Improving Position Estimation Using Phase Difference Information for Two-Dimensional Communication System

Thongtat Oransirikul

Cooperative Education Report submitted in partial fulfilment for the degree of Bachelor of Science Program in Information Technology
Faculty of Information Technology
Thai-Nichi Institute of Technology
Academic Year 2011

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Faculty	Information Technology
A.D.	2011

Abstract

Company	National Institute of Information and Communications Technology
Place	2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0288, Japan
Type of Business	Research Center
Department	New Generation Wireless Communications Research Center
Position	Research Assistant
Advisor Name	Dr. Bing Zhang

Two-dimensional (2D) communication is a novel communication technology, which uses a sheet of special structure that allows a physical surface to propagate radio signals, and a coupler that is used to input / output radio signal. Furthermore, the 2D communication technology can be applied for the power transmission by using high-power carrier waves which can easily allocate a lot of sensors on the two dimensional sheet, and gather data from each node with high throughput.

This cooperative education report presents an evaluation of position estimation method in 2D communication system, in which a device placed on the surface of 2D communication sheet.

We estimate the position of device using phase and power difference of input electrodes upon receiving pilot signal from the device. We use a C program for position estimation to calculate experiment data and Gnu plot program to plot position estimation graphs. The result in this report would be useful for future research.

Keywords: 2D Communication, Position Estimation, Phase and Power Difference

Acknowledgement

Completing this research is not as smooth as silk. In fact, it has been quite a tough journey. However, this project is one of the best trip in my study life. This great accomplishment could not be possible without the courtesy and contribution of all the people I'm grateful for. The author would like to thank Dr. Saprangsit Mruetusatorn, the author's advisor of the project and Dr. Bing Zhang, the author's supervisor of the project, who had been a great advisor as well as a great inspirers. Thank you Dr. Takashi Matsuda for giving me valuable knowledge and for being there for me from the beginning to the end of the project. Thank you Mr. Youiti Kado, Mr. Toshifumi Oota, Mr. Takuya Inoue and Mrs. Noriko Morioka for all the help, advice, and coordination throughout the project. The author is most grateful for the extraordinary opportunity handed by National Institute of Information and Communications Technology (NICT) and my university, Thai-Nichi Institue of Technology (TNI). This wonderful project would not happen without these two major contributors. The author had gained a lot more experience than the author could have imagined.

Last but not least, the author would like to send a warm appreciation to the family and friends. Ones have been a great support and motivation throughout the author's entire life.

Once again everyone, thank you, and thank you very much.

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Introduction

1.1 Workplace Name and Location

1.1.1 Name in English

National Institute of Information and Communications Technology (NICT)

1.1.2 Name in Japanese

独立行政法人 情報通信研究機構

1.1.3 Address

2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0288, Japan

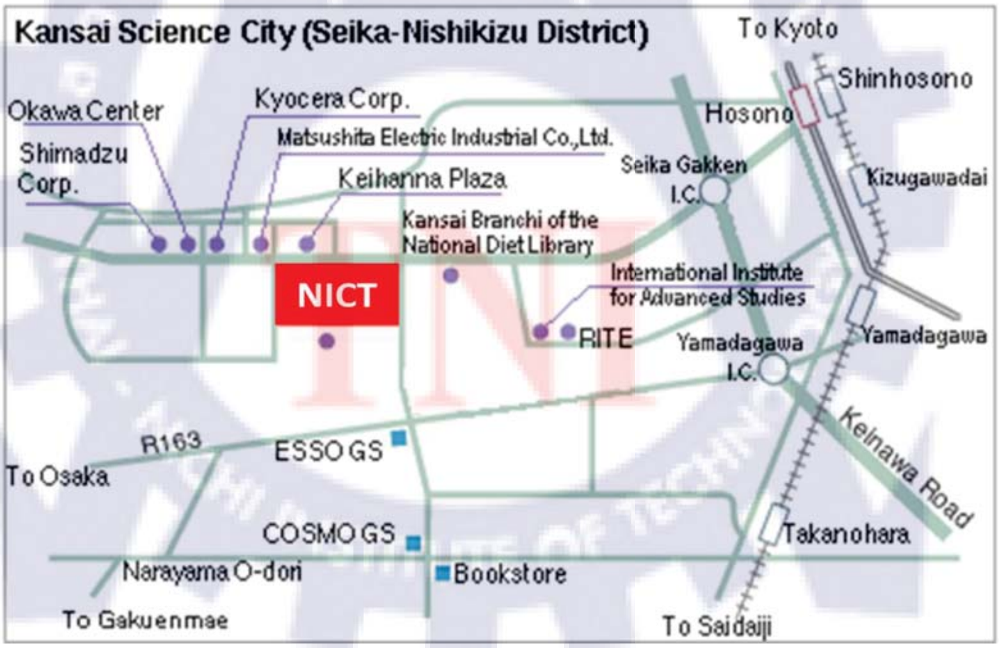


Figure 1.1 Map of NICT

1.2 About NICT

The National Institute of Information and Communications Technology (NICT), an incorporated administrative agency, was established by merging the Communications Research Laboratory (CRL), an incorporated administrative agency and the Telecommunications Advancement Organization (TAO).

1.2.1 Mission

As the sole national research institute in the information and communication filed, we as NICT will strive to advance national technologies and contribute to national policies in the field, by promoting our own research and development and by cooperating with and supporting outside parties.

1.2.2 Vision

NICT believes that the essential role of communications is to promote our mutual understanding and to achieve better relations between people and people, people and society, and between people and nature, by overcoming the various boundaries which may exit between generation, nations, etc. NICT will make every effort to become a world leader in achieving to realize this dream of universal communication.

1.2.3 Action Principles

1.2.3.1 Creating Technologies

NICT will undertake research and development by pursuing original technologies, world-leading technologies, and technologies which should benefit society.

1.2.3.2 Contributions to Society

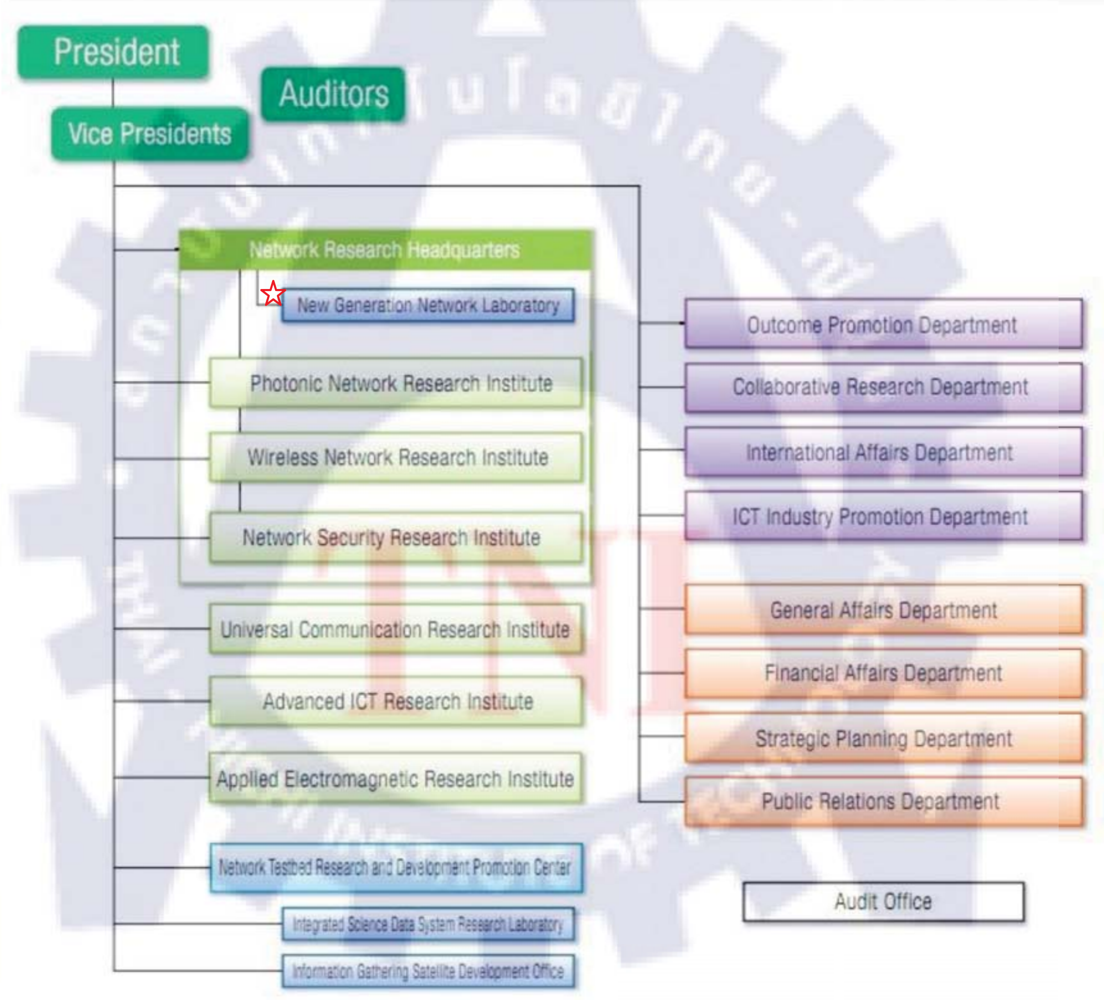
NICT will try to disseminate the results of our research throughout society by utilizing every means and opportunity.

1.2.3.3 Devotion to Self-Improvement

NICT will exercise our maximum capacity or ability by acknowledging the importance of our social responsibilities and devoting ourselves to self-improvement with a strong sense of ethics and a spirit of independence.

1.3 Organization

NICT Headquarters is located in Tokyo and some research center office, are located all over in Japan.



Figue1.2 NICT Organization Chart

1.4 Job Description

Position: Research Assistant

General tasks: Responsible for supporting the on-going development projects. Position Measurement and Estimation using retro-directive scheme for near-flied communication system.

1.5 Training Supervisor

Name: Dr. Bing Zhang

Position: Senior Researcher and Training Supervisor

1.6 Training Period

From July 8,2011 to November 3,2011 (4 months)

1.7 Research Objective

The objective of this project is to estimate the position of a device on a Two-Dimensional Communication Sheet (2DC sheet) in order to concentrate on providing location-specific for Location-specific Multimedia Services.

1.8 Expected Result

The expected result of this project is to precisely estimate the position of a device on a Two-Dimension Communication Sheet.

Chapter 2

Applied Theories and Technologies

2.1 Introduction

To improve our daily life supported by improving the surrounding tool or furniture is a fundamental step to do. For example, tables are very common and useful furniture. The table can be improved by the new technology of epoch-making Two-Dimensional Communication (2DC). The two-dimensional communication (2DC) is a novel physical form of communication that utilizes the surface as a communication medium to provide both data and power transmission services to the devices placed atop it. To enable 2DC to detect the position of sensor devices on the 2D communication (2DC) sheet, NICT had proposed a simple and highly accurate position identifying method that maps phase and power level differences measured at electrode array corresponding to a pilot signal sent by device. In 2DC, a Two-Dimension Communication sheet (2DC sheet) becomes the communication to propagate to carrier wave of device, which is placed on the top of 2DC sheet. By adding position detection function to the 2DCS, the location specific multimedia service can be realized that are beneficial in our daily life. The 2DC sheet is not just establish a communication connection between 2 devices, but it also can provide other services including power supply provision, high speed transmission, high security, estimation position of the device, etc. Further the 2DC can also provide energy power transmission. Therefore, not only the intelligent devices, such as notebook computers, smart phones, tablets, but also any hand-held devices, such as cameras, hand-held game consoles, music players, can be wirelessly charge via the 2DC sheet.

2.2 Related works

The concept of “Network Surface” was first proposed by Scott et al. [1] in October 1998 at the Laboratory for Communication Engineering, Cambridge University. The surface of a table is covered with network surface, which provide network connectivity to specially augmented object, when these object are physically placed on top of surface. When an object (e.g. smartphone, a notebook computer) connect, a handshaking protocol assign function such as data or power transmission to the various conductive paths that are established.

Lifton and Paradiso have proposed Pushpin Computing system [2]. They use a surface with pushpins and layered conductive sheets, where direct contact to conductive layers in the board is used to obtain power. Networking is established locally via infrared and capacitive coupling, with neighboring pushpins in a closed (about 10cm) range. The pins are required to be close to each other, and network routing needs to be completely handled in a distributed fashion, which increases the complexity a great deal for use a network in home environments. To envisage high-speed networking capabilities, Laerhoven et al. proposes that the conductive layer can be used as a bus network for pins [3].

2.3 Two-Dimension Communication System [4]

2D communication system sheet consists of two components: a 2DC sheet and a connector. Figure 2.1 illustrates the basic structure of the 2DC sheet, which is composed of four layers; solid conductive (S-) layer, dielectric (D-) layer, mesh conductive (M-) layer, and protection (P-) layer. The conductive fabric is usually copper or aluminum, whereas the dielectric material is polystyrene. The purpose of P-layer is to protect humans from directly coming in contact with the M-layer. With this layered composition, an electromagnetic (EM) wave can be confined within the 2DC sheet depending on the relative permittivity of the D-layer and the mesh structure of the M-layer. When the frequency of EM is 2.4 GHz and the relative permittivity of D-layer is 2.3, the inter-stripe distance and the stripe width of M-layer can be set to 7 mm and 1 mm respectively. However, the electromagnetic wave can still be seeped out from the surface of the 2DC sheet. We called this phenomenon an “evanescent wave” (Figure 2.2). The evanescent wave is formed when the electromagnetic wave inside the 2DC sheet is reflected off the surface. The term “evanescent” means “tending to vanish”. This is because the intensity of evanescent wave decays exponentially according to the distance from the surface of the 2DC sheet to the air. Meanwhile, the connector is an antenna by which an electromagnetic wave is extracted from or inserted into the 2DC sheet.

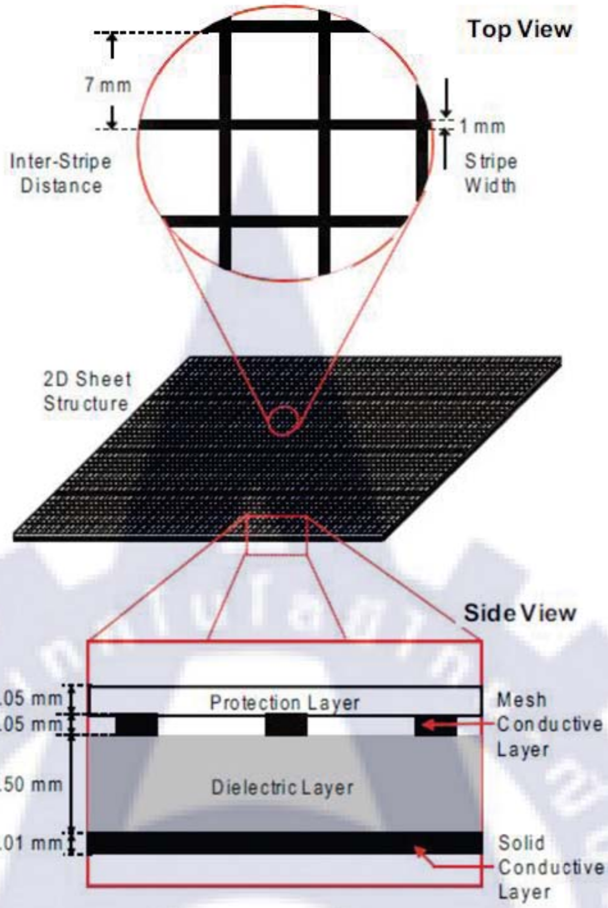


Figure2.1 Structure of the 2DC sheet

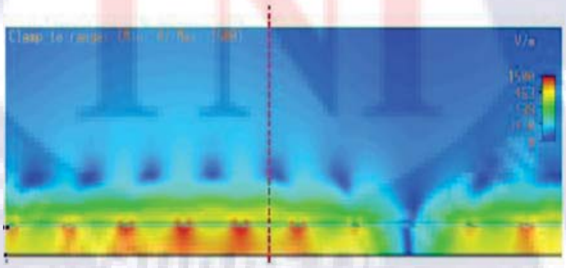


Figure2.2 Evanescent wave

2.4 Position Estimation Method

In this section, we describe an abstract of position estimation method. Position estimation method used two factors, phase and power level. If there are two electrodes at the edge of 2DC sheet and electrodes receive electromagnetic wave from a device on the 2DC sheet, phase difference and power level difference of electromagnetic wave occurred between electrodes. Thus, we use these factors to estimate the position for 2DCS. We explain a principle of phase difference and power level as in the Sections 2.5 and 2.6. After that, we explain the position estimation in Section 2.7.

2.5 Phase Difference of Multiple Inputs

The phase difference [5][6] or phase shift, also called a sinusoidal waveform (Sine Wave) is the angle Φ (Greek letter Phi) in degrees or radians that the waveform has shifted from a certain reference point along the horizontal zero axis. In other words, phase shift is the lateral difference between two or more waveforms along a common axis and sinusoidal waveforms of the same frequency which can have a phase difference.

The phase difference, Φ of an alternating waveform can vary from between 0 to its maximum time period, T of the waveform during one complete cycle and this can be anywhere along the horizontal axis between, Φ = 0 to 2π (radians) or Φ = 0 to 360° depending upon the angular units used. Figure 2.3 shows example of difference distance between two electrodes and antenna, $\overline{c0p2}$ and $\overline{c0p3}$. Figure2.3 shows phase difference.

When the device moves, the phase differences of every pair of neighboring plugs are changed. The phase difference of $\overline{c0p2}$ and $\overline{c0p3}$ is presented as follow:

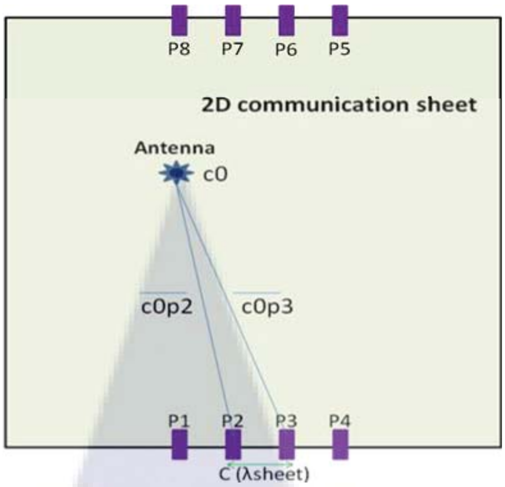


Figure2.3 Difference distance of two electrode arrays

2.5.1 Phase Difference Equation

$$D_{2,3} = \left| \frac{\overline{cop_2}}{\lambda sheet} - \frac{\overline{cop_3}}{\lambda sheet} \right| \quad (2.1)$$

$$\Phi = D \times 2\pi \quad (2.2)$$

Where $\lambda sheet$ is the wave length of electromagnetic wave in the 2DC sheet and Φ is the phase angle in degrees or radians that the waveform has shifted either left or right from the reference point.

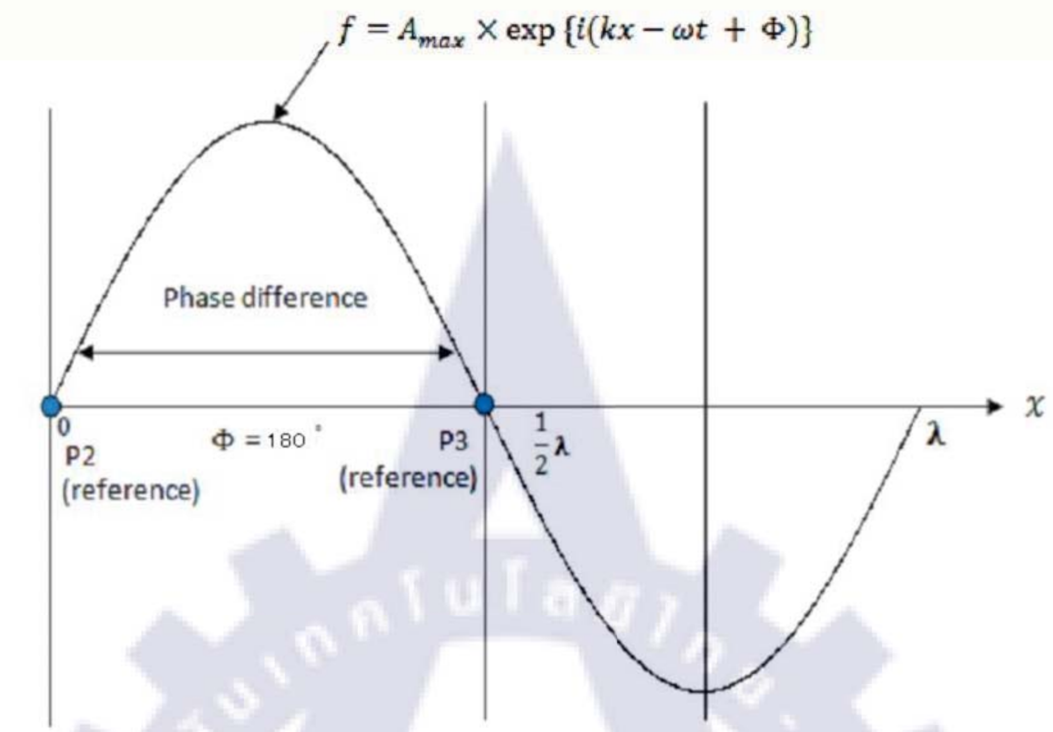


Figure2.4 Phase Difference

2.5.2 Wave Function Equation

$$f = A_{max} \times \exp\{i(kx - \omega t + \Phi)\} \qquad (2.3)$$

Where:

A_{max}	:	the amplitude of the waveform.
exp	:	the Exponential Function.
i	:	the complex number.
k	:	wave number (spatial frequency) can be associated with the wavelength by the relation $k = \frac{2\pi}{\lambda}$
x	:	the distance.
ω	:	the angular frequency of the waveform in radian/sec.
t	:	the time.
Φ (phi)	:	the phase angle in degrees or radians that a waveform has shifted either left or right from the reference point.

2.6 Path Loss

Path loss or path attenuation is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through medium like space or 2DC sheet. Path loss is a major component in the analysis and design of a telecommunication system.

This term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as propagation loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium, the distance between the transmitter and the receiver, and the height and location of antennas. [7]

2.6.1 Path Model for 2D Communication Medium [8]

The electromagnetic wave that propagates inside the 2D sheet is attenuated with the distance. In the wireless medium, the total signal power typically is assumed to decay with $1/d^{\alpha}$, where d is the distance from the transmitting slide and α is the path loss coefficient of 3~4. However, in the 2D medium, the total signal power is assumed to decrease with distance, in which α is equivalent to one based on the Friss transmission equation. Unlike a wireless medium, the total received power in a 2D medium can vary from the touched size of the connector placed on top of the 2DC sheet. For simplicity, we can model the total received power proportional to the connector diameter (D). The total received power in the 2D medium depends on the coordinator placement; either the coordinator is at any point on the 2D sheet or at the corner. Thus, the total received power (Pr) when the coordinator is at any point can be expressed as

$$P_r = P_s \frac{D}{2\pi d} \quad (2.4)$$

And the total received power when the coordinator is at the corner can be expressed as

$$P_r = P_s \frac{2D}{\pi d} \quad (2.5)$$

Where P_s is the power supply of the coordinator in watts. Figure 2.5 shows the 2D path-loss model when the coordinator is at any point or at the corner of the 2DC sheet.

