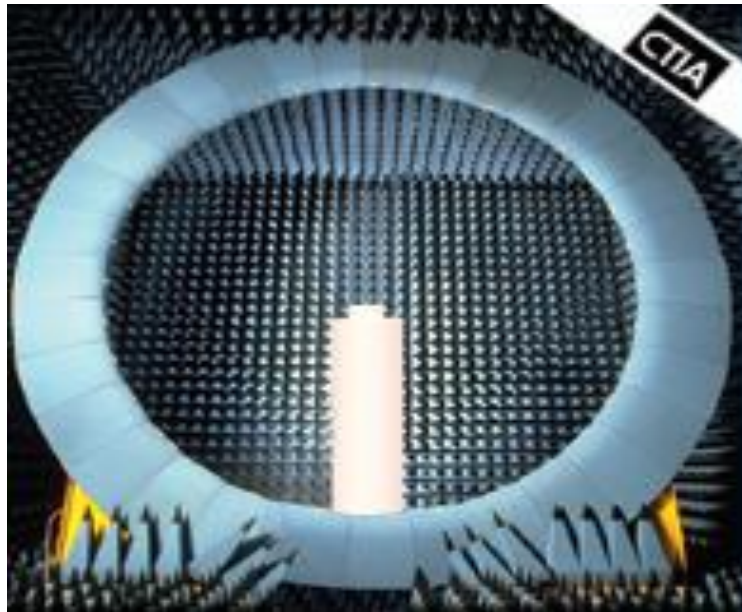
Figure 10 The Satimo SG24 23 probes. [6]

3.2.2 Description of measurements Set-up

The satimo star gate 24 it is made up of a probe array is a circular arch with 23 dual-polarized antenna probes encircling a rotation table, on which the AUT is mounted for measuring The dimensions of the anechoic room are 4 m x 4 m x 4 m, and the distance between the rotating phone and the probe antenna is around 2.4 m. [6], The typical diagram of Star gate 24 measurements as shown in figure 11.
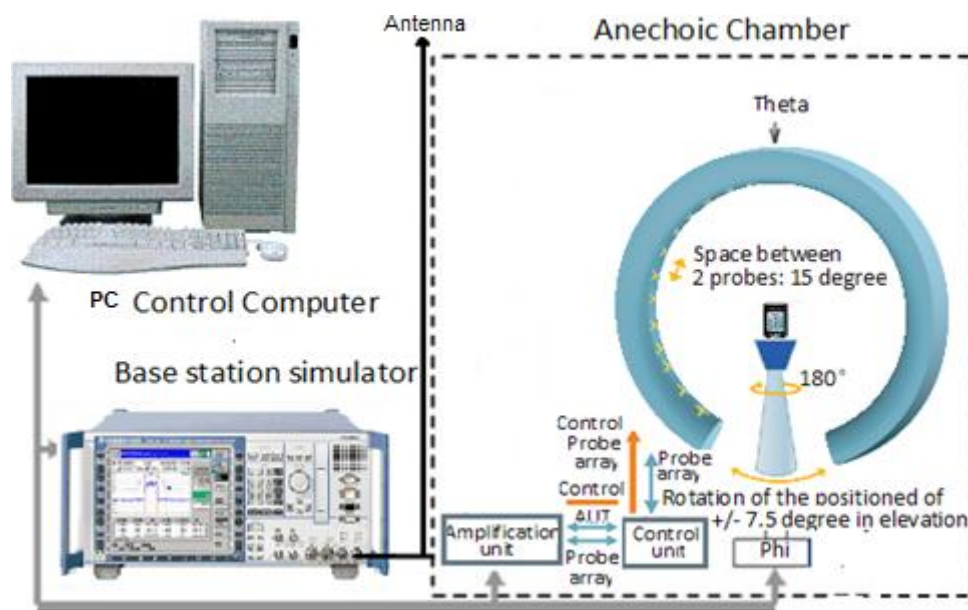
Figure 11 Block diagram of anechoic chamber Satimo measurement system [6] for active testing.

The measurement control and data acquisition processes are done by a standard PC control computer running the software called SatEnv [15]. This software is used for the post-processing and the visualization of the transmitted measurement data. The software SatEnv allows the user to have access to a wide range of diagnostics and post processing features automatically using macro commands.

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3.2.3   Measurements process

Before the measurements, the calibration must be done. This is done by connecting a gain standard reference antenna and cable to the calibrated output of a power source and the vector network analyzer (VNA).By subtracting the losses due to cables from measurement data and then calculating the difference between the EIRP measured and EIRP expected(gain multiplied by the input power)   gives the calibrated path loss[16].

The measurements are done using a base station simulator (BSS), which is used to set up a call, base station simulator, which control phone call. The measurement starts by the base station simulator establishing a call with the phone and then The SatEnv software starts recording the measurements for up and down link in each polarization. The phone measurement is done by rotating it in azimuth and elevation for every 15 degrees increments, i.e. for each cut 528 measurements are recorded in each transmit measurements i.e. the product of 11 theta cuts, 24 phi cuts, 2 polarizations[17].These measurements are recorded in the SatEnv software. The measurements data is used to get the Total radiated power (TRP) and the 3D radiation pattern

4 Measurements and Results

4.1 DUT measurements

The ten commercially available mobile phones were tested at 900 MHz and 1800 MHz bands. The tested DUT's were bar type and flip type either with an external or internal antennas. The detailed description of the mobile phones measured is given in table 1.

DUT	Antenna type	Frequency of operation	Phone type	Extra Features
DUT 1	Internal Antenna	GSM900,1800,1900MHz	Bar	Video,MP3 Bluetooth, IR EDGE,USB& Camera
DUT 2	External Antenna	GSM900,1800,1900MHz	Flip	Camera,IR
DUT 3	Internal Antenna	GSM900,1800,1900MHz	Flip	Bluetooth,MP3 EDGE, Camera
DUT 4	Internal Antenna	GSM900,1800,1900MHz	Flip	Bluetooth,MP3, IR,Camera
DUT 5	Internal Antenna	GSM900,1800,1900MHz	Bar	Digital Compass, Mp3 IR EDGE & Camera
DUT 6	Internal Antenna	GSM 900,1800MHz	Bar	IR
DUT 7	Internal Antenna	GSM900,1800,1900MHz	Bar	Bluetooth, Camera, IR
DUT 8	Internal Antenna	GSM900,1800MHz	Bar	Camera, Mp3,IR
DUT 9	Internal Antenna	GSM900,1800MHz	Bar	Camera, IR
DUT 10	Internal Antenna	UMTS, GSM900,1800,1900MHz	Bar	HSCSD, Video, MP3 Bluetooth, Camera

Table 1 Mobile phones measured

4.2 EMSCAN Measurement Results

P_{rad} for each mobile was measured on the EMSCAN near field scanner. The setting of measurements were at GSM 1800   Channel 512   Tx 1710, 2   Rx 1805, 2

The results of P_{rad} measurements of DUT's for both face up and the face down are presented in table 2.