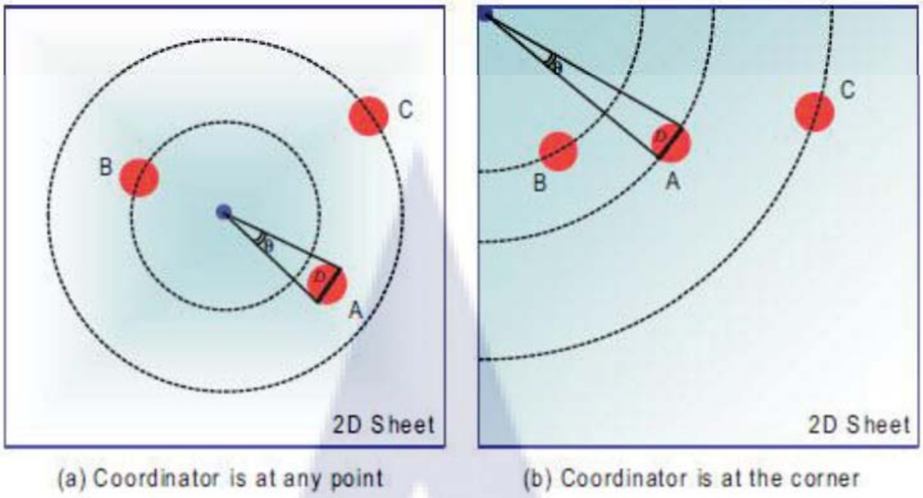


Figure2.5 Path-loss model for 2D Communication

2.7 Position Estimation Equation

In the evaluation, we propose three equations that are squared, absolute and square root to find the accurate position of device. These equations can show the accurate position and error position of device. First we measure the phase and power level information of several points on the 2DC sheet and make a database in advance. Tables 2.1 and 2.2 show the way to gather the database of first time and second time.

Table2.1 The database of first time.

X	Y	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8
25	12	A11	A12	A13	A14	A15	A16	A17
65	17	A21	A22	A23	A24	A25	A26	A27
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

125	52	An1	An2	An3	An4	An5	An6	An7

Table2.2 The database of second time.

X	Y	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8
25	12	B11	B12	B13	B14	B15	B16	B17
65	17	B21	B22	B23	B24	B25	B26	B27
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
125	52	Bn1	Bn2	Bn3	Bn4	Bn5	Bn6	Bn7

Then we compare the phase and power differences of database between 1st time and 2nd time. We estimate the minimum result of these formulas as estimated position.

The formulas show as:

Square Formula $\sum_{i=1}^{n}(D_{i,i+1} - d_{i,i+1})^2$ (2.6)

Absolute Formula $\sum_{i=1}^{n} |D_{i,i+1} - d_{i,i+1} |$ (2.7)

Square root Formula $\sum_{i=1}^{n} \sqrt{|D_{i,i+1} - d_{i,i+1}|}$ (2.8)

Where, $D_{i,i+1}$ is phase difference or power level difference of electrode *i* and *i*+1 from database, and $d_{i,i+1}$ is that from measured value.

2.7.1 Example of position estimation

In this part we explain about position estimation method. Figure 2.6 shows the measurement area. After gathering all data of every point (Both 1st time and 2nd time measurement), we estimate the position by using square formula. If a position has minimum value, the position is estimation position. F7 is minimum value that position is estimation position shows in figure2.9.

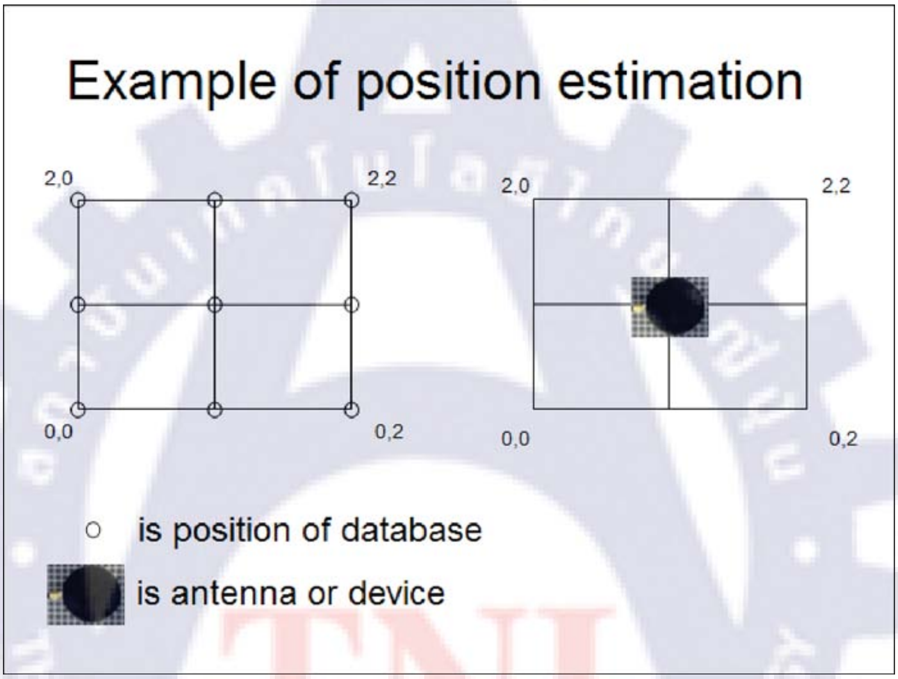


Figure2.6 Measurement area

Example of position estimation

	Phase difference				
Position (x, y)	Electrode 1-2	Electrode 2-3	Electrode 3-4	Electrode 5-6	Electrode 7-8
0,0	A_1	B_1	C_1	D_1	E_1
0,1	A_2	B_2	C_2	D_2	E_2
0,2	A_3	B_3	C_3	D_3	E_3
1,0	A_4	B_4	C_4	D_4	E_4
1,1	A_5	B_5	C_5	D_5	E_5
1,2	A_6	B_6	C_6	D_6	E_6
2,0	A_7	B_7	C_7	D_7	E_7
2,1	A_8	B_8	C_8	D_8	E_8
2,2	A_9	B_9	C_9	D_9	E_9

Database Table of neighbor electrode 1st measurement

Figure2.7 Database of first measurement

Example of position estimation

	Phase difference				
Position (x, y)	Electrode 1-2	Electrode 2-3	Electrode 3-4	Electrode 5-6	Electrode 7-8
0,0	a_1	b_1	c_1	d_1	e_1
0,1	a_2	b_2	c_2	d_2	e_2
0,2	a_3	b_3	c_3	d_3	e_3
1,0	a_4	b_4	c_4	d_4	e_4
1,1	a_5	b_5	c_5	d_5	e_5
1,2	a_6	b_6	c_6	d_6	e_6
2,0	a_7	b_7	c_7	d_7	e_7
2,1	a_8	b_8	c_8	d_8	e_8
2,2	a_9	b_9	c_9	d_9	e_9

Database Table of neighbor electrode 2nd measurement

Figure2.8 Database of second measurement

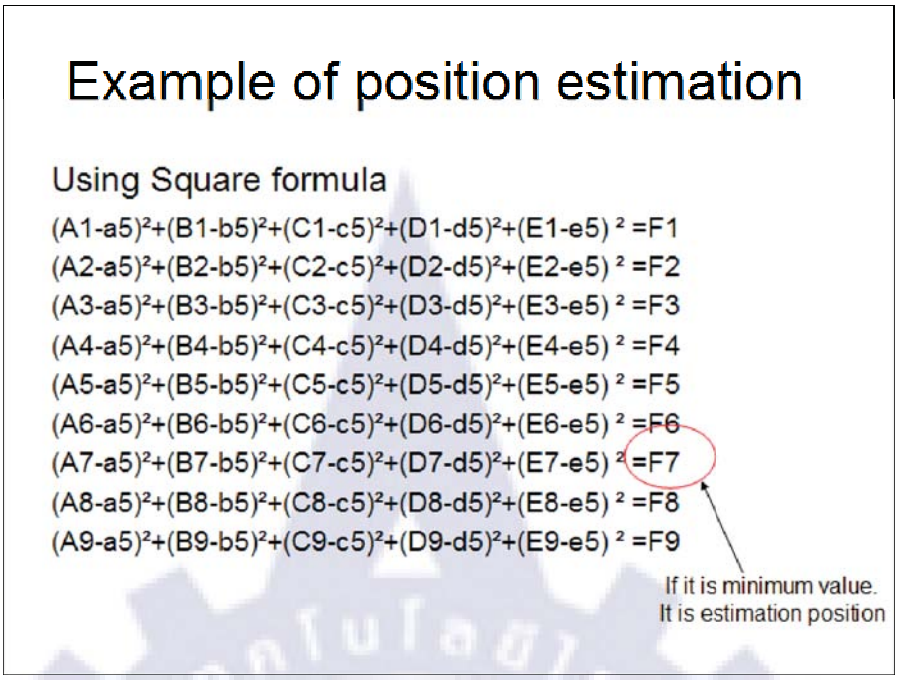


Figure2.9 Calculate result using square formula

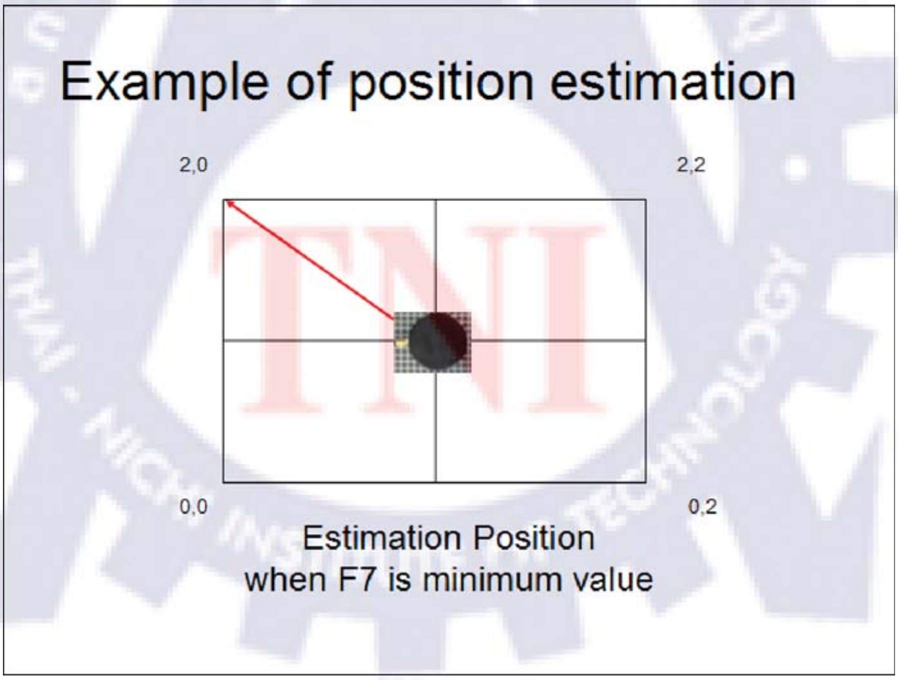


Figure2.10 Estimation position

Chapter 3

Work Plan and Process

3.1 Work Plan

Table3.1 Project work plan

Subject	July					August					September					October					November				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Study about Near-field communication																									
Measurement																									
Evaluation of conventional estimation methods																									
Improve position estimation methods																									
Data summary and Preparation for presentation																									
Presentation																									

3.1.1 Measurement Phase and Power of 2Dimensional Communication sheet

Table3.2 Measurement work plan

Subject	July					August					September					October					November				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Measurement of position of device every 2.5cm. interval, that input electrode are attached on the top and right, top and bottom, and 4sides of 2DC sheet with absorber																									
Measurement of position of device every 2.5cm. interval, that input electrode are attached on the top and right, top and bottom, and 4sides of 2DC sheet without absorber																									
Measurement of position of device every 2.5cm. interval, 20 times that input electrode are attached on the top of 2DC sheet with absorber																									
Measurement of position of device every 2.5cm. rotate antenna that input electrode are attached on the top of 2DC sheet with absorber																									

3.2 Work Description

In this project we are responsible to measure phase and power level information of pilot signal that is sent from antenna on the 2DC sheet to electrode array. We have 8 experiments that input electrodes are attached at the differences edges of the 2DC sheet, i.e. top, top and right, top and bottom and 4sides. Some experiments do not attached absorbers. For most of experiments, we measure twice every 2.5cm on 2DC sheet. After that we calculate estimation formulas and plot the graph to evaluate the correct position and error distance of each experiment.

3.3 Experimental Setup

There are totally four types of setups and each setup contains specific case as follow:

Setup 1 attach wave absorbers sheet at the edge of 2DC sheet

(I) Electrode arrays are clipped at the top and right side of 2DC sheet.

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet.

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet.

Setup 2 do not attach wave absorbers sheet Figure3.1 at the edge of 2DC sheet.

(I) Electrode arrays are clipped at the top and right side of 2DC sheet.

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet.

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet.

Setup 3 wave absorbers sheet Figure3.1 is attach at of 2DC the edge sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm.

(I) Electrode arrays are clipped at the top side of 2DC sheet.

Setup 4 wave absorbers sheet Figure3.1 at the edge of 2DC sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm.

(I) Antenna set at 45°.

(II) Antenna set at 90°.

(III) Antenna set at 135°.

(IV) Antenna set at 180°.

(V) Antenna set at 225°.

(VI) Antenna set at 270°.

(VII) Antenna set at 315°.

(VIII) Antenna set at 360°.

3.3.1 Setup 1

In This experiment we attach wave absorbers sheet at the edge of 2DC sheet (Figure3.1).

(I) Electrode arrays are clipped at the top and right side of 2DC sheet.

This measurement setup consists of four modules, a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm (Figure3.2). The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device has 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.7 shows the experiment setup that mainly consists of an electrode array which is clipped on the top and right side of the 2DC sheet.

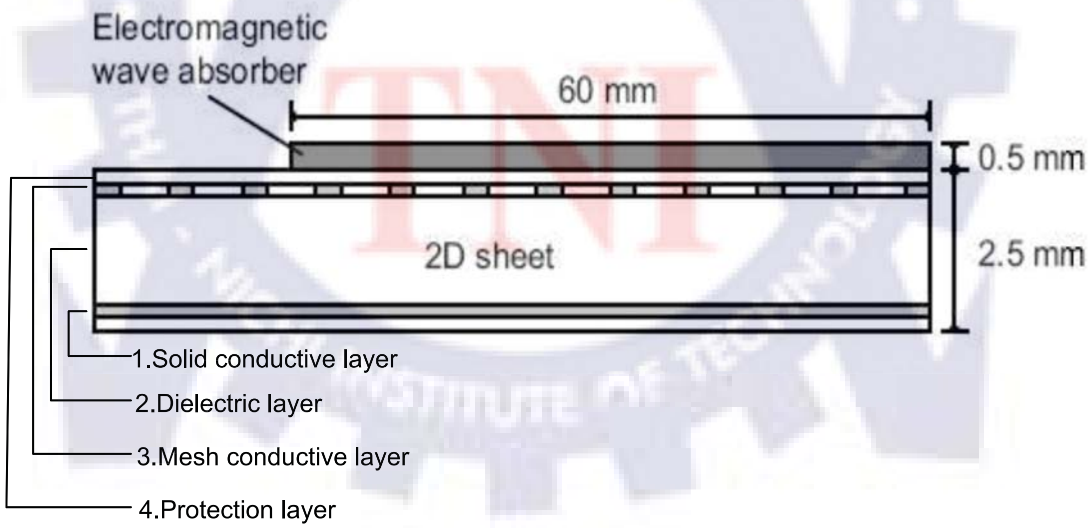
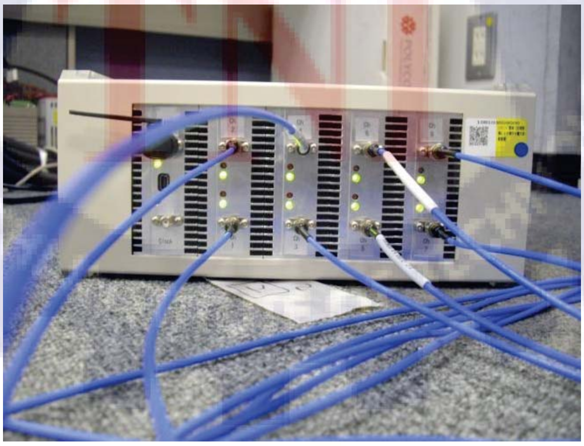


Figure3.1 Cross section view of the 2DC sheet

Figure3.2 The 2D sheet



Fifgure3.3 Phase angle and power level measuring device

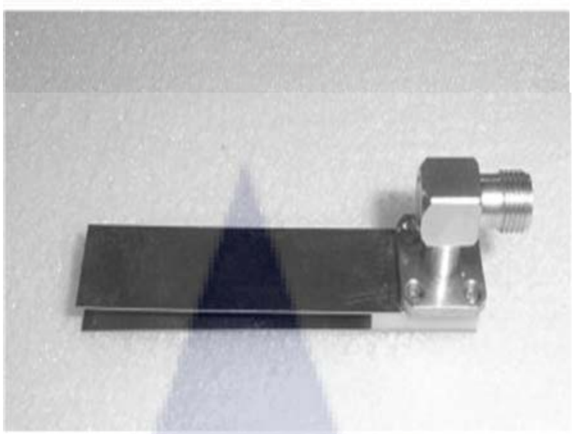


Figure3.4 The electrode

Figure3.5 Client for pilot signal transmission

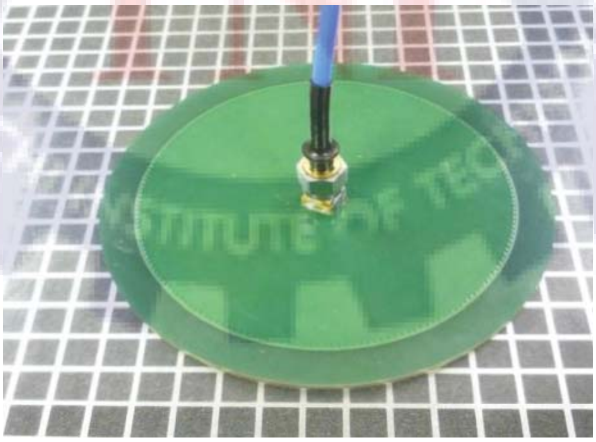


Figure3.6 The antenna

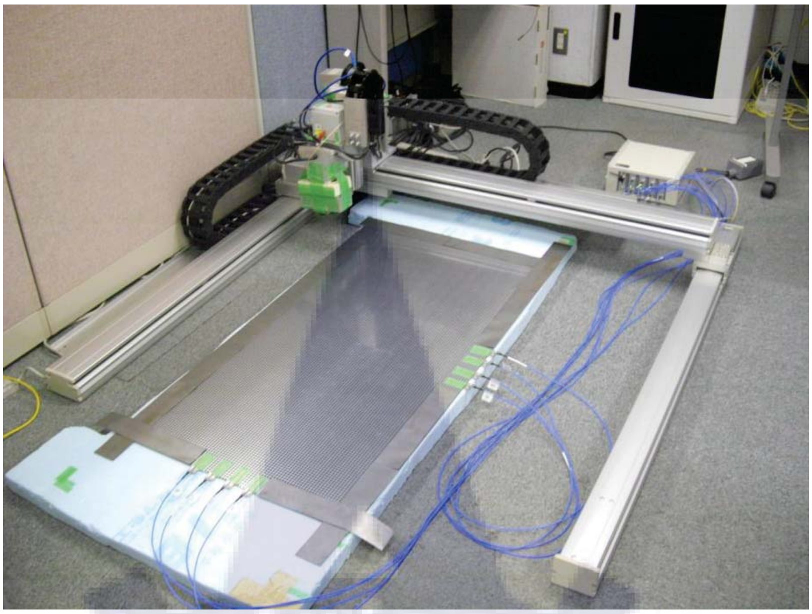


Figure3.7 Experiment setup1 (I)

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm. The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.8 shows the experiment setup that mainly consists of an electrode array which is clipped on the top and bottom side of the 2DC sheet.

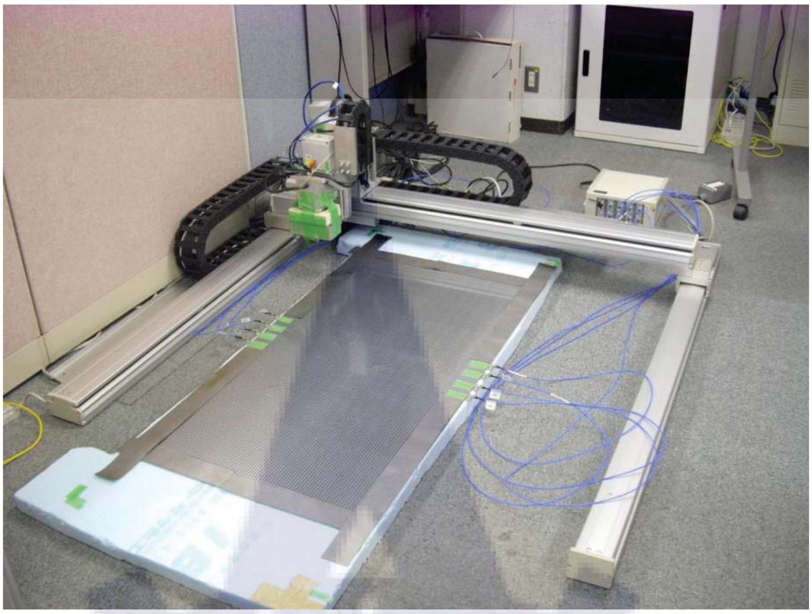


Figure3.8 Experiment setup1 (II)

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm. The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.9 shows the experiment setup that mainly consists of an electrode array which is clipped on the 4 sides of the 2DC sheet.

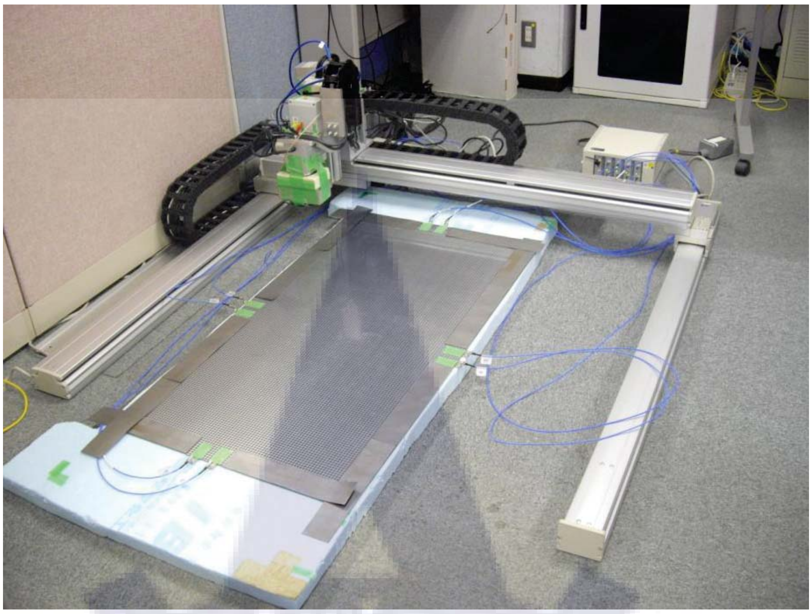


Figure3.9 Experiment setup1 (III)

3.3.2 Setup 2

This experiment do not Attach wave absorbers sheet Figure3.1 at the edge of 2DC sheet.

(I) Electrode arrays are clipped at the top and right side of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm. The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis Figure3.2. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.10 shows the experiment setup that mainly consists of an electrode array which is clipped on the top and right side of the 2DC sheet.

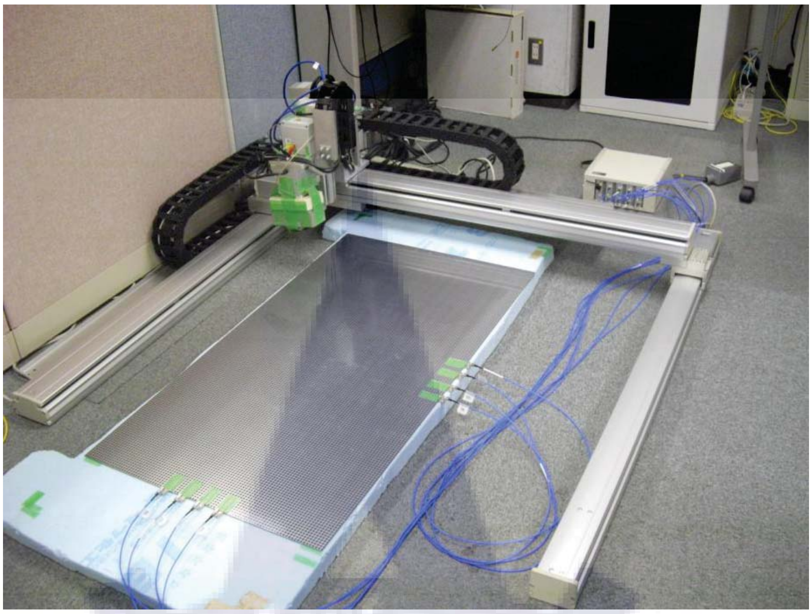


Figure3.10 Experiment setup2 (I)

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm. The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.11 shows the experiment setup that mainly consists of an electrode array which is clipped on the top and bottom side of the 2DC sheet.

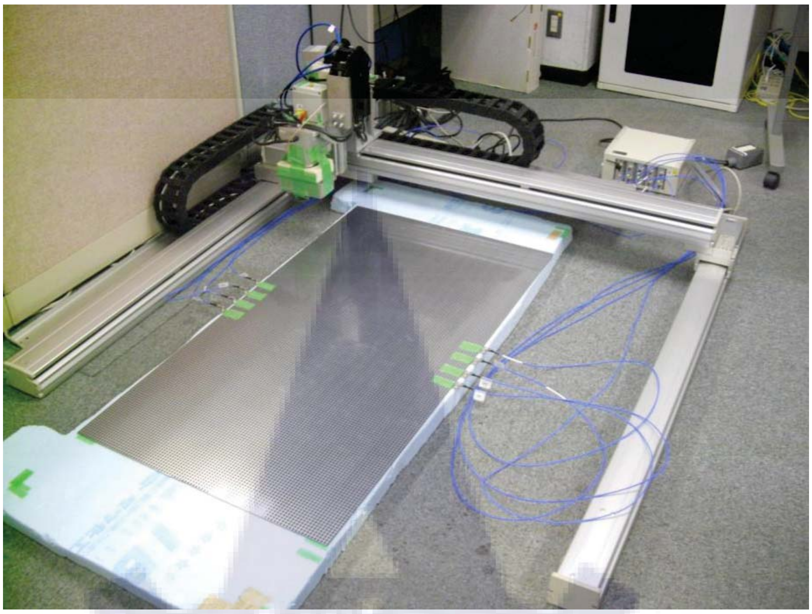


Figure3.11 Experiment setup2 (II)

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 60cm x 40cm. The measurement position starts at 45cm to 105cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.12 shows the experiment setup that mainly consists of an electrode array which is clipped on the 4 sides of the 2DC sheet.

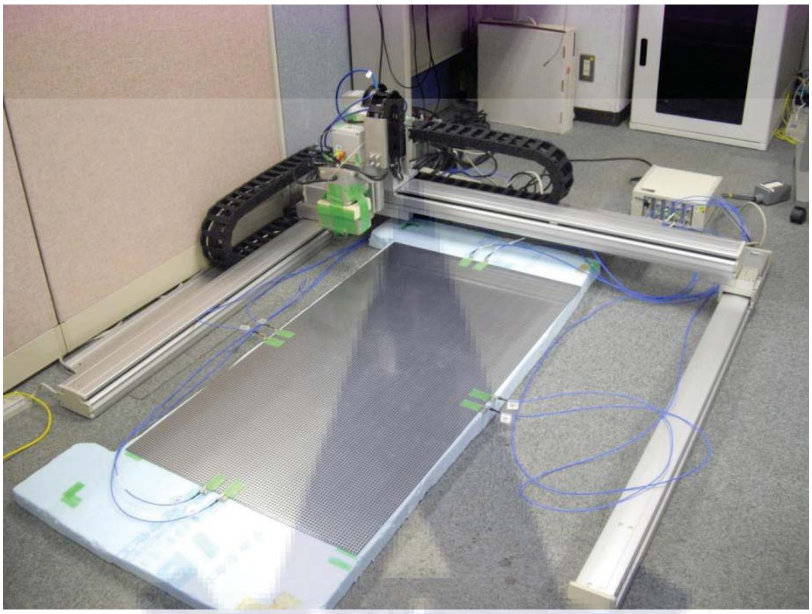


Figure3.12 Experiment setup2 (III)

3.3.3 Setup 3

In this experiment wave absorbers sheet Figure3.1 is attach at the edge of 2DC sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm.

(I) Electrode arrays are clipped at the top side of 2DC sheet.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.13 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

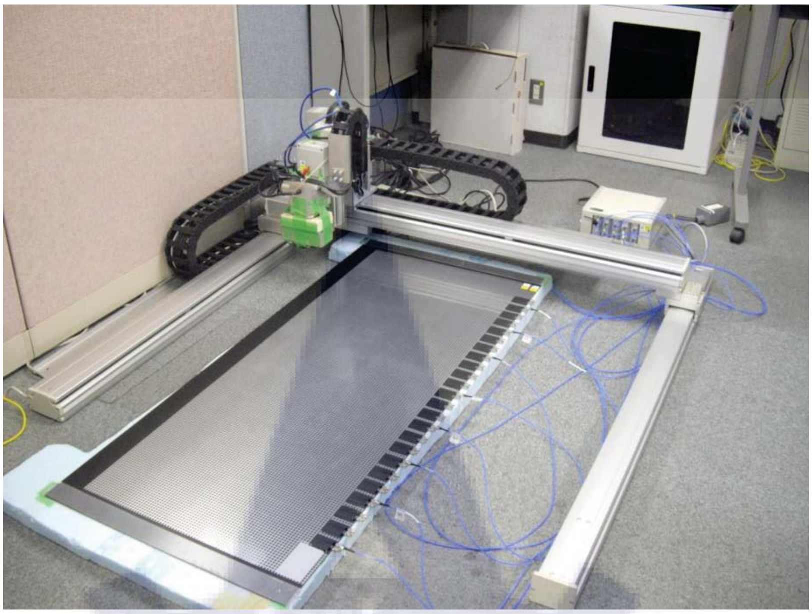


Figure3.13 Experiment setup3

3.3.4 Setup 4

This experiment Attach wave absorbers sheet Figure3.1 at the edge of 2DC sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm.

(I) Antenna set at 45°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.14 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

Figure3.14 Experiment setup4 (I)

(II) Antenna set at 90°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.15 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

Figure3.15 Experiment setup4 (II)

(III) Antenna set at 135°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.16 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

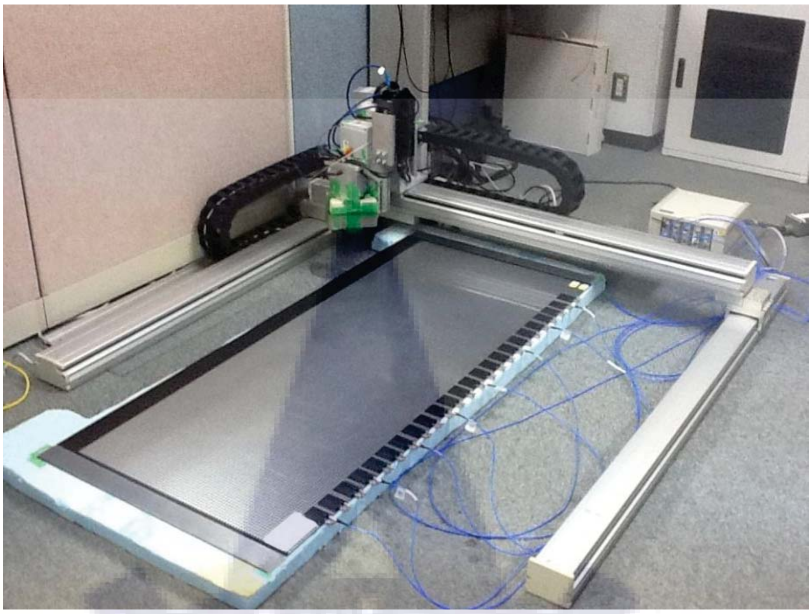


Figure3.16 Experiment setup4 (III)

(IV) Antenna set at 180°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.17 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

Figure3.17 Experiment setup4 (IV)

(V) Antenna set at 225°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.18 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

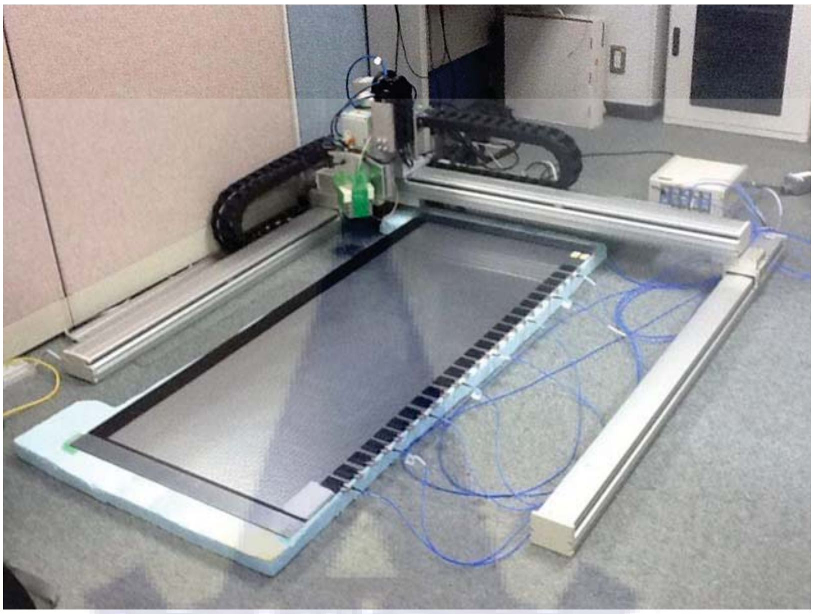


Figure3.18 Experiment setup4 (V)

(VI) Antenna set at 270°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.19 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

Figure3.19 Experiment setup4 (VI)

(VII) Antenna set at 315°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.20 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

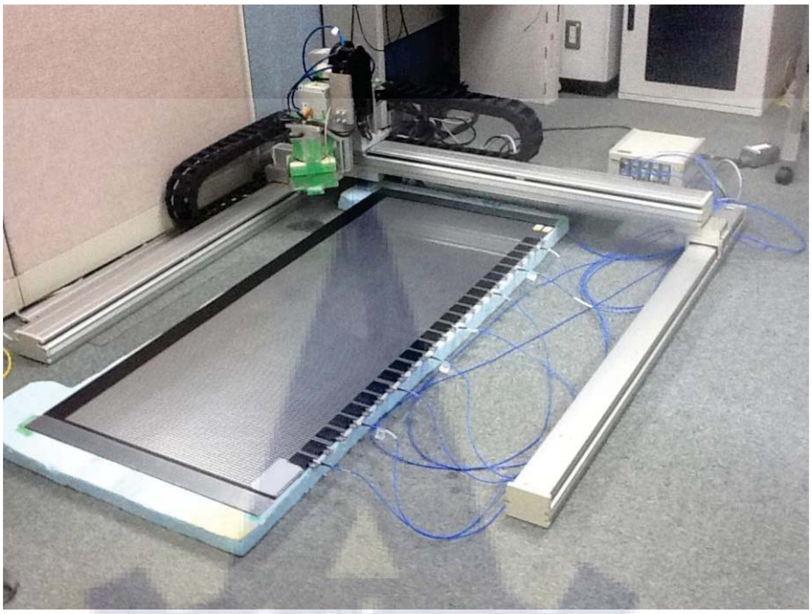


Figure3.20 Experiment setup4 (VII)

(VIII) Antenna set at 360°.

This measurement setup consists of four modules a 2DC sheet, a phase angle measuring device, an electrode array, and a client for pilot signal transmission. The 2D sheet size is 150cm x 64cm and the measurement area is 100cm x 40cm. The measurement position starts at 25cm to 125cm along the x-axis and 12cm to 52cm along the y-axis. Figure3.3 shows the phase angle and power level measuring device. The phase angle measuring device have 8 ports, each port can send or receive signal via coaxial cable. The phase angle measuring device and electrode array are connected by coaxial cables. Figure3.4 shows the electrode, the electrode size is 12mm x 47mm. Figure 3.5 shows the client for pilot signal transmission. Figure3.6 shows an antenna, the diameter of antenna is 8.6cm.

Figure3.21 shows the experiment setup that mainly consists of an electrode array which is clipped on the top side of the 2DC sheet and electrode interval is 15cm.

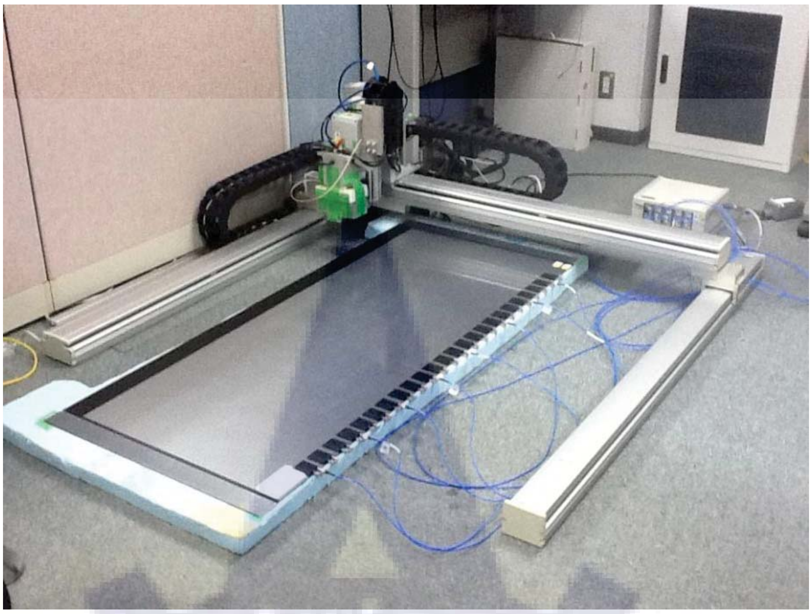


Figure3.21 Experiment setup4 (VIII)

3.4 Experimental Method

To estimate a precise position of the device that is placed on the 2DC sheet, the proposed measurement of the phase differences of the pilot signal on 2DC sheet. The pilot signal is sent by antenna and spreads throughout the 2DC sheet. Then pilot signal reaches to electrode array. Measuring the phase and power level at every electrode, the value of the phase and power level difference of each pair of neighboring electrode is obtained and every position on the 2DC sheet also has unique phase information.

The experiment in this cooperative education report all perform in one test room. For most experiment, we measure 2 times of every 2.5cm interval respectively.

3.4.1 As mention above setup 1 and setup 2 measurement area is 60cm x 40cm with start point of (45,12) and end point of (105,52) on the 2DC sheet, and this measurement has a measurement step which is 2.5cm interval.

We use C program for measuring phase and level data. First, we set measuring program input starting point, end point and measurement step. Secondly, we compile program and run the program (phase angle measurement device is connected to measurement PC via USB cable). This program outputs the phase and level data of measured points. After that measurement program gathers data and separates phase data and level data collected into files show in table3.3. This experiment needs 2 times measurements and a lone period of time (e.g. 2 hours) to start a new (second) measurement. The longer time of lone period the better for experiment, Since the short lone period to start a new measurement, it can be assumed as the same condition of first time so we cannot get the real result of position estimation.

Table3.3 Excel sheet sample of data

Position	E1	E2	E3	E4	E5	E6	E7	E8
45,12	-10.3	-13	-24.2	-14	-17	-27.4	-11.4	-15
45,14.5	-14.2	-17.6	-30.8	-19.4	-17	-26	-13	-14
45,17	-16.4	-15.8	-23	-10.9	-20	-23	-14.2	-13
45,19.5	-13	-14	-27.5	-13	-24	-26	-15.3	-15
45,22	-14.2	-13	-22	-11.6	-23	-26	-14.2	-15
45,24.5	-11.2	-14.9	-25.3	-15.8	-21	-27.4	-14.2	-17
45,27	-12.1	-12.2	-23	-12.3	-21	-27.4	-14.2	-16
45,29.5	-13	-18.5	-28.6	-15.8	-22	-28.8	-17.5	-16
45,32	-13	-12.2	-23	-14	-22	-28.8	-20.8	-15
45,34.5	-15.3	-17.6	-25.3	-14	-22	-28.8	-19.7	-18
45,37	-13	-14	-26.4	-19.4	-23	-27.4	-17.5	-23
45,39.5	-14.2	-16.7	-25.3	-14.9	-22	-26	-16.4	-19
45,42	-14.2	-13	-99.9	-19.4	-20	-27.4	-19.7	-18
45,44.5	-15.3	-17.6	-27.5	-17.6	-17	-28.8	-19.7	-18
45,47	-14.2	-17.6	-33	-14.9	-18	-26	-19.7	-20
45,49.5	-18.6	-16.7	-29.7	-22.1	-17	-22	-15.3	-21
45,52	-16.4	-99.9	-26.4	-15.8	-18	-22	-15.3	-21
47.5,12	-15.3	-14	-23.1	-12.3	-20	-28.8	-16.4	-24
47.5,14.5	-13	-12.2	-24.2	-18.5	-21	-30.2	-16.4	-22
47.5,17	-13	-13	-22.1	-11.6	-25	-30.2	-16.4	-19
47.5,19.5	-12.1	-14	-99.9	-24	-30	-31.6	-19.7	-22
47.5,22	-13	-14	-24.2	-14	-26	-28.8	-18.6	-22
47.5,24.5	-11.2	-14.9	-28.6	-17.6	-24	-30.2	-17.5	-23
47.5,27	-15.3	-15.8	-25.3	-13	-21	-31.6	-17.5	-22
47.5,29.5	-11.2	-14.9	-30.8	-14.9	-23	-33	-20.8	-22
47.5,32	-15.3	-14.9	-23	-11.6	-24	-31.6	-23	-19
47.5,34.5	-14.2	-15.8	-29.7	-14	-25	-31.6	-23	-20
47.5,37	-15.3	-13	-23	-13	-25	-28.8	-20.8	-26
47.5,39.5	-13	-16.7	-23.1	-12.3	-26	-27.4	-18.6	-25
:	:	:	:	:	:	:	:	:
105,52	-23	-14.9	-25.3	-14	-15	-21	-11.4	-13

The second measurement uses the same method of the first time measurement. After gathering all data of every point (Both 1st time and 2nd time measurement), C program has been used (refer to Appendix A) to calculate the position estimation formulas. This program use data of phase and data of level of every point to calculate using 3 formulas which is mentioned on the theory section (2.6), (2.7), (2.8). After calculating estimation formulas, we get result of phase, level, and phase + level x 10 difference and result of correct estimation ratio (%), average of error (cm), and maximum error distance (cm).

Then Gnu plot program is used to plot the graph. Figure3.22 shows the example of position estimation graph using Gnu plot (refer to Appendix B)

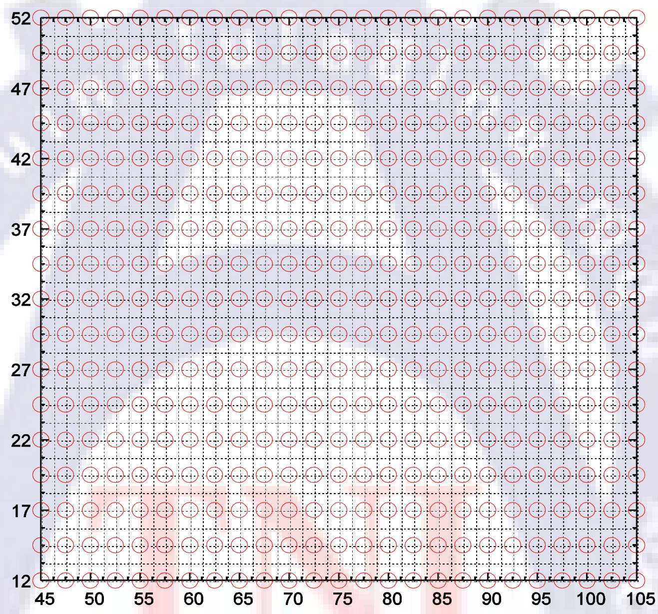


Figure3.22 Example of position estimation graph

3.4.2 As mention above setup (3) measurement area is 100cm x 40cm with start point of (25,12) and end point of (105,52) on the 2DC sheet, and this measurement has a measurement step which is 2.5cm interval average 20 times measurement for first measurement and 1cm interval for second measurement.

Then Gnu plot program has been used to plot the graph. Figure3.23 shows the example of position estimation graph using Gnu plot.