DUT	Antenna type	Prad $_{dBm}$ face upGSM1800	Prad $_{dBm}$ face down GSM1800
DUT 1	Internal Antenna	24.98	20.78
DUT 2	External Antenna	26.71	25.25
DUT 3	Internal Antenna	25.80	25.58
DUT 4	Internal Antenna	24.78	25.72
DUT 5	Internal Antenna	28.32	23.88
DUT 6	Internal Antenna	15.38	12.02
DUT 7	Internal Antenna	26.41	19.32
DUT 8	Internal Antenna	25.87	22.89
DUT 9	Internal Antenna	28.32	22.93
DUT 10	Internal Antenna	23.65	23.81

Table 2 Measured DUTs in EMSCAN

The radiated power, P_{rad} in dBm for both face up and the face down for each phone was measured and the results are shown in Figure 12. It can be seen that' there is a significant variation in the P_{rad} results for DUT 1,5,6,7,8 and 9 compare to other ones. This may be due to the different configuration of the antennas of the mobile phones .Another reason can be that these antennas are more directive at higher frequencies than at lower. Before making any conclusions about these results a more in depth study of the antenna of each mobile should be made.
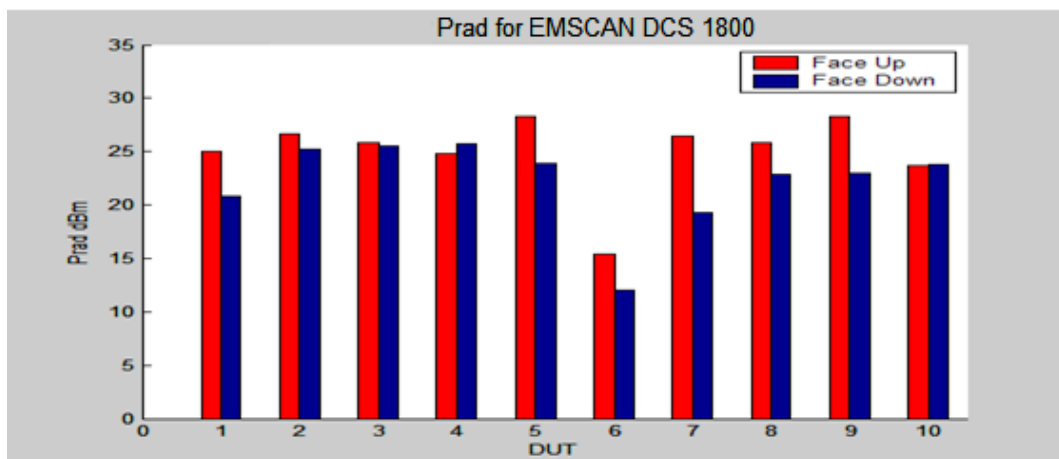

Figure 12 bar diagram of results for face up and face down

P*rad* for each mobile was measured on the EMSCAN near field scanner. The setting of measurements were at GSM 900   Channel 975 Tx 880.2 MHz   Rx 915 MHz

The results of P*rad* measurements of DUT's for both face up and the face down presented in table 3

DUT	Antenna type	Prad $_{dBm}$ face up GSM900	Prad $_{dBm}$ face down GSM900
DUT 1	Internal Antenna	31.68	31.63
DUT 2	External Antenna	26.24	25.86
DUT 3	Internal Antenna	29.92	30.08
DUT 4	Internal Antenna	30.79	29.80
DUT 5	Internal Antenna	30.51	30.46
DUT 6	Internal Antenna	26.52	24.95
DUT 7	Internal Antenna	29.12	28.79
DUT 8	Internal Antenna	30.35	29.09
DUT 9	Internal Antenna	30.84	29.17
DUT 10	Internal Antenna	33.01	32.78

Table 3 Measured different DUT in EMSCAN

The Prad measured at GSM 900 for both face up and face down of 10 phones is shown in Figure 13. From the figure it can be said that there is no significant change is seen in face up and face down power measured for 10 mobile phones.
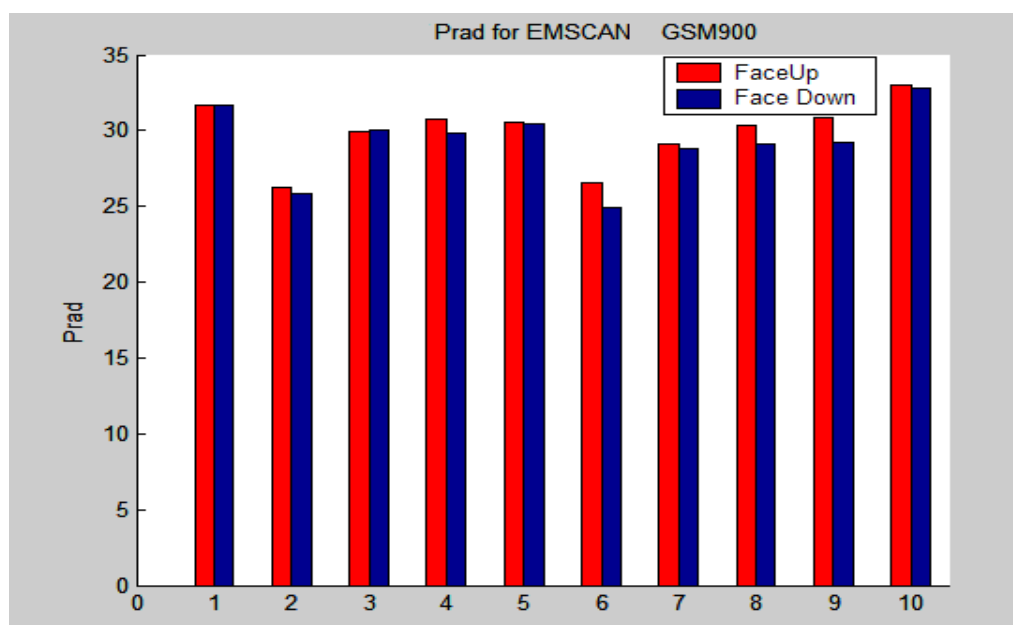
Figure 13 Bar diagram for results at 900MHz

The TRP for each mobile was measured on the EMSCAN near field scanner of each band in GSM900 and GSM1800 as shown in Table 4.

DUT	Antenna type	TRP $_{dBm}$ GSM 1800	TRP $_{dBm}$ GSM900
DUT 1	Internal Antenna	26.38	34.66
DUT 2	External Antenna	29.05	29.06
DUT 3	Internal Antenna	28.70	32.96
DUT 4	Internal Antenna	28.28	33.33
DUT 5	Internal Antenna	29.65	33.50
DUT 6	Internal Antenna	17.03	28.81
DUT 7	Internal Antenna	27.18	31.97
DUT 8	Internal Antenna	27.26	32.78
DUT 9	Internal Antenna	29.42	33.10
DUT 10	Internal Antenna	26.74	35.91

Table 4 Measured results of different for GSM 900 and 1800 bands
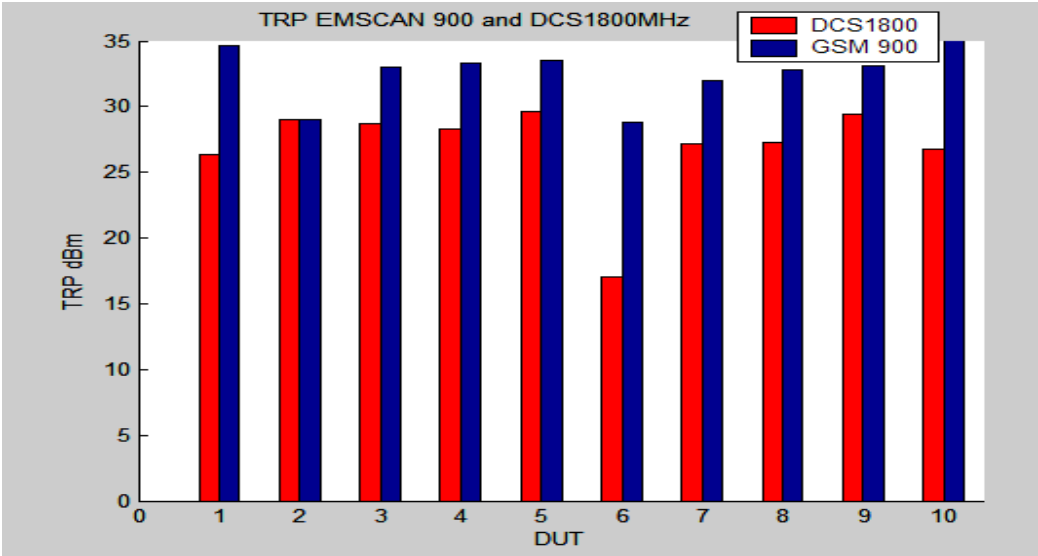

Figure 14 Graphical representation of results

Figure.14 summarizes the results of TRP from measurements of all the mobiles phones. The results presented that there is a difference of more than 3 dB among the measured mobiles for at 900 MHz and 1800 MHz except for DUT2.In DUT 2 it is observed that same TRP is measured both at 900 and 1800 MHz This is due to the fact that DUT 2 had external antenna and also it was a flip phone. This result shows the inability of EMSCAN to measure accurately the TRP of flip phones with external antenna. In DUT6 it is observed that the TRP value is 17.03dBm it is quite low the reason is that the mobile phone was old model, used extensively, may be antenna not working properly and also battery was discharging quickly than normal or might be mobile antenna is sensitive to outside environment.

30

4.3   Measurement results of mobile phones in 8 positions

The radiated power, P_{rad} in dBm for both face up and the face down for a single phone (DUT 7) in 8 different positions was measured at GSM 1800   Channel 512   Tx 1710, 2   Rx 1805, 2. A single phone was measured and moved across the grid of EM scanner over 45 degrees. To execute the TRP test, radiated power samples are collected along a sphere every 45 degrees. As shown in figure 15 these power samples are then integrated over the whole sphere to determine the total EIRP.

Figure 15   DUT (7) phones in 8 positions   Face up   Face down

4.3.1 Radiated power (P_{rad}) of mobile phones vs. positions:

P_{rad} for each mobile was then measured at different positions on the EMSCAN near field scanner. This was done to test the dependency of the measured radiated power on the positioning of the DUT. The results of P_{rad} measurements for both face up and the face down presented in table 5 show of DUT (7).

Angles (Degree)	Prad $_{dBm}$ face up GSM1800	Prad $_{dBm}$ face down GSM1800
0	26.28	26.41
45	20.07	19.61
90	25.95	25.69
135	18.99	19.42
180	18.86	19.28
225	27.25	26.61
270	19.78	19.29
315	26.57	26.64

Table 5 measured Prad at different positions

The Bar diagram in Fig 16 shows the Prad in dBm for both face up and the face down of a single phone in 8 different positions. The results in fig 16 suggest that no significant difference was observed in the measured power for face up and face down at one particular position. But Prad measured is different for same mobile at different positions. This is quite obvious from the fact that Prad is not average power but it is the power radiated at an instant.
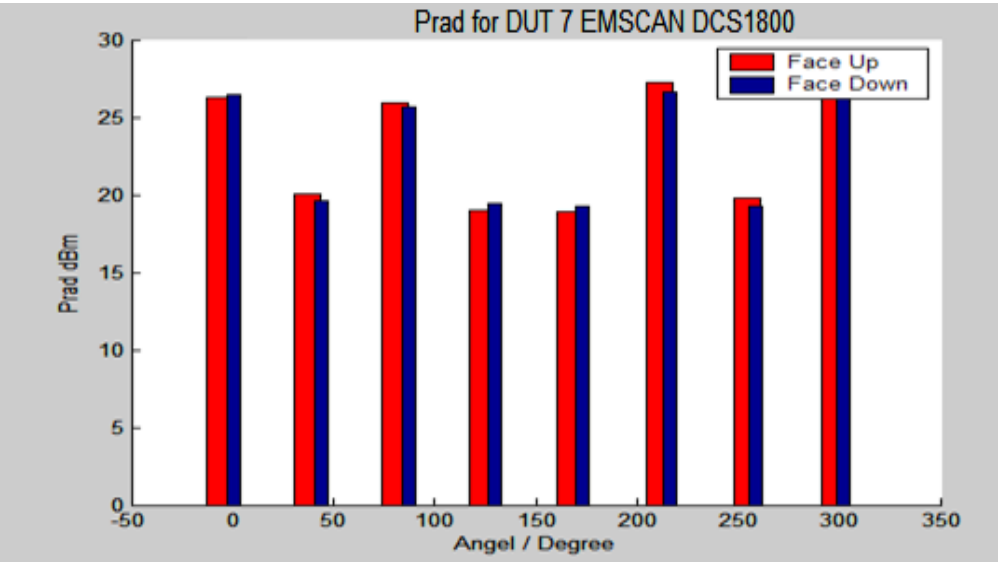

Figure 16 bar diagram for measured Prad for different positions

4.3.2 TRP vs. position of mobile phones

TRP for the mobile was measured at different positions as shown on Table 6 which is made to test the dependency of the measured radiated power on the positioning of the mobile phone on near field scanner**.** Bar diagram representation is also shown in figure 17. Figure 18 is the scattering of measured values of TRP for different mobile positions. The results suggest that there is a variation of around 1.25 dB between the maximum and the minimum value of the TRP measured in two different positions.