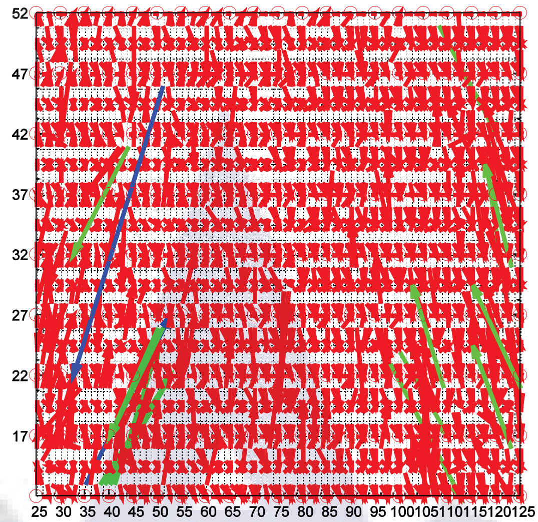


Figure3.23 Example of position estimation graph

3.4.3 As mention above setup 4 measurement area is 100cm x 40cm with start point of (25,12) and end point of (105,52) on the 2DC sheet, and this measurement has a measurement step which is 2.5cm rotate antenna measurement for first measurement to compare with 2.5cm interval average 20 times measurement from first measurement setup 3.

We use C program for measuring phase and level data. First, we set measuring program input starting point, end point and measurement step. Secondly, we compile program and run the program (phase angle measurement device is connected to measurement PC via USB cable). This program shows the phase and level data of each port of measured point. After that measurement program gather data and separate phase data and level data collect to files. This experiment we measurement 8 times follow angle of measurement (figure3.24).

After gathering all data of every point (Both 1st time and 2nd time measurement), C program has been used to calculate the position estimation result. This program used data of phase and data of level of every point to calculate using 3 formulas which was mentioned on the theory section (2.6), (2.7), (2.8). After program calculate we got result of phase, level, and phase + RSS*10 difference and result of correct estimation ratio (%), average of error (cm), and maximum error distance (cm).

Then Gnu plot program has been used to plot the graph. Figure3.25 shows the example of position estimation graph using Gnu plot.

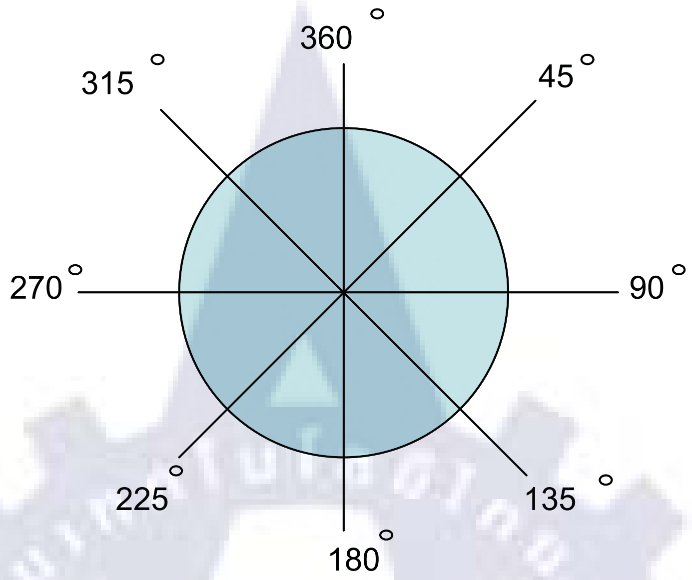


Figure3.24 Angle of measurement

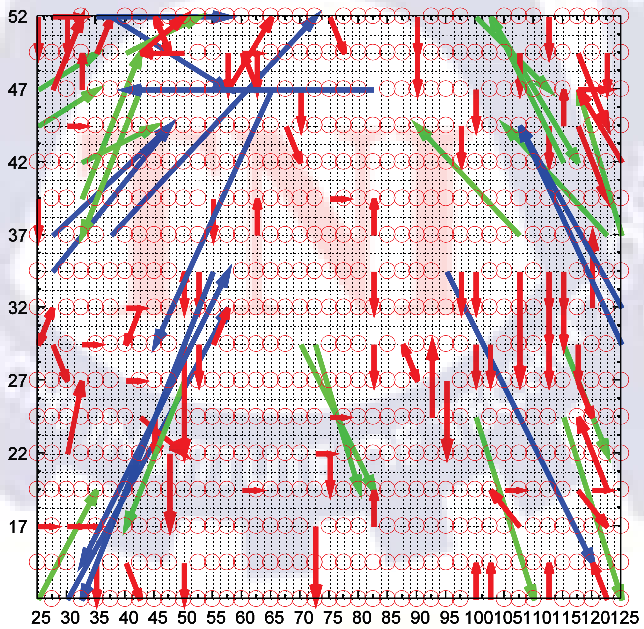


Figure3.25 Example of position estimation graph

Chapter 4

Experimental Result and Analysis

In this chapter, the result of position estimation by using phase difference of electrode array for Two-Dimensional Communication System according to above research method is present.

4.1 Evaluation result

There are totally four types of setups and each setup contains specific case as follow:

Setup 1 attach wave absorbers sheet at the edge of 2DC sheet as in the Section 4.1.1.

(I) Electrode arrays are clipped at the top and right side of 2DC sheet figure4.2 - 4.4.

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet figure4.5 -4.7.

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet figure4.8 - 4.10.

Setup 2 do not attach wave absorbers sheet Figure3.1 at the edge of 2DC sheet as in the- Section 4.1.2.

(I) Electrode arrays are clipped at the top and right side of 2DC sheet figure4.11 -4.13.

(II) Four electrodes are clipped at the top and bottom side of 2DC sheet figure4.14 – 4.16.

(III) Electrode arrays are clipped at the 4 sides of 2DC sheet figure4.17 – 4.19.

Setup 3 wave absorbers sheet Figure3.1 is attach at of 2DC the edge sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm as in the Section 4.1.3.

(I) Electrode arrays are clipped at the top side of 2DC sheet figure4.20 – 4.22.

Setup 4 wave absorbers sheet Figure3.1 at the edge of 2DC sheet. Electrode arrays are clipped at the top side of 2DC sheet and electrode interval is 15cm as in the Section 4.1.4.

(I) Antenna set at 45° figure 4.23 – 4.25.

(II) Antenna set at 90° figure 4.26 – 4.28.

(III) Antenna set at 135° figure 4.29 – 4.31.

(IV) Antenna set at 180° figure 4.32 – 4.34.

(V) Antenna set at 225° figure 4.35 – 4.37.

(VI) Antenna set at 270° figure 4.38 – 4.40.

(VII) Antenna set at 315° figure 4.41 – 4.43.

(VIII) Antenna set at 360° figure 4.44 – 4.46.

4.1.1 Evaluation result of 2.5cm interval with absorber (Setup 1)

The graph result by using 3 formulas which is Square formula, Absolute formula, and Square root formula. The measurement step is 2.5 cm interval for X-axis and Y-axis. Measure the selected area of 2DC sheet to confirm a device location concentrates on its location. The arrow which shows in the result is an error distance between origin point and estimated point, figure4.1 shows example of position estimation graph and how to read it.

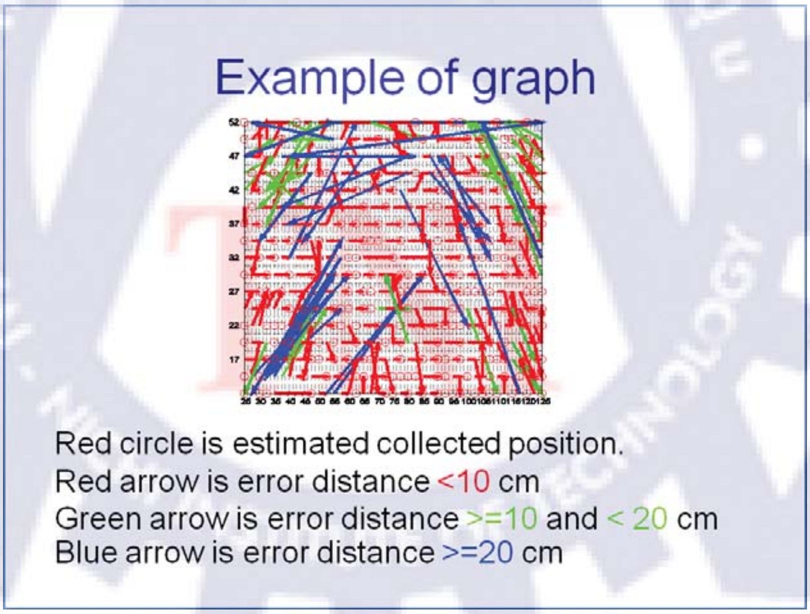


Figure4.1 Example of position estimation graph

1) Graph result of 2.5cm interval in which electrode arrays are clipped at the top and right side of the 2DC sheet.

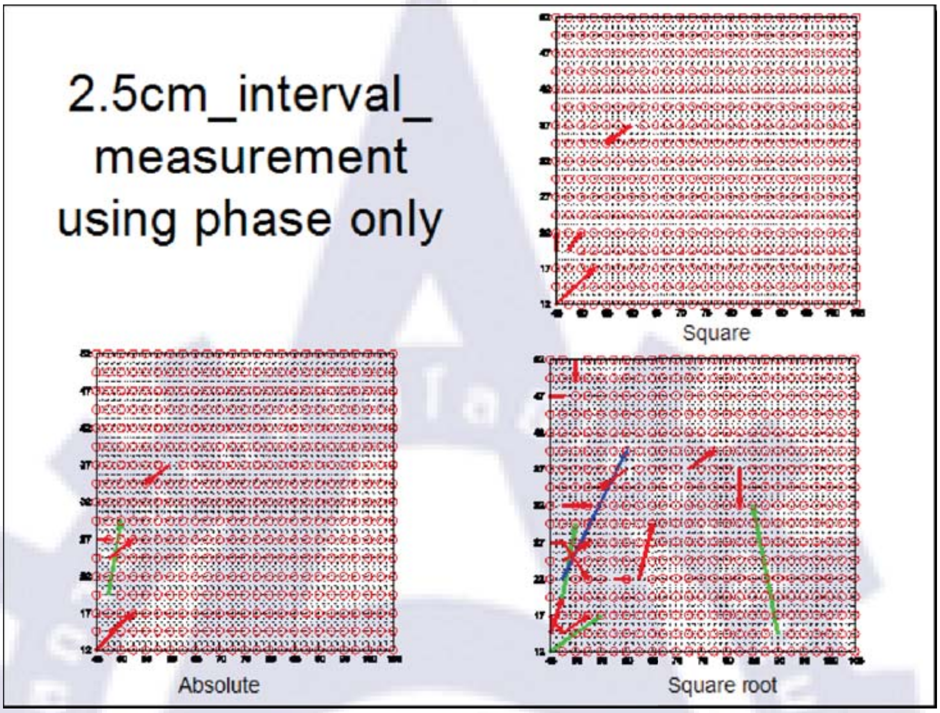


Figure4.2 Graph result of 2.5 cm interval using phase only. Square formula gives the best result, Number of position is smallest

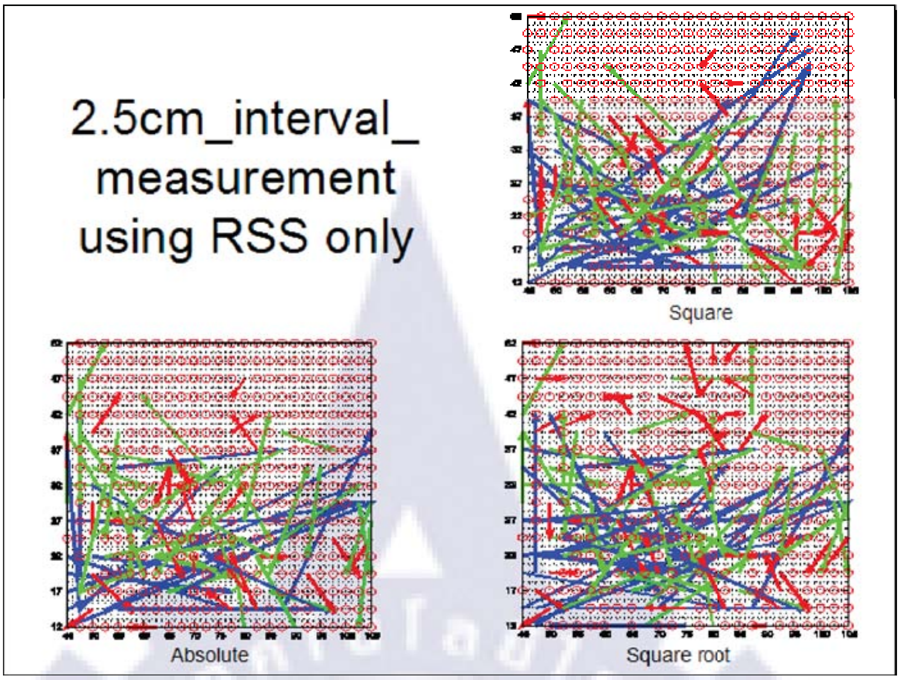


Figure4.3 Graph result of 2.5 cm interval using RSS only. Absolute formula gives the best result, Number of position is smallest

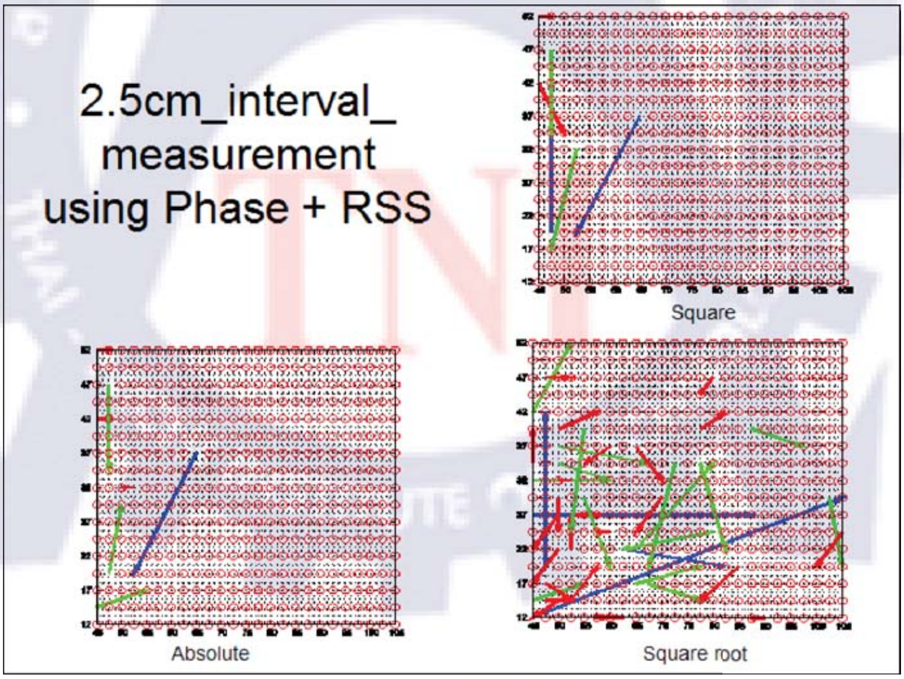


Figure4.4 Graph result of 2.5 cm interval using phase + RSS*10. Absolute formula gives the best result, Number of position is smallest.

Table4.1 Result data of each formula which electrode array is clipped at the top and right side of 2DC sheet

2.5cm_interval_measurement
(electrode 2 sides top, right)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	99.06	5.16	9.01	98.59	6.43	10.31	95.53	6.85	21.51
RSS	76.24	16.12	60.47	79.06	16.37	64.08	70.82	15.55	64.08
Phase-RSS	98.59	13.97	22.50	98.35	8.87	21.51	90.12	11.37	62.50

Best case is	Square formula using Phase
Worst case is	Square root formula using RSS

Table4.1 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the top and right side of 2DC sheet) the result shows that square formula using phase only gives the best result and square root formula using RSS only gives the worst result.

2) Graph result of 2.5cm interval in which electrode arrays are clipped at the top and bottom side of the 2DC sheet.

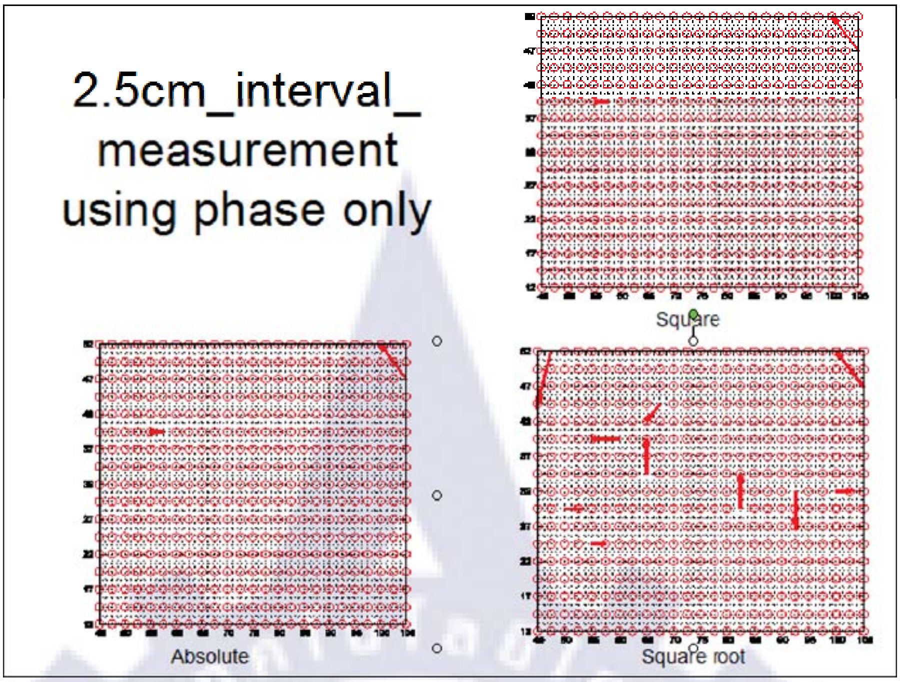


Figure4.5 Graph result of 2.5 cm interval using phase only. Square formula gives the best result, Number of position is smallest

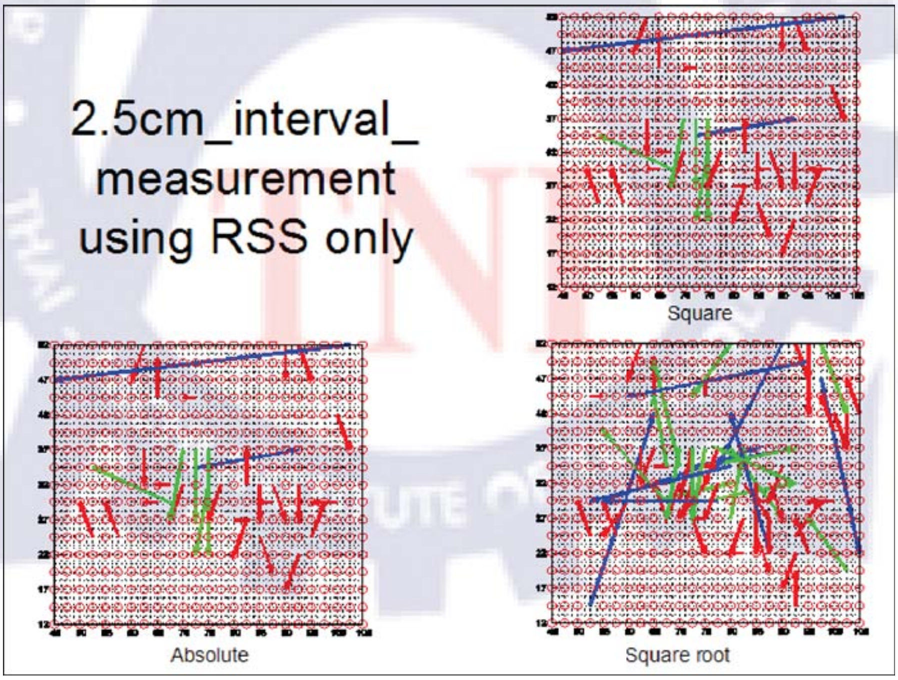


Figure4.6 Graph result of 2.5 cm interval using RSS only. Square formula gives the best result, Number of position is smallest.

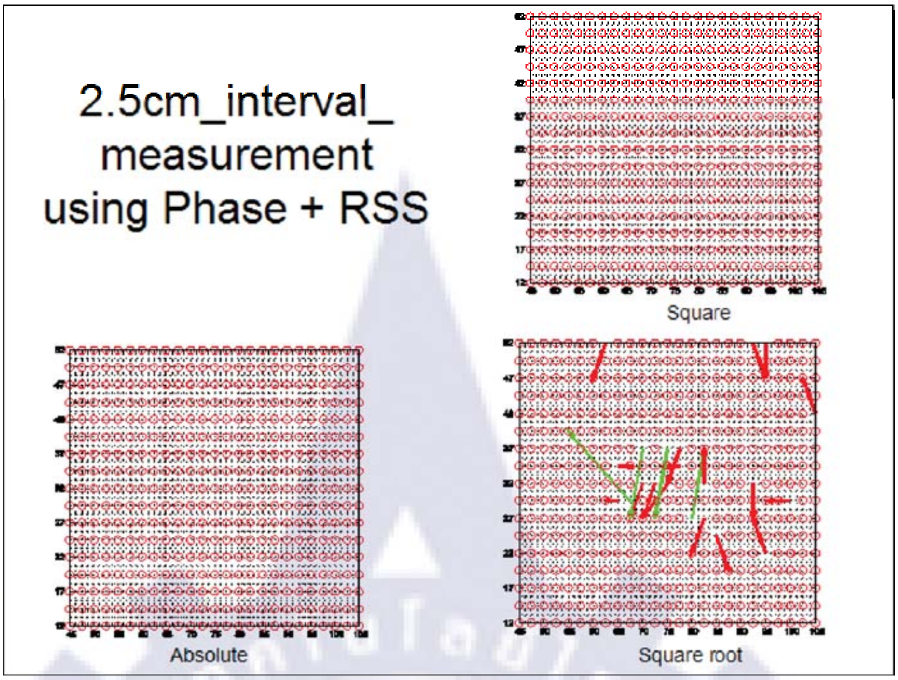


Figure4.7 Graph result of 2.5 cm interval using phase + RSS *10. Square and Absolute formula gives the best result, Number of position is smallest.

Table4.2 Result data of each formula which electrode array is clipped at the top and bottom-side of 2DC sheet.

2.5cm_interval_measurement
(electrode 2 sides top, bottom)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	99.53	4.79	7.07	99.29	2.85	3.54	97.41	4.18	7.91
RSS	92.71	8.19	57.72	89.88	7.63	31.62	84.24	9.70	35.36
Phase+RSS	100.00	0.00	0.00	100.00	0.00	0.00	95.06	6.28	16.01

Best case is	Square and absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.2 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the top and bottom side of 2DC sheet) the result show that square and absolute formula using phase + RSS *10 also gives the best result and square root formula using level only also gives the worst result.