Angles (Degrees)	TRP$_{dBm}$ GSM 1800
0	27.08
45	27.49
90	26.80
135	27.34
180	27.12
225	27.94
270	26.69
315	27.34

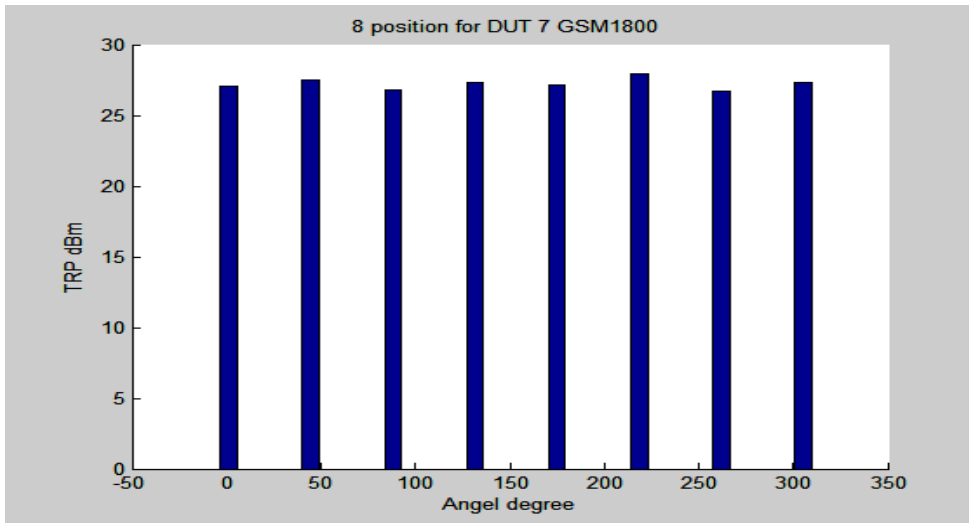**Table 6 TRP for different positions**

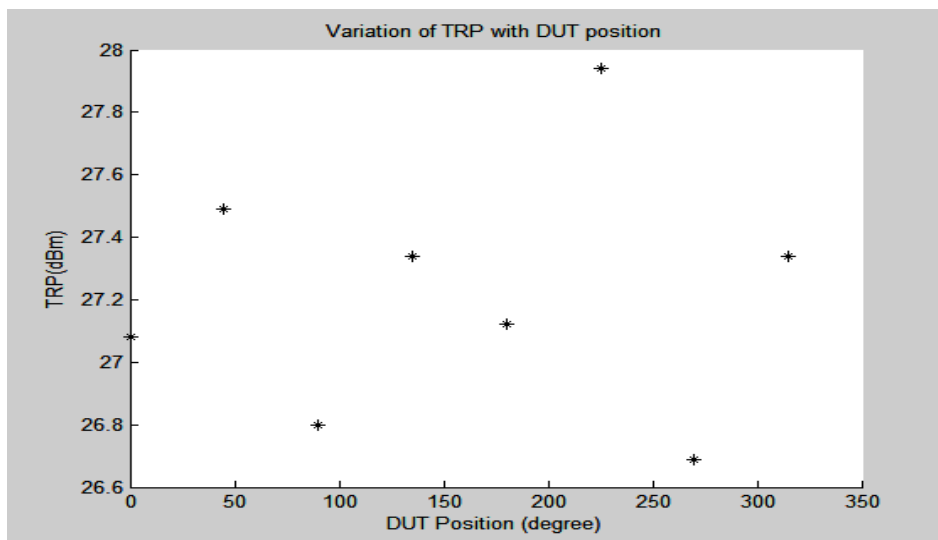**Figure 17 bar diagram for TRP for difference positions**

Figure 18 Scattering of TRP for different positions

4.4   Measurement Results of Satimo SG24 chamber

The 10 commercially available dual-band GSM900 and GSM1800 phones have been used. One external antenna Flip type marked DUT2, Two internal antenna Flip type phone marked DUT3, DUT4 and the others phone with internal antenna type bar marked DUT 1,5,6,7,8,9 and DUT10.

The Total radiation Power (TRP) results are presented in Table 7 of each mobile phone with diverse features on the SatimoSG 24 at GSM 900 and GSM 1800.

DUT	Antenna type	TRP$_{dBm}$ Satimo SG24 GSM 900	TRP$_{dBm}$ Satimo SG24 GSM 1800
DUT 1	Internal Antenna	26.80	24.30
DUT 2	External Antenna	28.60	27.30
DUT 3	Internal Antenna	29.90	27.20
DUT 4	Internal Antenna	30.20	26.50
DUT 5	Internal Antenna	29.70	28.70
DUT 6	Internal Antenna	25.60	22.40
DUT 7	Internal Antenna	29.20	24.80
DUT 8	Internal Antenna	28.90	25.20
DUT 9	Internal Antenna	28.20	27.20
DUT 10	Internal Antenna	30.00	23.30

Table 7 TRP of 10 mobile phones measured in SatimoSG24.

The Bar diagram in figure 19 summarize the measurements results of Total radiation Power(TRP) of each mobile phones on the Satimo SG 24 at GSM 900 and DCS 1800 bands.
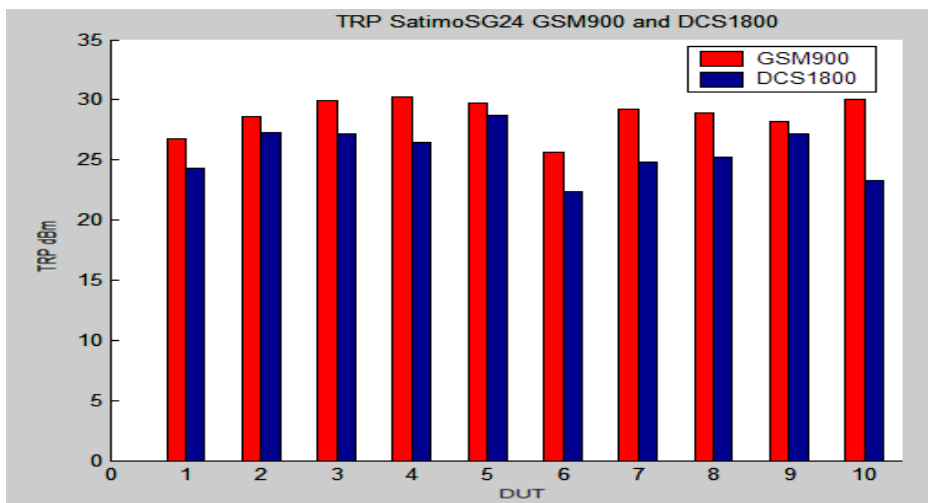