3) Graph result of 2.5cm interval in which electrode arrays are clipped at 4 sides of the 2DC sheet.

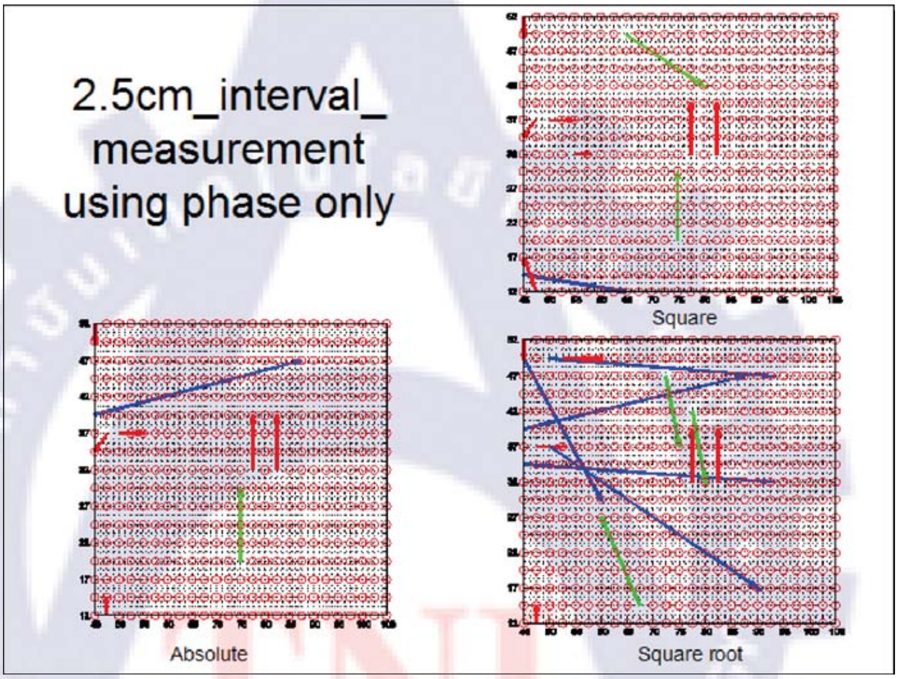


Figure4.8 Graph result of 2.5 cm interval using phase only. Square formula gives the best result, Number of position is smallest.

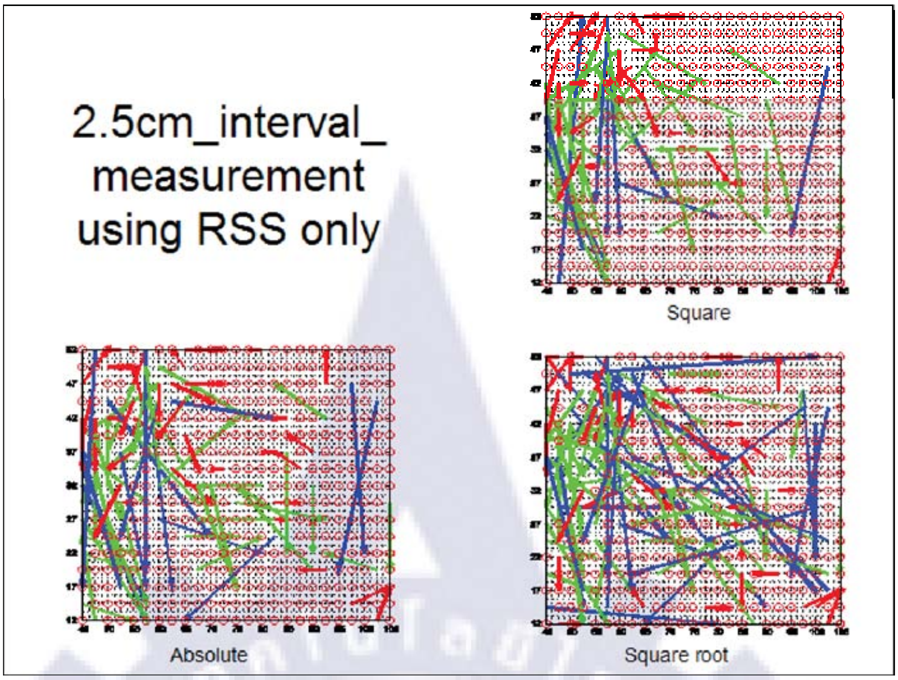


Figure4.9 Graph result of 2.5 cm interval using RSS only. Square formula gives the best result, Number of position is smallest.

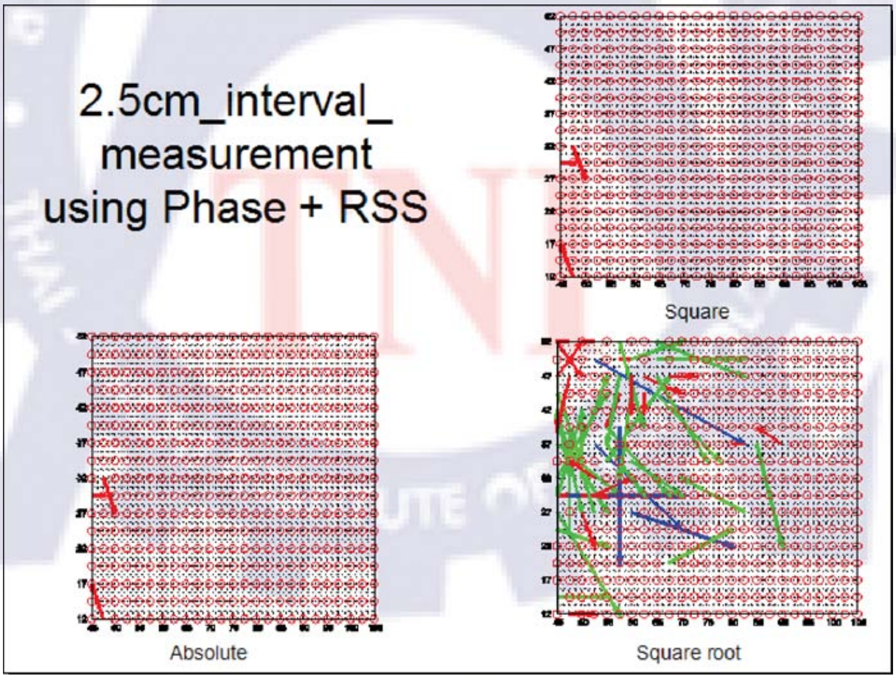


Figure4.10 Graph result of 2.5 cm interval using phase + RSS *10. Absolute formula gives-the best result, Number of position is smallest.

Table4.3 Result data of each formula which electrode array is clipped at the top and right side of 2DC sheet

2.5cm_interval_measurement
(electrode 4 sides)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	97.65	8.11	20.16	98.12	10.21	43.16	96.47	18.21	47.57
RSS	81.41	12.41	40.31	77.88	11.99	35.09	69.65	14.59	57.01
Phase-RSS	99.29	5.59	5.59	99.29	4.56	5.59	87.29	11.52	32.50

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.3 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the 4 sides of 2DC sheet) the result show that absolute formula using phase + RSS *10 gives the best result and square root formula using level only gives the worst result.

4.1.2 Evaluation result of 2.5cm interval without absorber (Setup 2)

The graph result by using 3 formulas which is Square formula, Absolute formula, and Square root formula. The measurement step is 2.5 cm interval for X-axis and Y-axis. Measure the selected area of 2DC sheet to confirm a device location concentrates on its location. The arrow which show in the result is an error distance between origin point and estimated point.

1)Graph result of 2.5cm interval in which electrode arrays are clipped at the top and right side of the 2DC sheet.

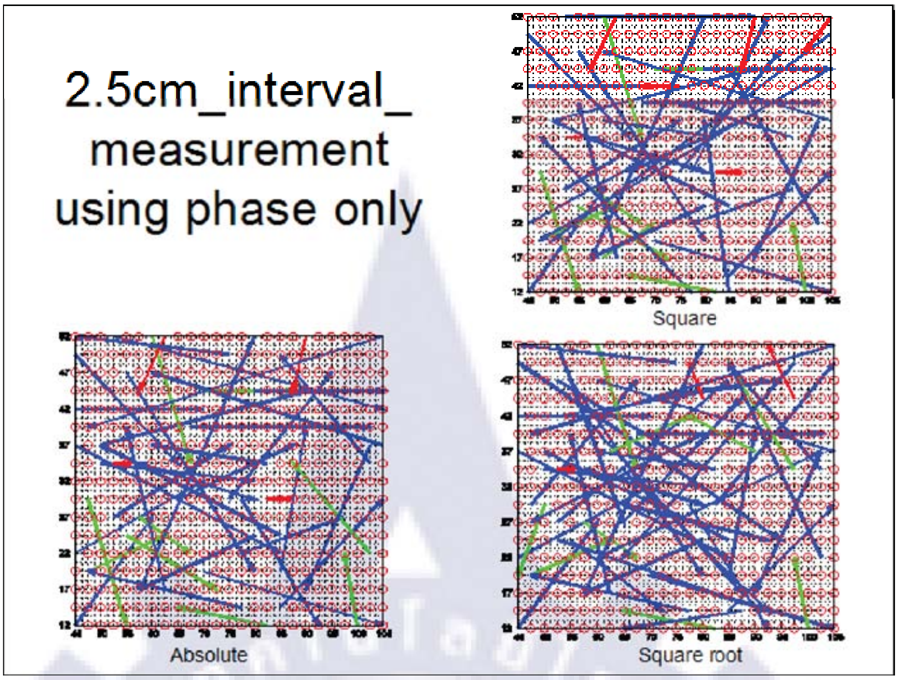


Figure4.11 Graph result of 2.5 cm interval using phase only. Square formula gives the best result, Number of position is smallest

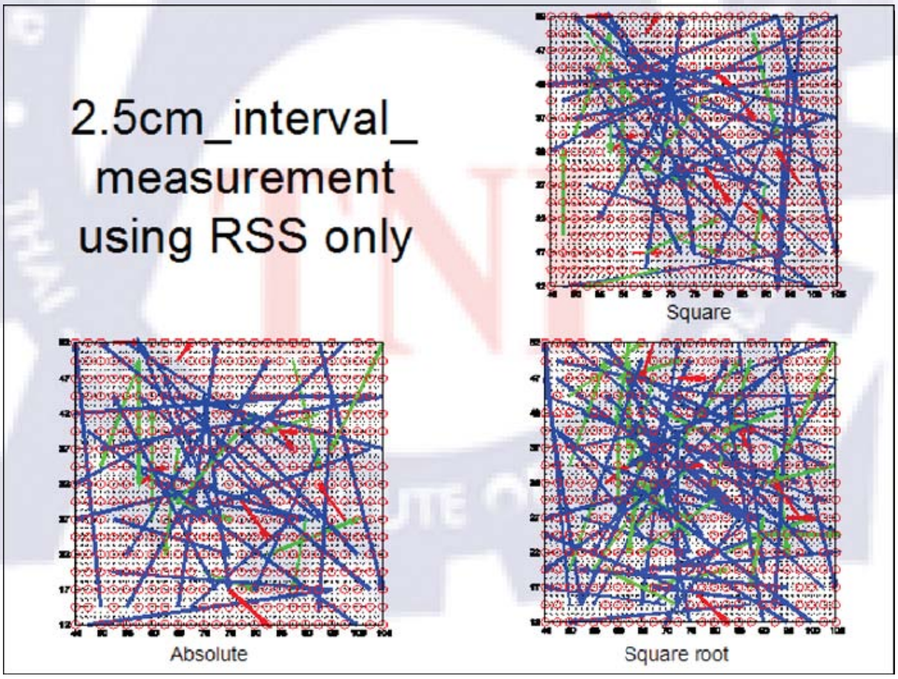


Figure4.12 Graph result of 2.5 cm interval using RSS only. Absolute formula gives the best result, Number of position is smallest

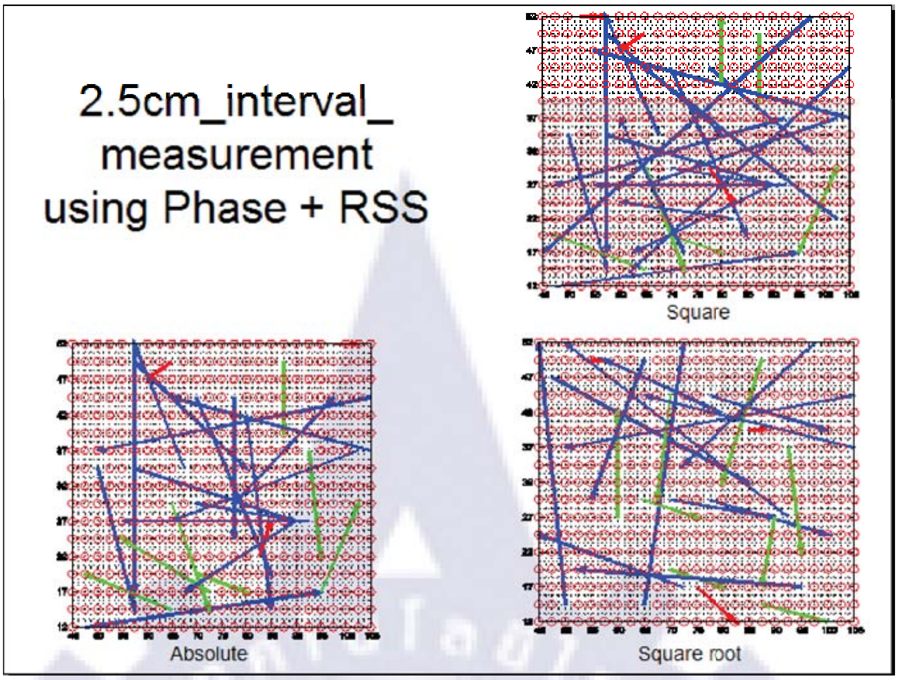


Figure4.13 Graph result of 2.5 cm interval using phase + RSS *10. Square root formula gives the best result, Number of position is smallest.

Table4.4 Result data of each formula which electrode array is clipped at the top and right side of 2DC sheet

2.5cm_interval_measurement
(electrode 2 sides top, right)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	89.18	24.81	62.70	89.41	25.40	58.84	87.06	27.70	58.84
RSS	87.29	25.51	55.51	87.76	25.34	55.51	78.82	25.73	59.42
Phase-RSS	93.41	27.24	63.10	93.88	24.01	55.51	94.12	23.92	55.51

Best case is	Square root formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.4 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the top and right side of 2DC sheet without absorber) the result show that square root formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

2) Graph result of 2.5cm interval in which electrode arrays are clipped at the top and bottom side of the 2DC sheet.

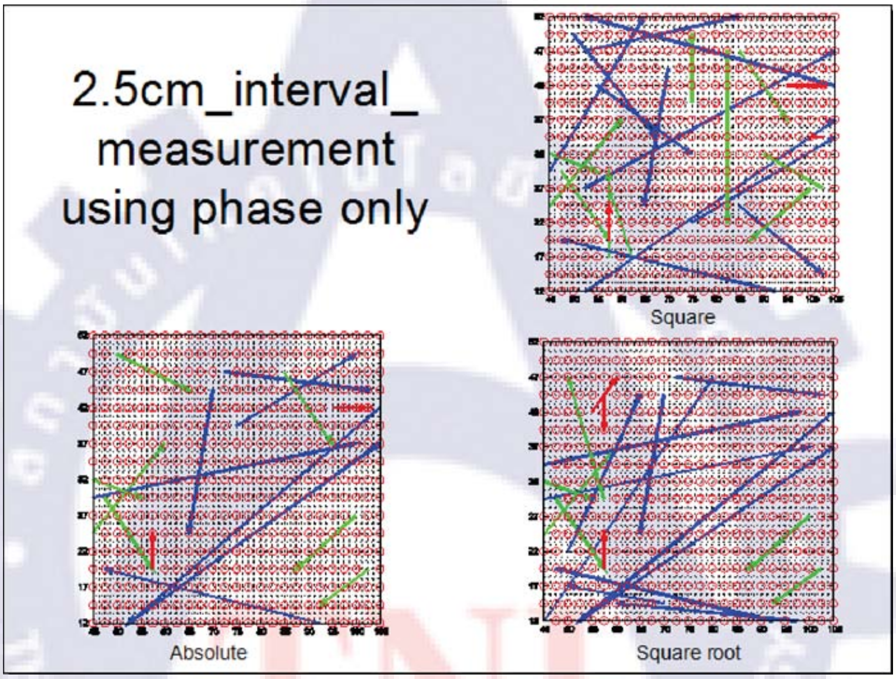


Figure4.14 Graph result of 2.5 cm interval using phase only. Absolute formula gives the best result, Number of position is smallest

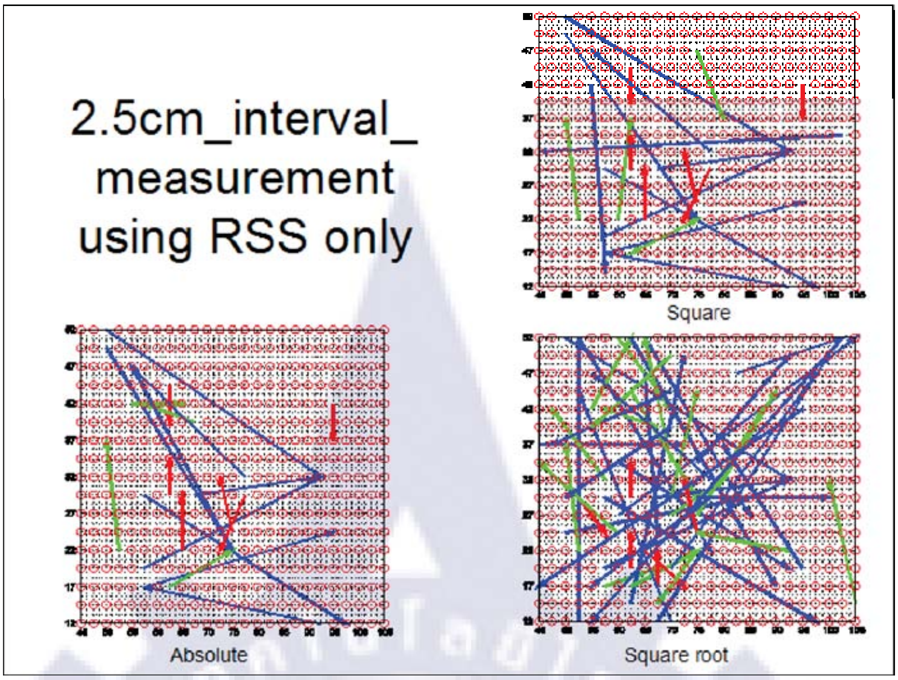


Figure4.15 Graph result of 2.5 cm interval using RSS only. Absolute formula gives the best result, Number of position is smallest.

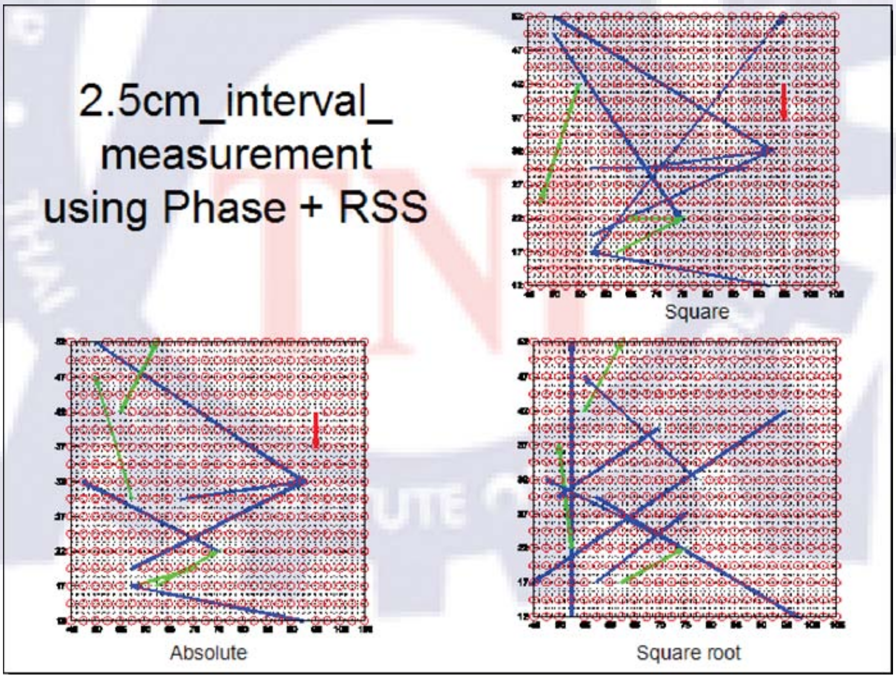


Figure4.16 Graph result of 2.5 cm interval using phase + RSS *10. Absolute formula gives the best result, Number of position is smallest.

Table4.5 Result data of each formula which electrode array is clipped at the top and bottom-side of 2DC sheet.

2.5cm_interval_measurement
(electrode 2 sides top, bottom)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	94.12	22.30	58.15	96.24	25.60	60.47	95.29	28.18	60.47
RSS	95.06	23.04	57.55	95.53	21.64	46.97	87.76	24.94	62.10
Phase+RSS	97.41	28.23	51.30	97.65	23.66	46.97	97.65	27.96	55.90

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.5 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the top and bottom side of 2DC sheet without absorber) the result show that absolute formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

3) Graph result of 2.5cm interval in which electrode arrays are clipped at 4 sides of the 2DC sheet.

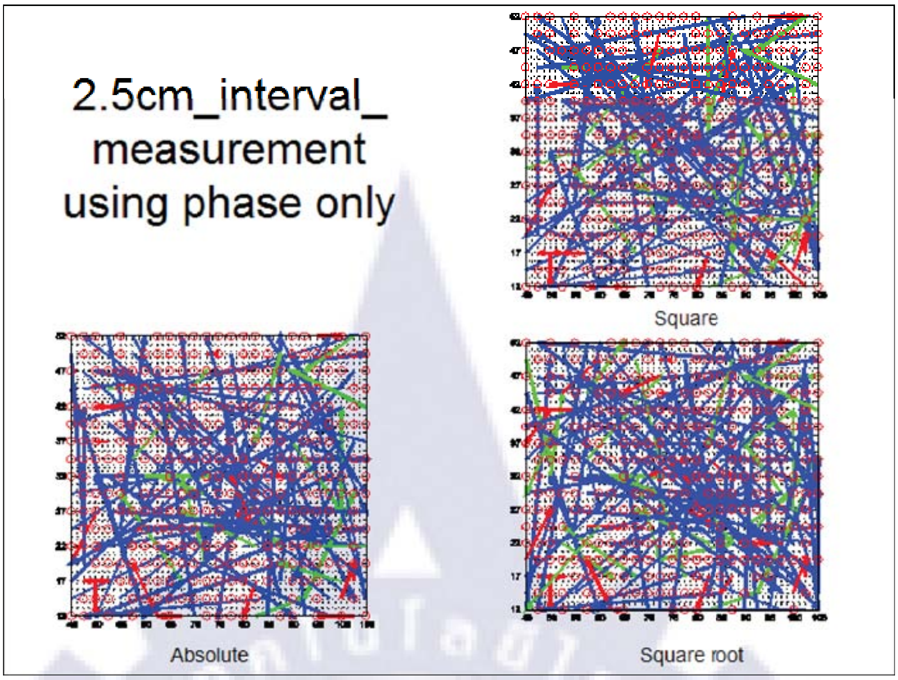


Figure4.17 Graph result of 2.5 cm interval using phase only. Absolute formula gives the best result, Number of position is smallest.

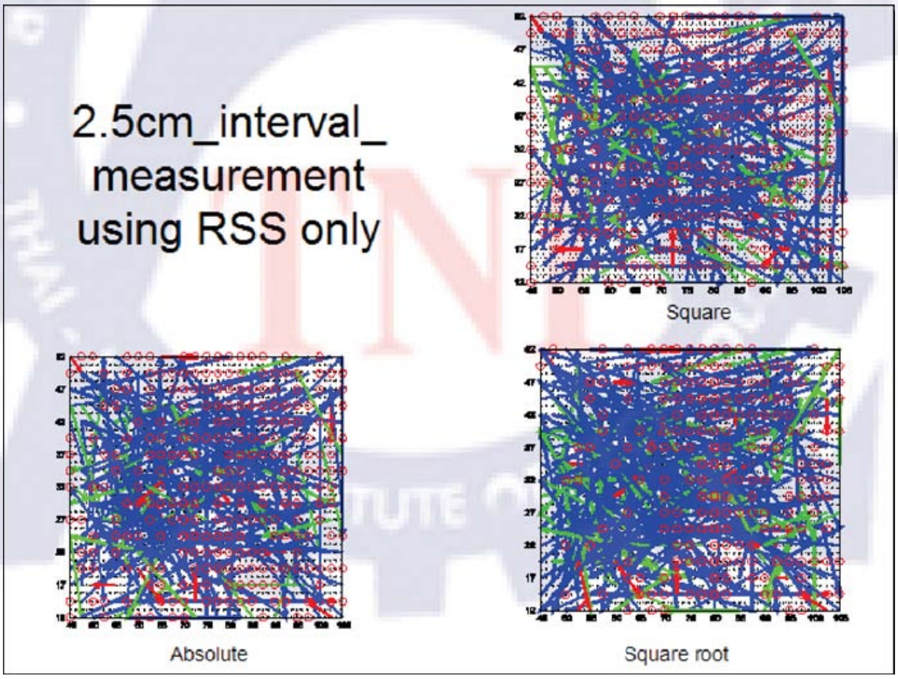


Figure4.18 Graph result of 2.5 cm interval using RSS only. Square formula gives the best result, Number of position is smallest.

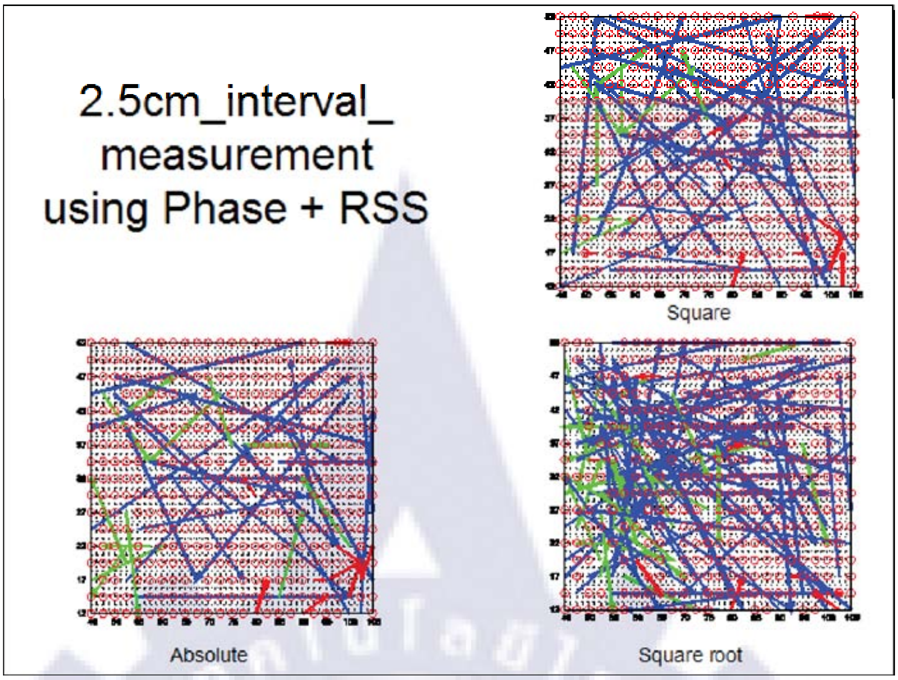


Figure4.19 Graph result of 2.5 cm interval using phase + RSS *10. Absolute formula gives the best result, Number of position is smallest.

Table4.6 Result data of each formula which electrode array is clipped at 4 sides of 2DC sheet

2.5cm_interval_measurement
(electrode 4 sides)

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	72.71	26.44	60.42	73.41	25.18	59.42	67.53	24.64	63.10
RSS	64.71	29.27	68.65	60.71	28.25	68.65	47.06	28.67	68.65
Phase+RSS	87.06	25.57	58.15	88.71	23.33	58.31	76.71	28.06	68.65

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.6 reveals the result after calculated by those 3 formulas, As for this condition (electrode array is clipped at the 4 sides of 2DC sheet without absorber) the result show that absolute formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

4.1.3 Evaluation result of 2.5cm interval average 20 times measurement for first measurement and 1cm interval for second measurement. (Setup 3)

The graph result by using 3 formulas which is Square formula, Absolute formula, and Square root formula. The measurement step is 2.5 cm for first measurement and 1 cm for second measurement interval for X-axis and Y-axis. Measure the selected area of 2DC sheet to confirm a device location concentrates on its location. The arrow which shows in the result is an error distance between origin point and estimated point.

1) Graph result of 2.5cm interval average 20 times measurement for first measurement and 1cm interval for second measurement.

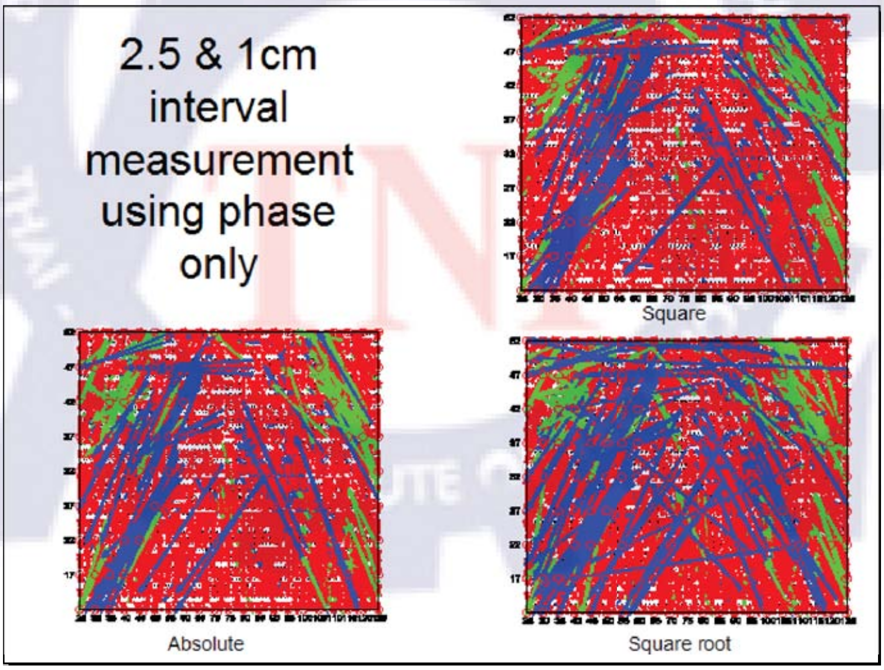


Figure4.20 Graph result of 2.5 &1cm interval using phase only.

Square formula gives the best result, Number of position is smallest

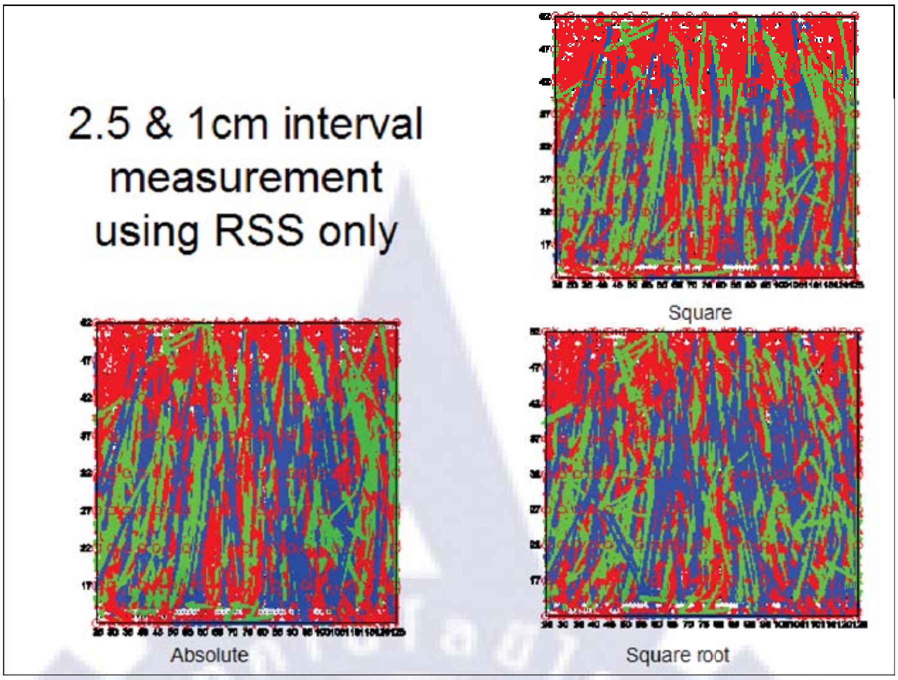


Figure4.21 Graph result of 2.5 & 1cm interval using RSS only. Square formula gives the best result, Number of position is smallest

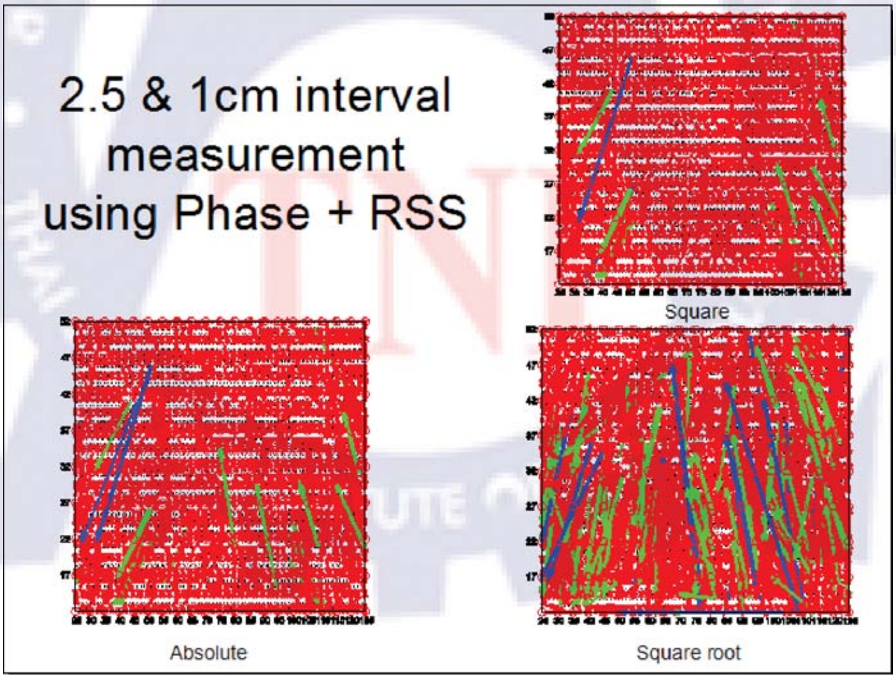


Figure4.22 Graph result of 2.5 & 1cm interval using phase + RSS *10. Square formula gives the best result, Number of position is smallest.

Table4.7 Result data of each formula which 2.5cm interval average 20 times measurement for first measurement and 1cm interval for second measurement.

2.5 & 1 cm interval measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	83.14	16.10	87.04	81.45	15.29	87.04	74.86	14.67	98.01
RSS	54.60	11.12	50.00	52.21	11.20	49.00	44.87	11.77	48.00
Phase-RSS	94.64	25.26	30.30	93.07	20.33	30.30	75.75	10.45	48.00

Best case is	Square formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.7 reveals the result after calculated by those 3 formulas, As for this condition (2.5cm interval average 20 times measurement for first measurement and 1cm interval for second measurement) the result show that square formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

4.1.4 Evaluation result of 2.5cm interval average 20 times measurement for first measurement and rotate antenna measurement. (Setup 4)

The graph result by using 3 formulas which is Square formula, Absolute formula, and Square root formula. The measurement step is 2.5 cm interval for first measurement and rotate antenna measurement for X-axis and Y-axis. Measure the selected area of 2DC sheet to confirm a device location concentrates on its location. The arrow which show in the result is an error distance between origin point and estimated point.

1) Graph of 2.5cm interval average 20 times measurement for first measurement and 45°measurement.

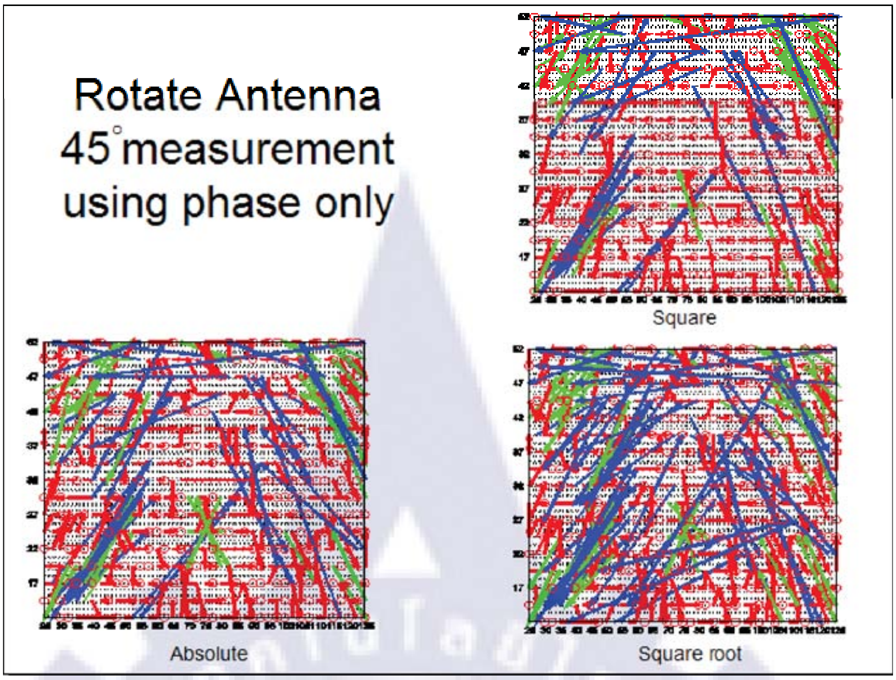


Figure4.23 Graph result of 45° using phase only. Square formula gives the best result, Number of position is smallest

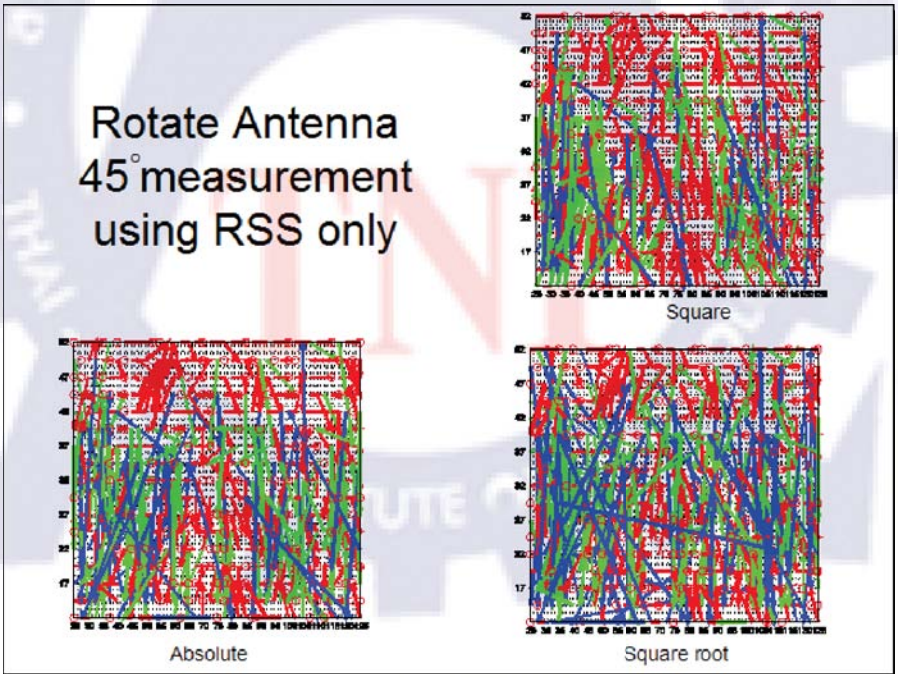


Figure4.24 Graph result of 45° using RSS only. Square formula gives the best result, Number of position is smallest

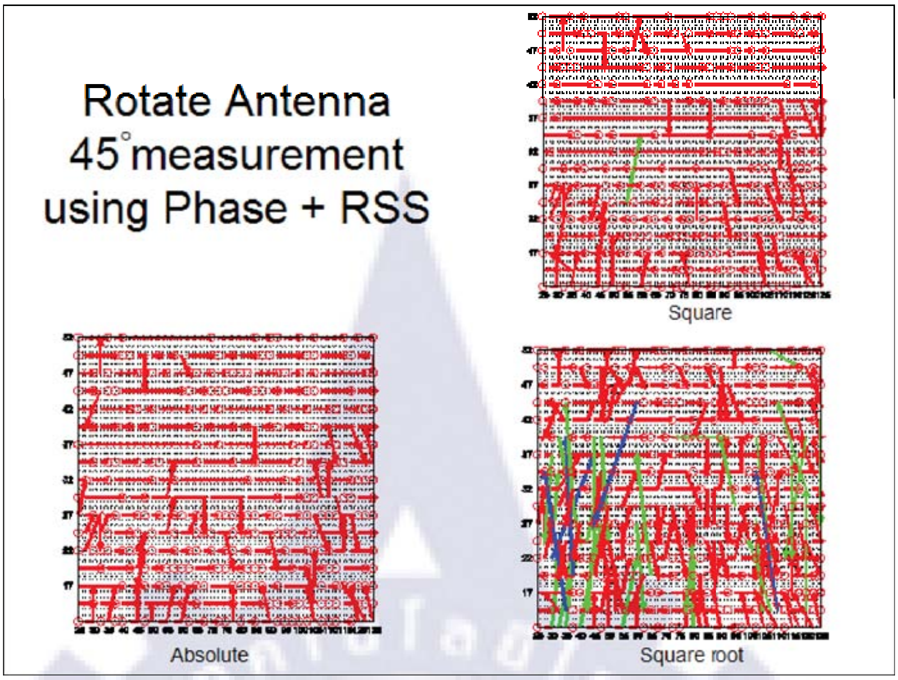


Figure4.25 Graph result of 45° using phase + RSS *10. Absolute formula gives the best result, Number of position is smallest.

Table4.8 Result data of each formula which rotate antenna set at 45°

Rotate Antenna 45° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	36.15	5.98	85.15	34.29	6.44	85.15	30.70	8.45	97.53
RSS	24.82	7.31	37.58	22.53	7.57	37.58	20.23	9.44	82.84
Phase-RSS	41.18	2.83	11.18	42.75	2.82	9.01	34.15	4.29	23.05

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.8 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 45°) the result show that square formula using phase + RSS*10 gives the best result and square root formula using RSS only also give the worst result.

2) Graph of 2.5cm interval average 20 times measurement for first measurement and 90°measurement.