Figure 19 GSM 900 and DCS 1800 measurements on SatimoSG24 system

5 *Comparison of TRP of EMSCAN and Satimo SG24 chamber*

The TRP measurements have been carried out in a Satimo SG24 anechoic chamber and the EMSCAN (Lab Express) for both GSM900 and GSM1800 low bands i.e.975 and 512 channels respectively. Table 8 shows the results of measured values from both systems. Figure 20 shows comparison between the measured values of TRP from both the systems. .The results of TRP show a correlation of 79% for GSM 1800 band and 49% for GSM 900 frequency band between two measurement methods and the TRP results of measured values from the EMSCAN (Lab Express) are high compared with the TRP results of measured values from the SatimoSG24 for both bands This is due to the estimate of the correlation coefficient obtained is biased at GSM900 ,This biasness is a shown figure 20 because the mean of the measured TRPs is not the same as that measured TRP values of each mobile also the EMSCAN has a tolerance in ERIP +/- 3dB "according to EMSCAN specification", and might be the EMSCAN is sensitive to interference frequencies from the outside environment. Except the DUT6 at GSM1800 is low as discussed in Section 4.2.

DUT	Antenna type	SatimoSG24-TRP/GSM 900	EMSCAN-TRP/GSM 900	SatimoSG24-TRP/GSM1800	EMSCAN-TRP/GSM 1800
DUT 1	Internal Antenna	26.80	34.66	24.30	26.38
DUT 2	External Antenna	28.60	29.06	27.30	29.05
DUT 3	Internal Antenna	29.90	32.96	27.20	28.70
DUT 4	Internal Antenna	30.20	33.33	26.50	28.28
DUT 5	Internal Antenna	29.70	33.50	28.70	29.65
DUT 6	Internal Antenna	25.60	28.81	22.40	17.03
DUT 7	Internal Antenna	29.20	31.97	24.80	27.18
DUT 8	Internal Antenna	28.90	32.78	25.20	27.26
DUT 9	Internal Antenna	28.20	33.10	27.20	29.42
DUT 10	Internal Antenna	30.00	35.91	23.30	26.74

Table 8 comparison of results of Satimo SG24 and EMSCAN
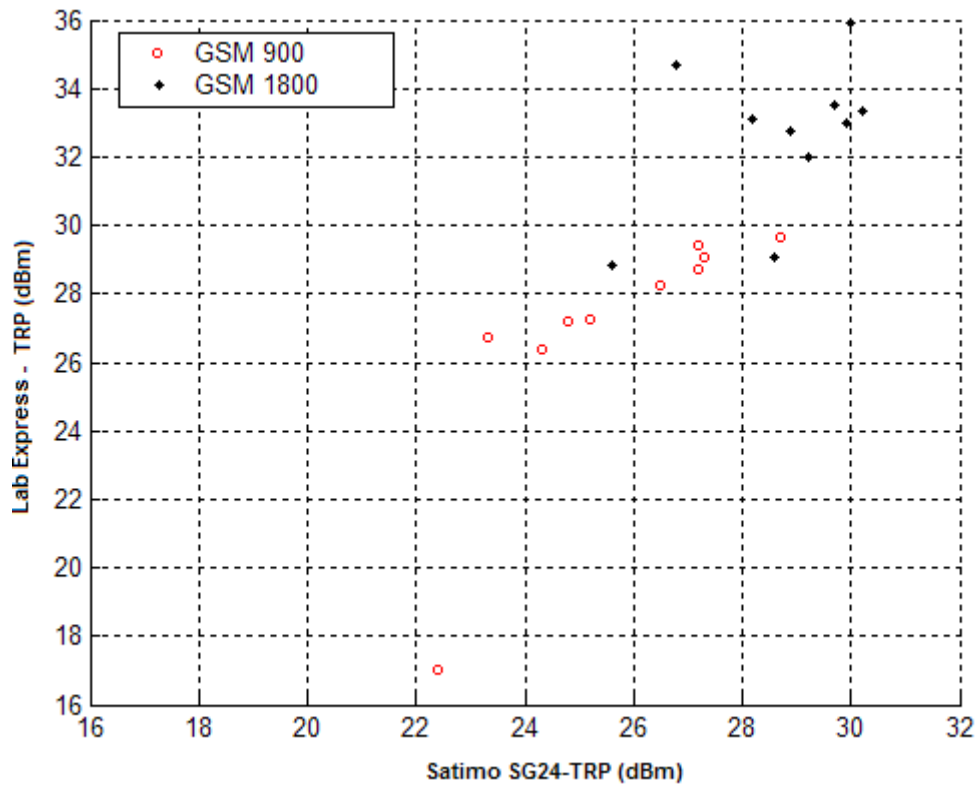
Figure 20 Comparison of Satimo SG24 and Lab Express measured values

The TRP measurements is estimated by computing the difference between total radiated in EMSCAN and total radiated power within the SatimoSG24 anechoic chamber at GSM 900 and GSM 1800 for the 10 mobiles phone as shown in table 9. It can be seen clearly that EMSCAN performs better for directive antennas like GSM 1800 as compared to omni directional or less directive GSM 900 antennas.

DUT	Antenna type	TRP dB Diff EMSCAN and SG24GSM 900	TRP dB Diff EMSCAN and SG24 GSM 1800
DUT 1	Internal Antenna	7.86	2.08
DUT 2	External Antenna	0.46	1.75
DUT 3	Internal Antenna	3.06	1.50
DUT 4	Internal Antenna	3.13	1.78
DUT 5	Internal Antenna	3.80	0.95
DUT 6	Internal Antenna	3.21	5.37
DUT 7	Internal Antenna	2.77	2.38
DUT 8	Internal Antenna	3.88	2.06
DUT 9	Internal Antenna	4.90	2.22
DUT 10	Internal Antenna	5.91	3.44

Table 9 difference in values of EMSCAN and SatimoSG24 in GSM 900 and GSM 1800

Bar diagram representation of The TRP of the 10 DUT phones were measured for GSM 900 and GSM 1800 low bands i.e.975 and 512 channels respectively. The results obtained with the EMSCAN were compared with the measured results of Satimo SG24 as shown in figure 21.