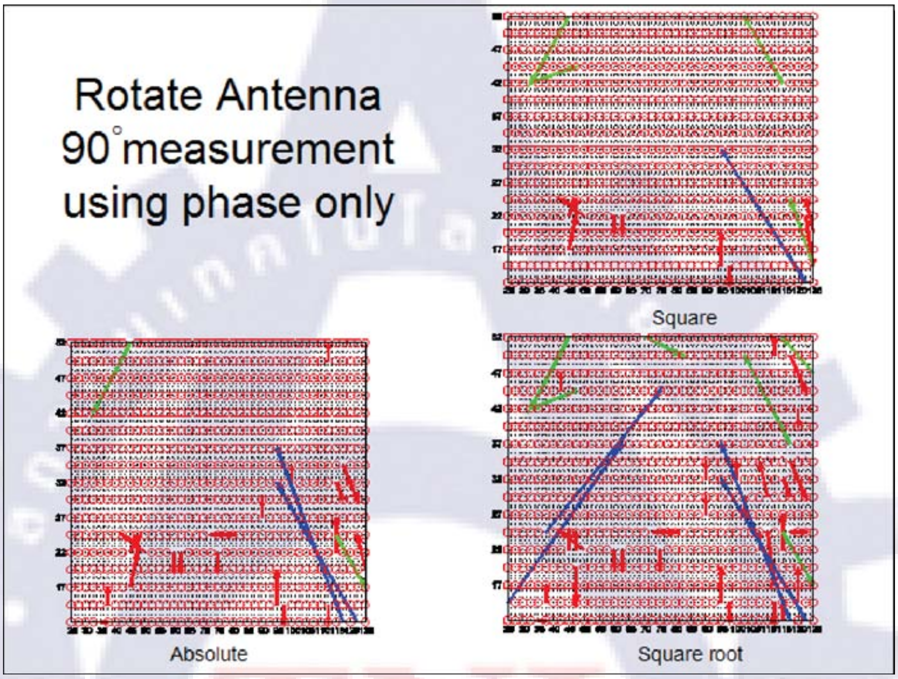


Figure4.26 Graph result of 90° using phase only. Square formula gives the best result, Number of position is smallest

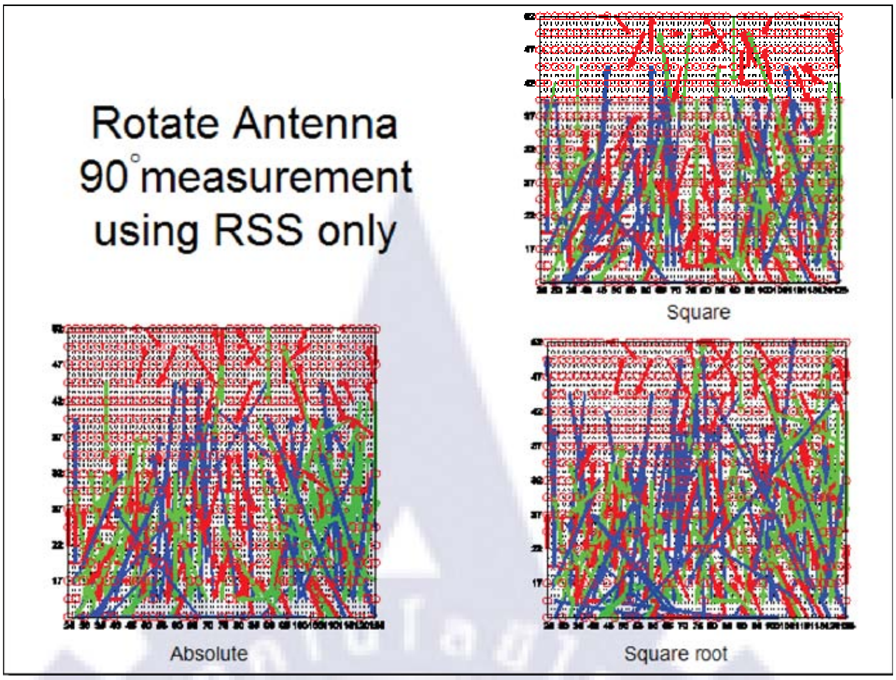


Figure4.27 Graph result of 90° using RSS only. Square formula gives the best result, Number of position is smallest

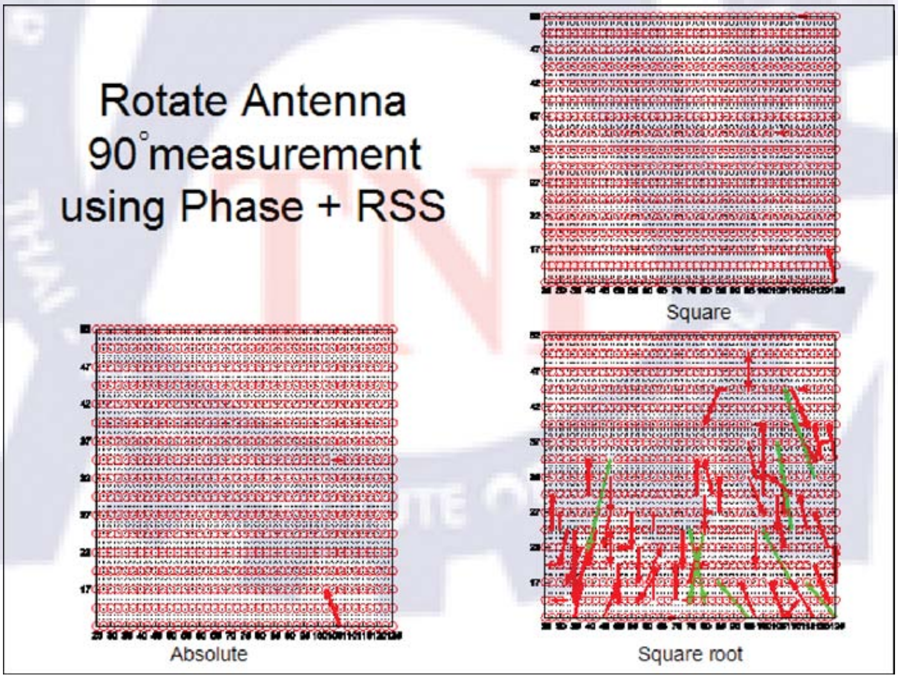


Figure4.28 Graph result of 90° using phase + RSS *10. Absolute formula gives the best result, Number of position is smallest.

Table4.9 Result data of each formula rotate antenna set at 90°

Rotate Antenna 90° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	97.85	9.28	34.00	96.56	7.27	34.00	94.12	8.78	43.73
RSS	64.42	10.39	52.50	62.27	10.82	52.50	56.38	12.18	53.68
Phase-RSS	99.57	3.53	5.59	99.71	4.79	7.07	88.95	5.93	16.01

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.9 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 90°) the result show that square formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

3) Graph of 2.5cm interval average 20 times measurement for first measurement and 135°measurement.

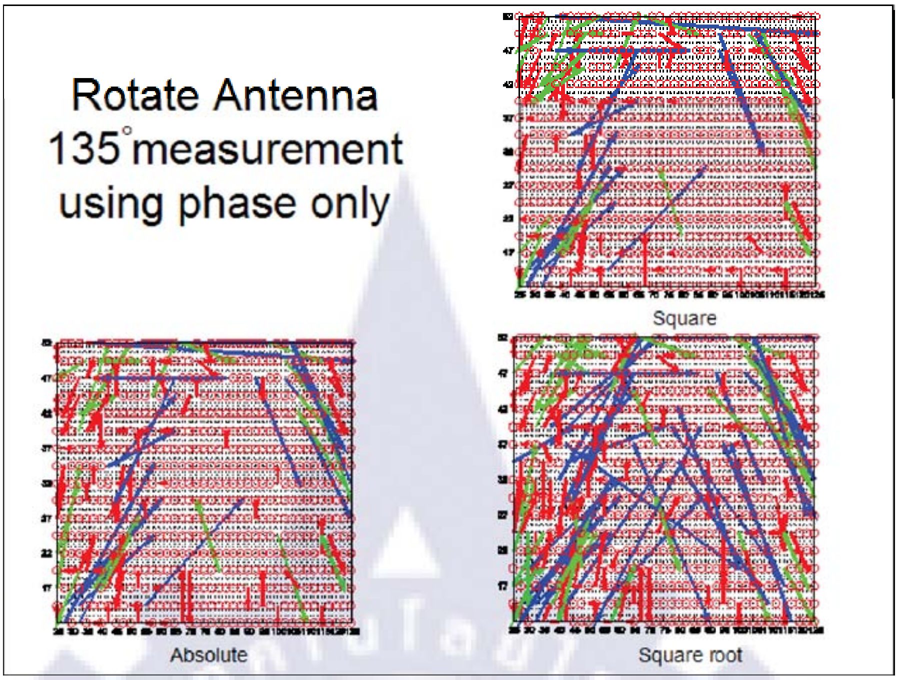


Figure4.29 Graph result of 135° using phase only. Square formula gives the best result, Number of position is smallest

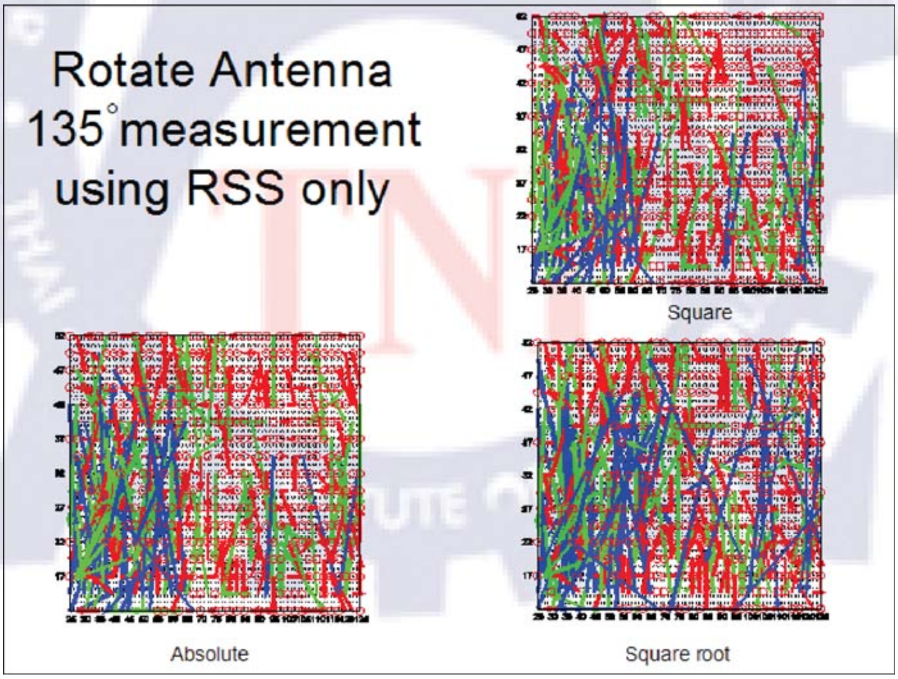


Figure4.30 Graph result of 135° using RSS only. Absolute formula gives the best result, Number of position is smallest

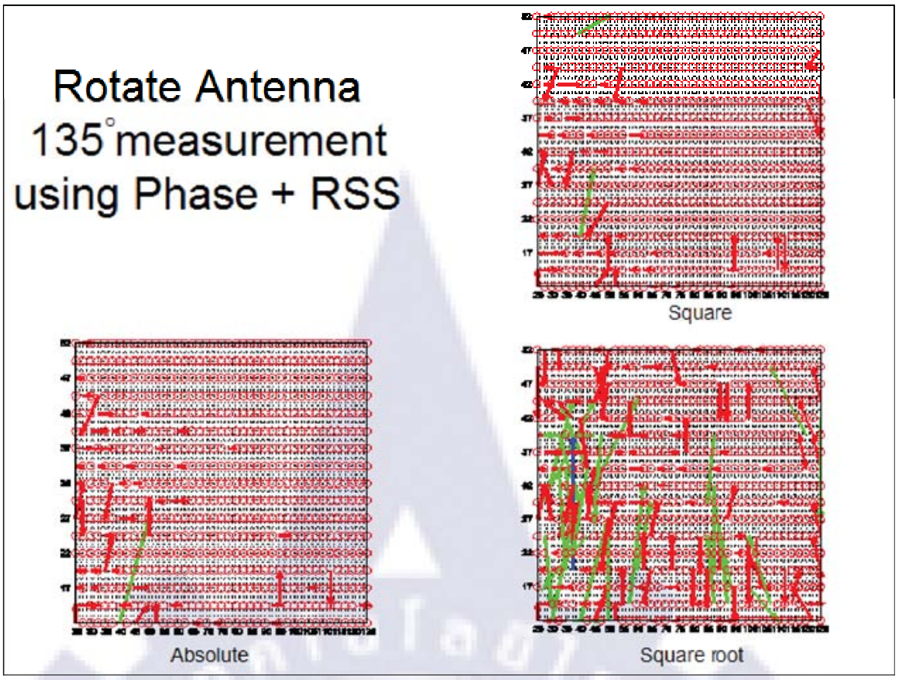


Figure4.31 Graph result of 135° using phase + RSS *10. Absolute formula gives the best result, Number of position is smallest.

Table4.10 Result data of each formula rotate antenna set at 135°

Rotate Antenna 135°measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	83.36	10.20	87.54	82.07	10.27	87.54	71.45	11.19	72.50
RSS	49.64	9.85	35.79	51.94	9.78	35.79	45.05	10.82	83.82
Phase-RSS	89.96	3.59	11.18	91.94	3.43	18.03	74.18	5.62	20.00

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.10 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 135°) the result show that square formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

4) Graph of 2.5cm interval average 20 times measurement for first measurement and 180°measurement.

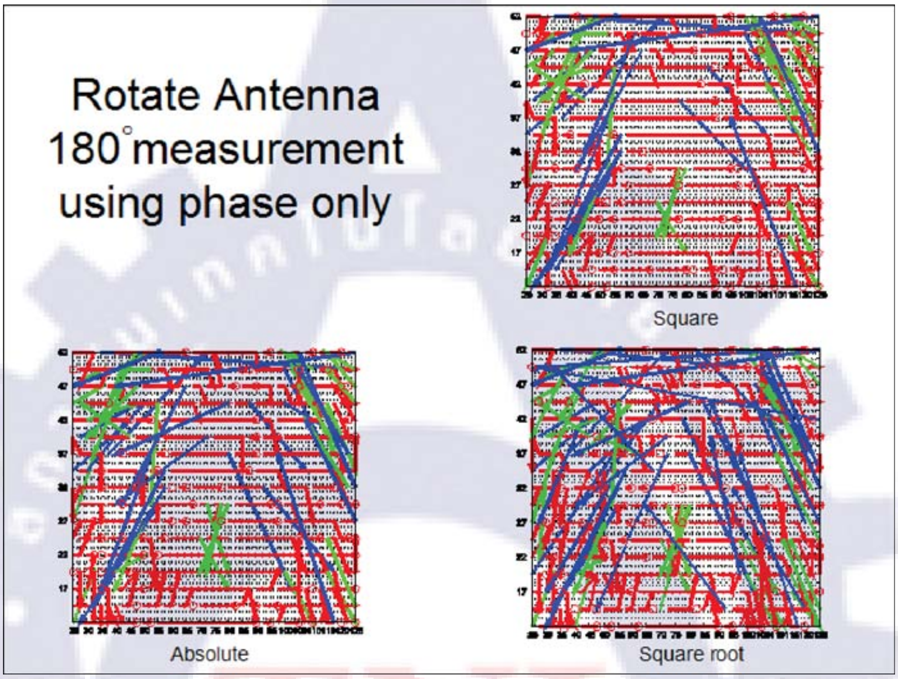


Figure4.32 Graph result of 180° using phase only. Square formula gives the best result, Number of position is smallest

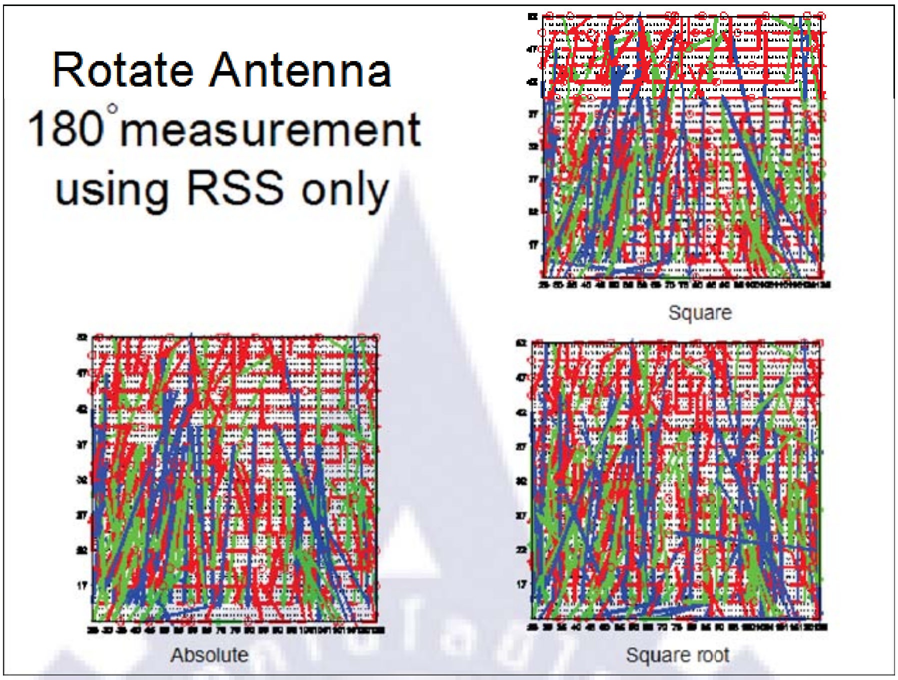


Figure4.33 Graph result of 180° using RSS only. Square formula gives the best result, Number of position is smallest

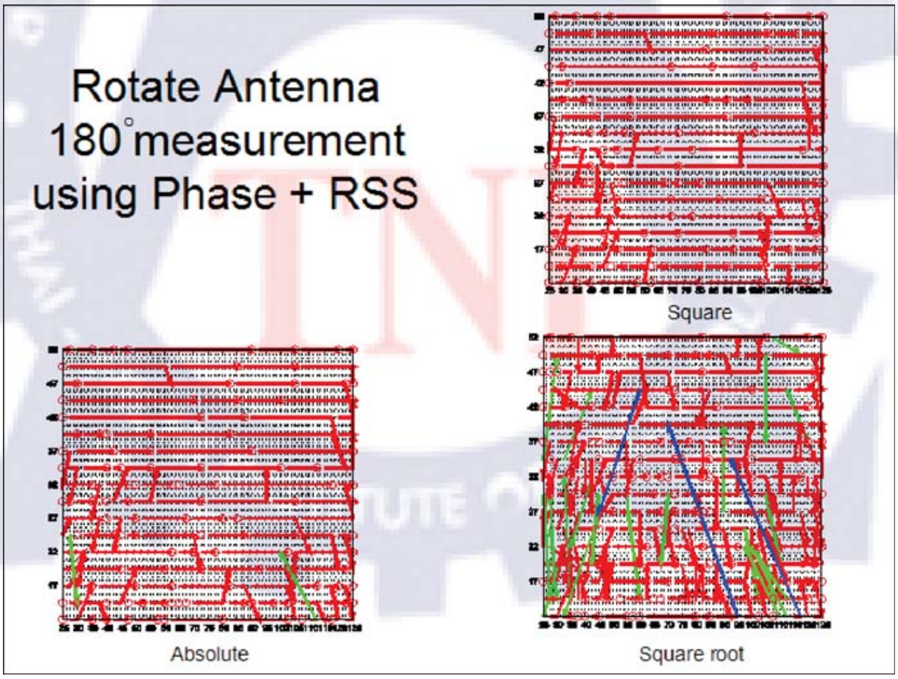


Figure4.34 Graph result of 180° using phase + RSS *10. Square root formula gives the best result, Number of position is smallest.

Table4.11 Result data of each formula which rotate antenna set at 180°

Rotate Antenna 180°measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	13.49	4.41	87.54	12.48	4.61	87.54	12.48	5.65	100.28
RSS	15.21	6.74	42.57	13.63	6.74	38.89	12.77	7.83	52.02
Phase-RSS	17.22	2.67	7.07	16.50	2.73	16.01	18.22	3.74	37.17

Best case is	Square root formula using Phase + RSS
Worst case is	Square root formula using phase

Table4.11 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 180°) the result show that square formula using phase + RSS *10 gives the best result and square root formula using RSS only gives the worst result.

5) Graph of 2.5cm interval average 20 times measurement for first measurement and 225°measurement.

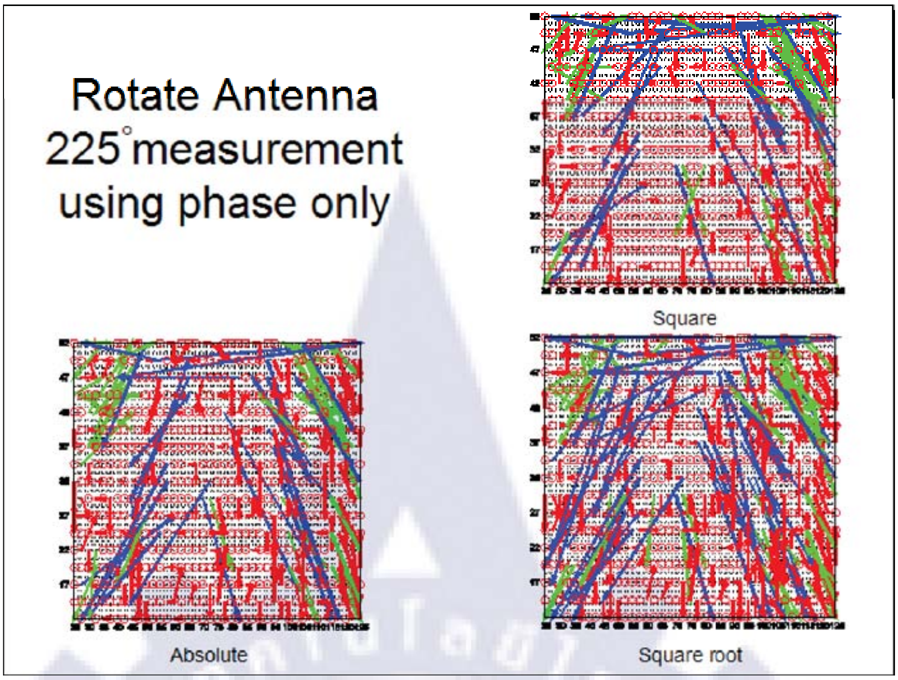


Figure4.35 Graph result of 225° using phase only. Square formula gives the best result, Number of position is smallest

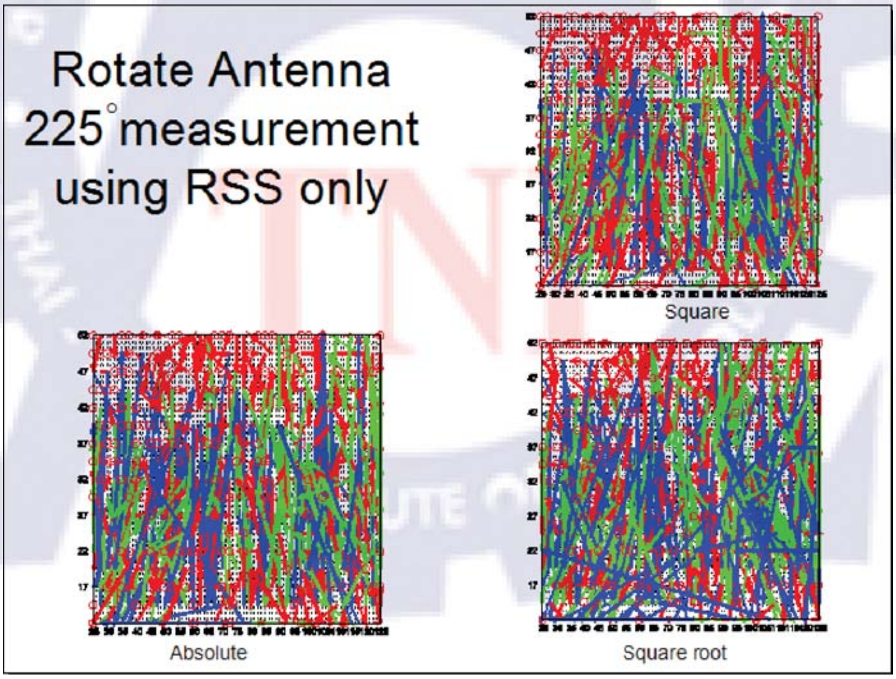


Figure4.36 Graph result of 225° using RSS only. Square formula gives the best result, Number of position is smallest

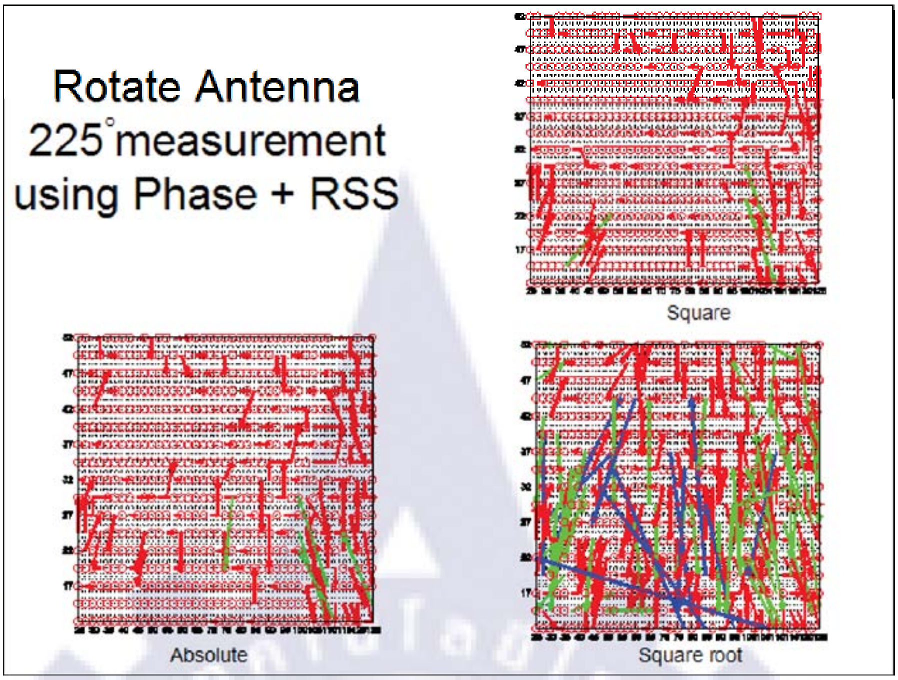


Figure4.37 Graph result of 225° using phase + RSS *10. Square formula gives the best result, Number of position is smallest.