The TRP were calculated from decibel values. . The standard deviation between the GSM 900 and GSM 1800 low bands i.e.975 and 512 channels respectively is up to 2.7 – 3.3 dB. It can be seen that variation in the TRP results is large when compare DUT 2 and DUT 6 In this case might incorrect measurement or DUT is fit for GSM900.
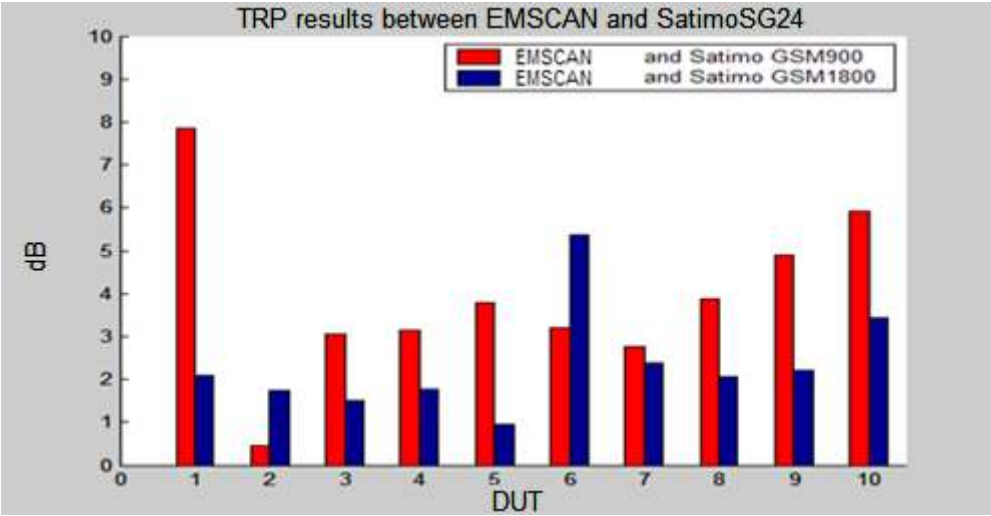

Figure 21 bar diagram for the comparison between EMSCAN and SG 24 measurement systems

The radiation pattern measurements for GSM1800 and GSM 900 were done for a DUT using near field scanner and the results are shown in figure 22.These patterns are compared with the radiation patterns measured in SatimoSG24 and the results are shown in figure 23.
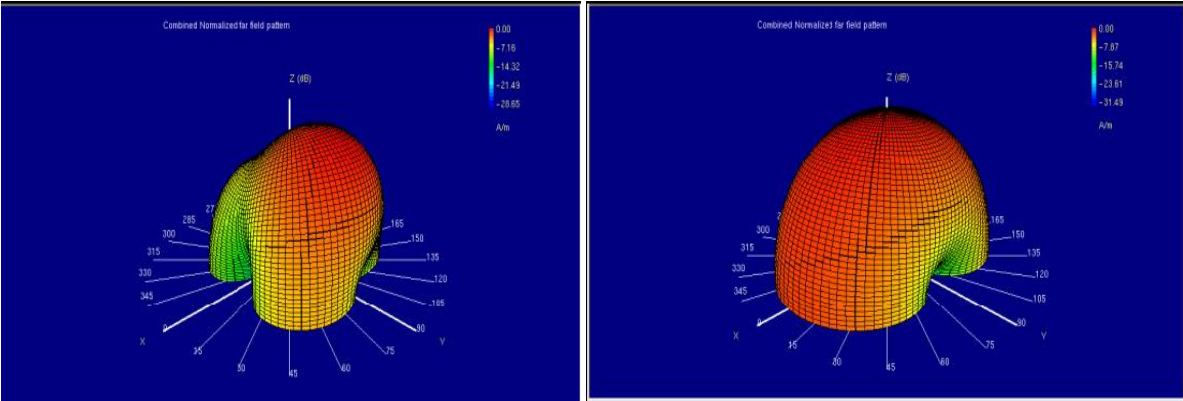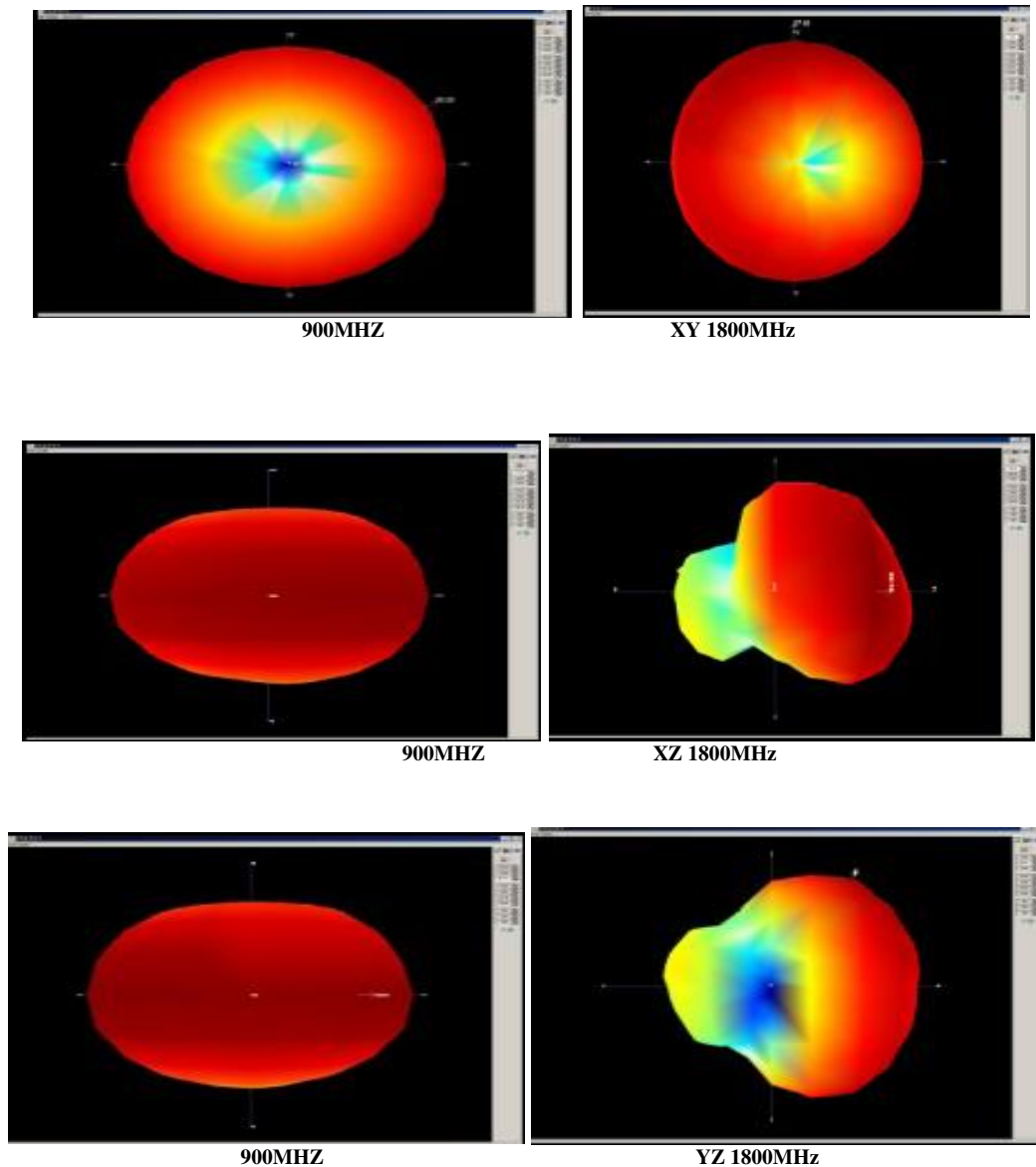

Figure 22 Far field radiation pattern of DUT10 at DCS1800 (left)and GSM900(right) from Lab Express

900MHZ   **XY 1800MHz**

900MHZ   **XZ 1800MHz**
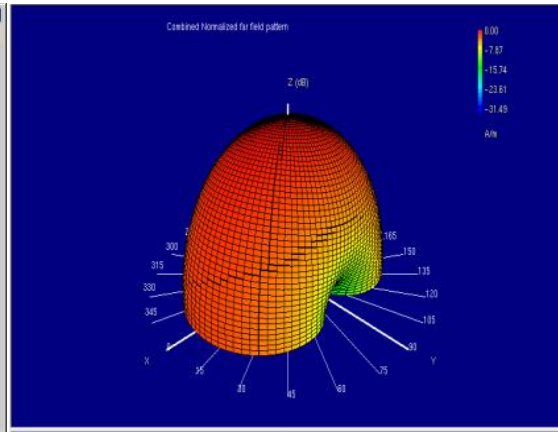

900MHZ   **YZ 1800MHz**

Figure 23 3D radiation Patterns of DUT10 measured in Satimo SG24 anechoic chamber

5.1   *Matlab implementation*

The implementation of the 3D pattern approximation of antenna radiation patterns was implemented in the Matlab environment, which is suitable for calculating with matrices of large dimensions. DUT 10 for GSM 900 was tested in both the systems and these results were implemented in matlab . Figure 24 and figure 25 we have seen that the result of TRP of DUT 10 was   29.136 dBm from the Matlab program which is almost the same result that we got from SatimoSG24 which was 30 dBm.
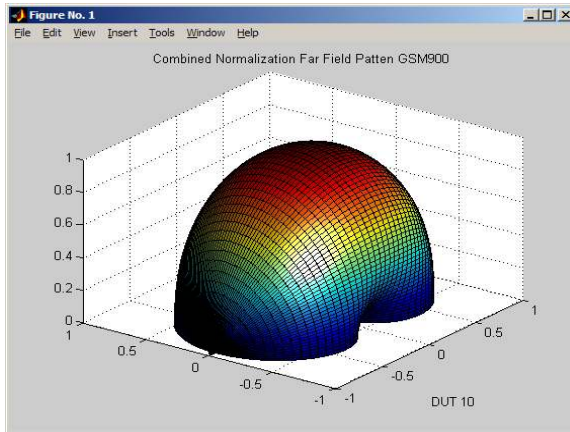
Figure 24 simulated results in Matlab   **results from EMSCAN**
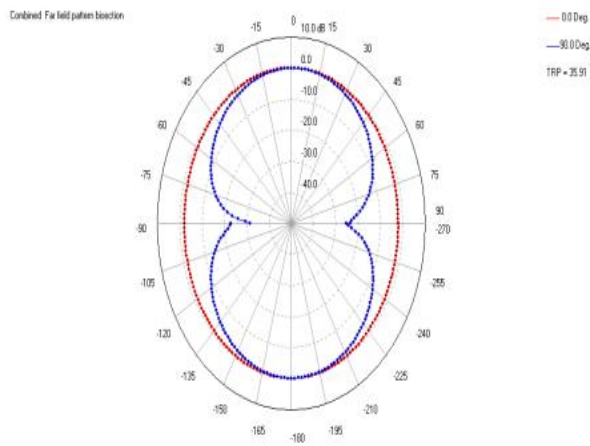
Figure 25 polar plot of far field EMSCAN   **polar plot for far field in Matlab**
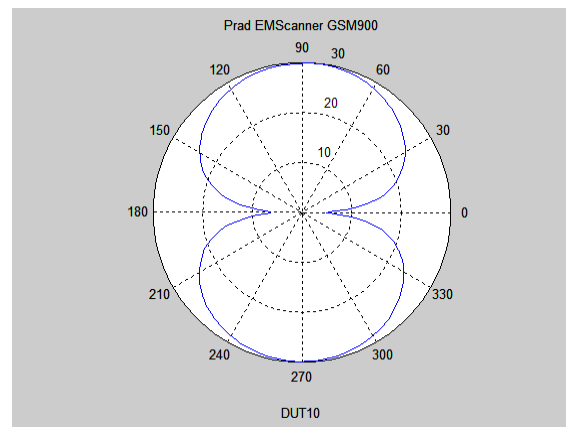
Also the results from Satimo SG 24 were also plotted in Matlab.

Results from SatimoSG 24 were also plotted in Matlab. Figure 26 shows the radiation pattern from the Satimo SG 24 system. Figure 27 shows the implemented plots in Matlab.

Figure 26 SG 24 XY GSM 900   **SG 27 ZY GSM 900**

Figure 27   Matlab 3D radiation pattern top of view of the 3D pattern in Matlab

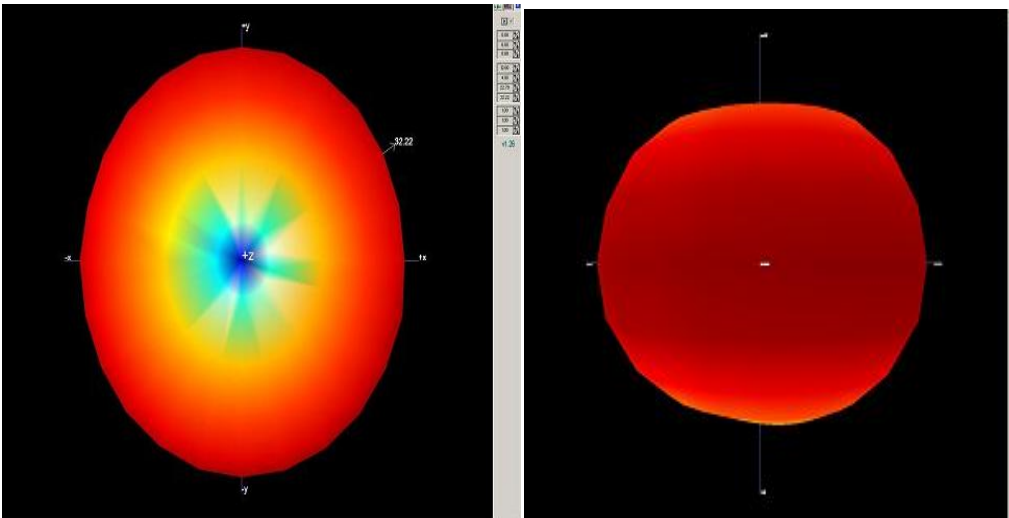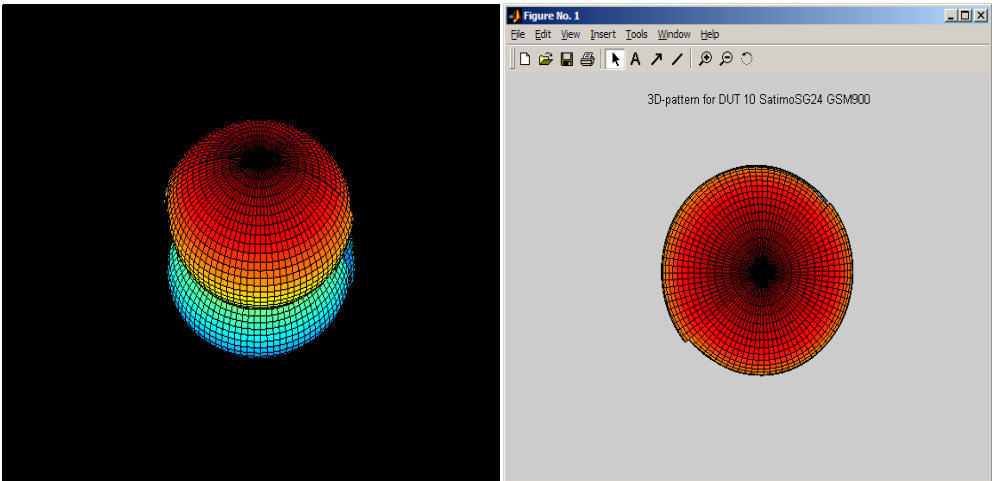# 6 Preliminary Conclusions and future work

6.1   Conclusions

EMSCAN can be used in a production environment. Real time scanning speeds and highly repeatable near and far field measurement capability makes the system attractive.
 It is quite useful in designing and testing of antennas at low band. After calibration, absolute results were improved but not much accurate as compared to Satimo SG 24 system.

Although EMSCAN cannot replace Satimo SG 24 system fully as the correlation among two methods was found to be low at GSM900 and it was not so high at GSM 1800, but still it is a useful tool. It is quite useful in optimizing loading effects and interference from surrounding antennas. It has a great potential in aiding for the design of MIMO (Multi Input Multi Output) systems.

The cost of the EMSCAN is very less compare to the cost of Satimo SG24 measurement facility. Hence such systems are cost efficient to use. It solely depends on the requirement that what is needed to measure and how much a tradeoff between accuracy and budget.

6.2   Future Work

Future work would be to optimize the measurement system for measuring absolute levels and accuracy.

Encode the EMSCAN system in MATLAB or EMS Electromagnetic simulation software such as Ansoft- HFSS or MW studio-CST will also help in optimizing the system performance. Results from EMSCAN were imported into Matlab were plotted in MATLAB. This will help to analyze the results more deeply.

Accuracy of the EMSCAN can be increased by avoiding interference from other sources. This can be done by putting the scanner in isolated environment and then measurements should be taken.

Effect of hand on mobile should also be taken under consideration while taking measurements. This will give more accurate estimate of the performance.

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Appendix (MATLAB program)

Program used for plotting Figure 20

```
% Comparison of TRP of EMSCAN vs Satimo SG24
% CORRCOEF Correlation coefficients

x=[24.3 27.3 27.2 26.5 28.7 22.4 24.8 25.2 27.2 23.3 ];%satimoSG24 TRP DCS 1800MHz
y=[26.38 29.05 28.7 28.28 29.65 17.03 27.18 27.26 29.42 26.74];%EMSCAN TRP DCS 1800MHz

w=[26.8 28.6 29.9 30.2 29.7 25.6 29.2 28.9 28.2 30];% atimoSG24 TRP GSM 900MHz
s=[34.66 29.06 32.96 33.33 33.5 28.81 31.97 32.78 33.1 35.91];% EMSCAN TRP GSM 900MHz


 R_DCS1800 = corrcoef(x,y)
R_GSM900 = corrcoef(w,s)


 scatter(x,y,10,'ro')
hold on
 scatter(w,s,10,'kd')
  legend('GSM900','DCS1800')
axis([16 32 16 36])
title('TRP Comparison EMSCAN vs SatimoSG24')
xlabel('SatimoSG24-TRP(dBm)')
ylabel('EMSCAN-TRP(dBm)')
```

Program used for plotting Figure 24

```matlab
Z = data;%    import the data for DUT 10 which is measured by the EMSCAN
el = Z(1,:).'/180*pi;%  Elevuation
az = linspace(-90,90,51).'/180*pi;% Azimuth
r = reshape(Z(2:end,:),5151,1); % reshape the Data
r = r./max(abs(r));%Normalization

[X,Y] = meshgrid(el,az);
[fil col] = size(X);
Zin = reshape(r,fil,col);

% process color and shape
C = Zin;
C = fliplr(C);
% determine min and max radius values in interpolated data
Zin = fliplr(Zin);

mnz = min(min(Zin));
mxz = max(max(Zin));
shape = Zin; %  shape data

shape = shape + abs(mnz); %  normalize to zero
mns = min(min(shape)); %  limitation the shape
mxs = max(max(shape));

rat = mxs - mns; % scale the shape
shape = (shape/rat);

shape(shape<(rat/125)) = rat/125; % limit nulls depths for visibility

[x y z] = sph2cart(X,Y,shape); % cartesian coorinates

surf(z,y,x)% plot surface
```

Program used for plotting Figure 25

```matlab
%%% Polar plot for far field in Matlab for DUT 10
angle = data(:,1)/100; % needs to import the data file for EMSCAN for DUT 10

pow1 = abs(data(:,2));
pow1_N = (10*log10(pow1/max(pow1))+30);

% Far field plot
polar(pi/180*angle,pow1_N)
```