Table4.12 Result data of each formula which rotate antenna set at 225°

Rotate Antenna 225° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	64.71	8.43	87.54	59.25	8.15	85.15	48.92	8.95	85.15
RSS	26.54	9.53	38.16	24.53	10.28	52.50	18.36	11.95	83.10
Phase+RSS	75.75	3.52	16.77	73.74	3.73	16.01	45.77	6.50	83.10

Best case is	Square formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.12 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 225°) the result show that square formula using phase + RSS*10 gives the best result and square root formula using level only gives the worst result.

6) Graph of 2.5cm interval average 20 times measurement for first measurement and 270°measurement.

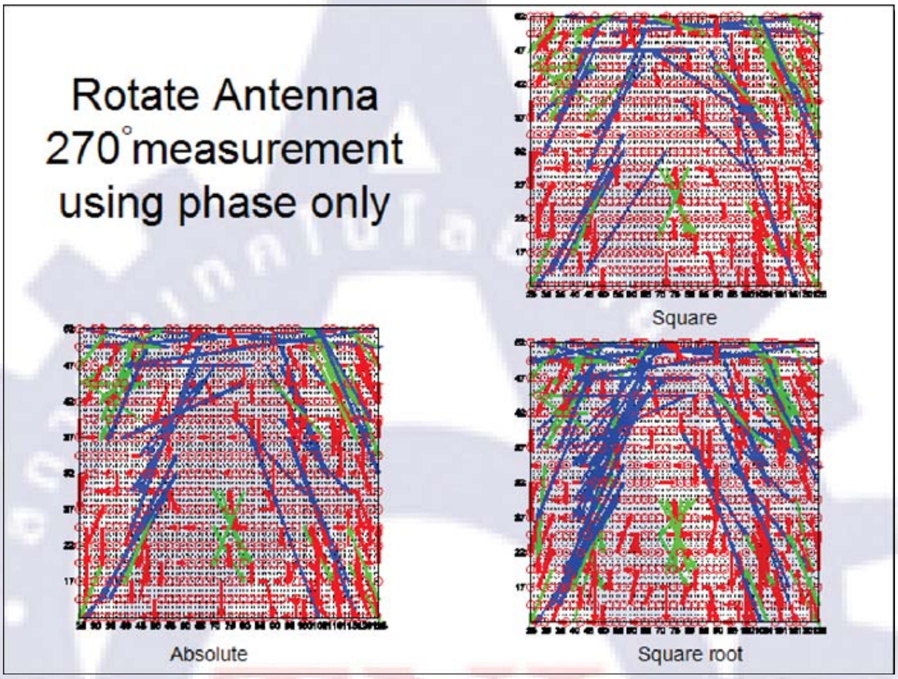


Figure4.38 Graph result of 270° using phase only. Square formula gives the best result, Number of position is smallest

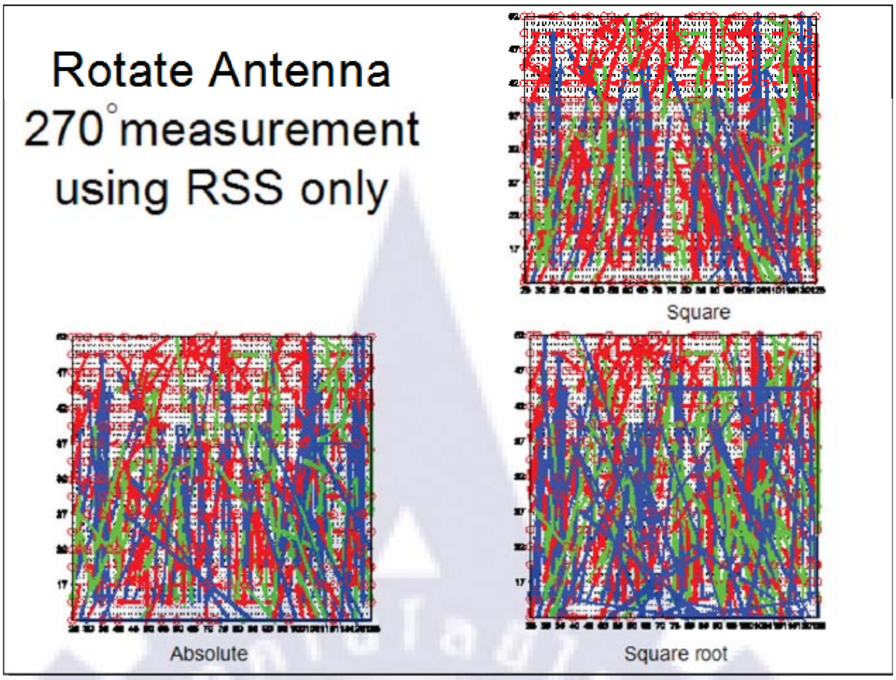


Figure4.39 Graph result of 270° using RSS only. Square formula gives the best result, Number of position is smallest

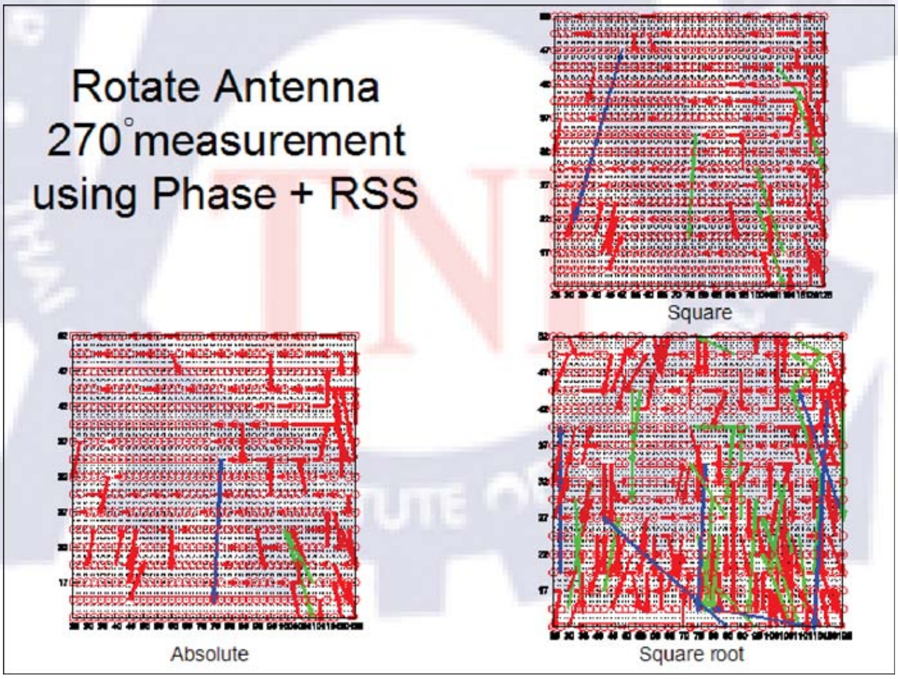


Figure4.40 Graph result of 270° using phase + RSS x 10. Square formula gives the best result, Number of position is smallest.

Table4.13 Result data of each formula which rotate antenna set at 270°

Rotate Antenna 270° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	68.58	8.25	87.54	65.57	8.70	87.54	55.09	9.47	87.54
RSS	34.58	9.00	41.00	33.43	9.52	52.50	26.26	11.38	50.00
Phase-RSS	79.77	3.71	30.52	78.62	3.48	20.16	56.10	5.25	45.07

Best case is	Square formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.13 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 270°) the result show that square formula using phase + RSS x 10 gives the best result and square root formula using RSS only gives the worst result.

7) Graph of 2.5cm interval average 20 times measurement for first measurement and 315°measurement.

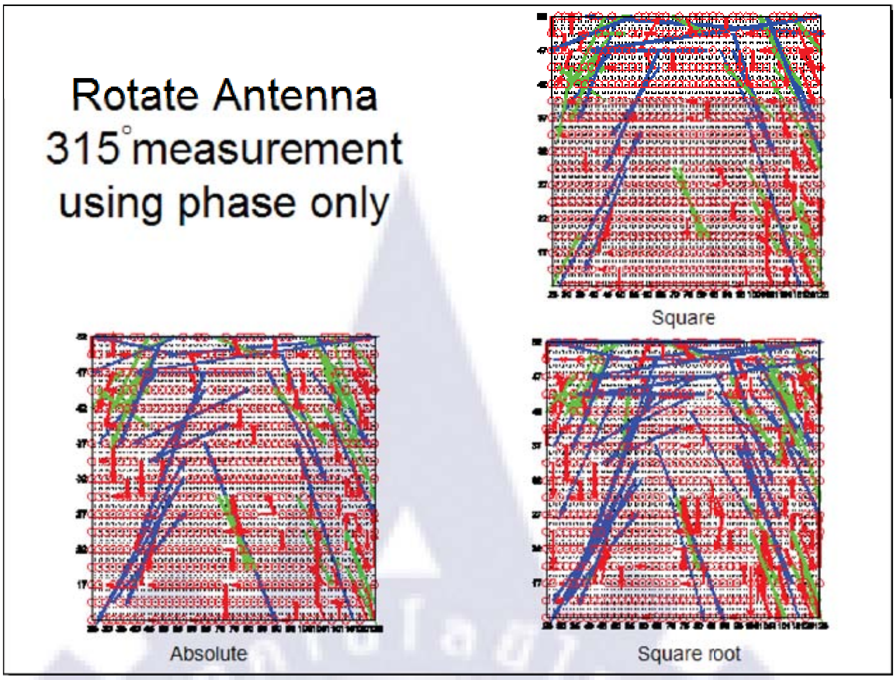


Figure4.41 Graph result of 315° using phase only. Square formula gives the best result, Number of position is smallest

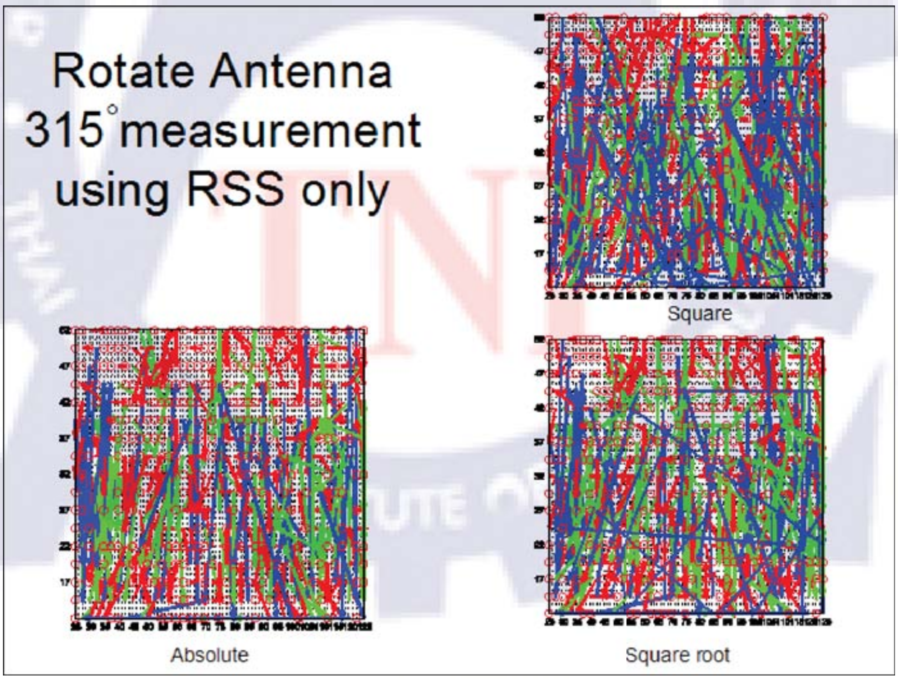


Figure4.42 Graph result of 315° using RSS only. Absolute formula gives the best result, Number of position is smallest

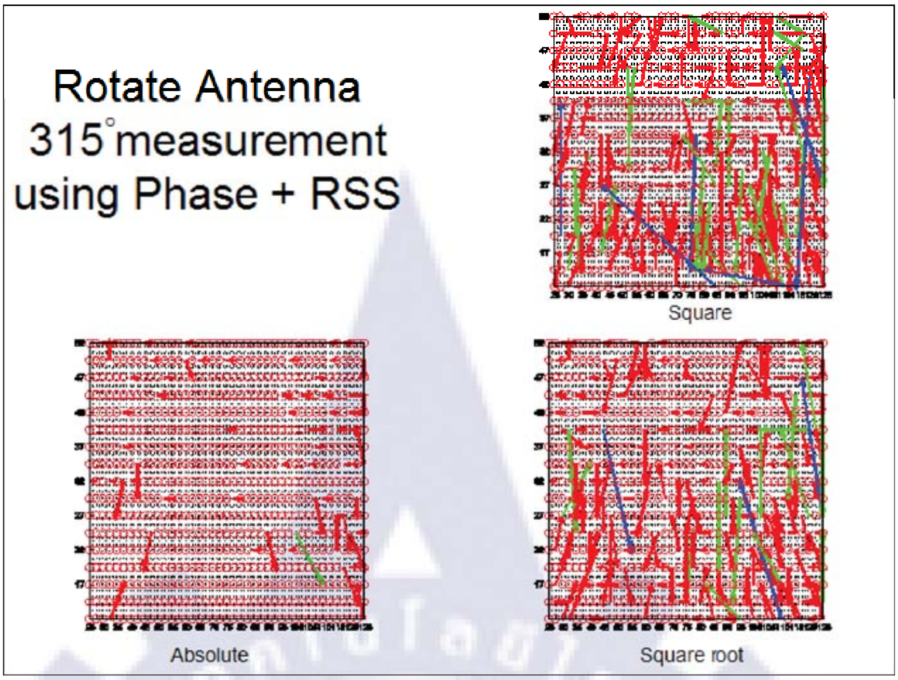


Figure4.43 Graph result of 315° using phase + RSS x 10. Square formula gives the best result, Number of position is smallest.

Table4.14 Result data of each formula rotate antenna set at 315°

Rotate Antenna 315° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	81.49	9.55	87.54	77.76	10.14	85.15	70.30	11.68	97.50
RSS	42.04	8.93	53.50	42.47	9.25	52.50	37.88	10.50	87.54
Phase+RSS	90.82	3.45	12.50	90.53	3.32	12.50	67.72	4.94	25.00

Best case is	Square formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.14 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 315°) the result show that square formula using phase + RSS x 10 gives the best result and square root formula using RSS only gives the worst result.

8) Graph of 2.5cm interval average 20 times measurement for first measurement and 360°measurement.

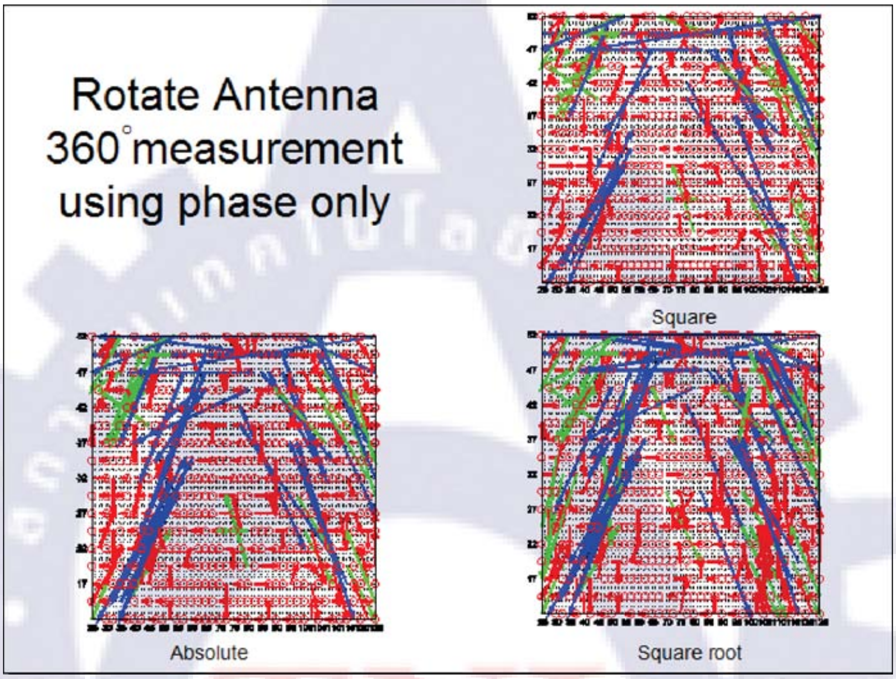


Figure4.44 Graph result of 360° using phase only. Square formula gives the best result, Number of position is smallest

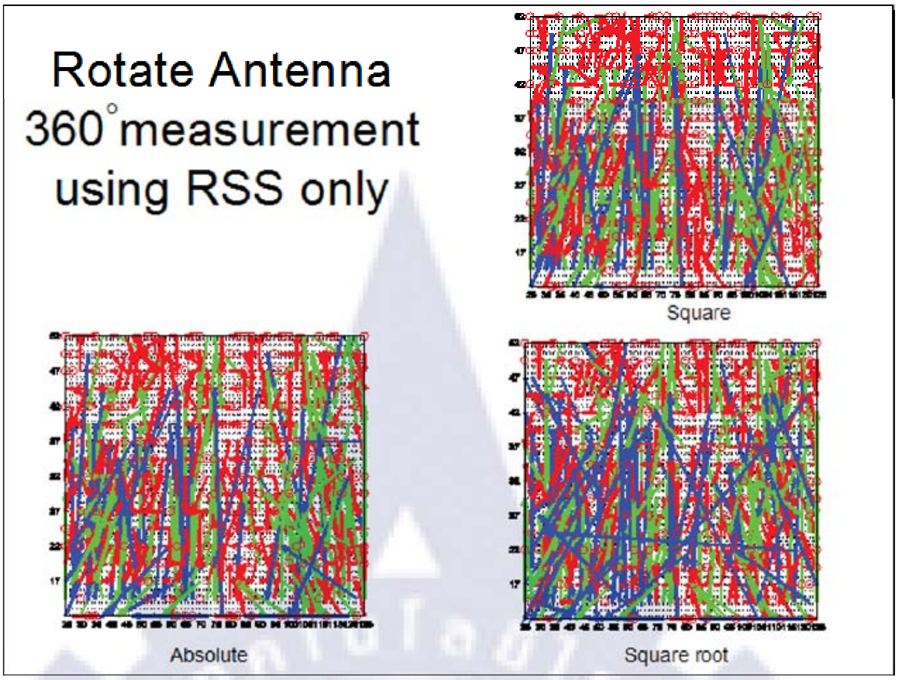


Figure4.45 Graph result of 360° using RSS only. Square formula gives the best result, Number of position is smallest

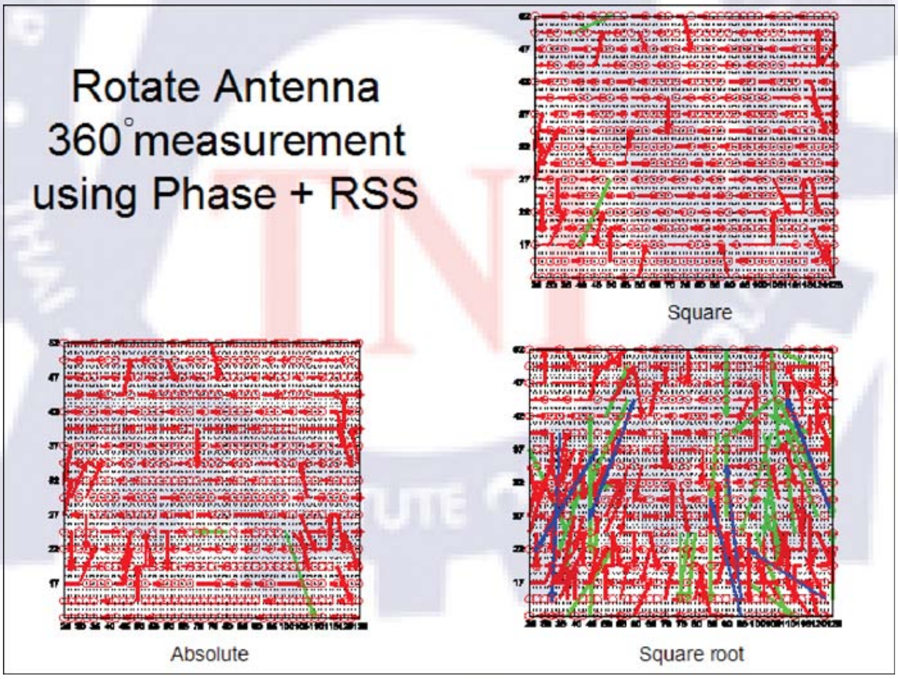


Figure4.46 Graph result of 360° using phase + RSS x 10. Absolute formula gives the best result, Number of position is smallest.

Table4.15 Result data of each formula which rotate antenna set at 360°

Rotate Antenna 360° measurement

	Square			Absolute			Square root		
	Correct estimation ratio[%]	Avg. of error [cm]	Max. error [cm]	Correct estimation radio[%]	Avg. of error [cm]	Max error [cm]	Correct estimation ratio[%]	Avg. of error [cm]	Max error [cm]
Phase	58.68	7.13	85.15	54.81	7.80	85.15	48.21	8.48	85.15
RSS	30.70	8.31	37.17	28.69	8.45	35.36	24.53	9.77	85.04
Phase-RSS	67.58	2.98	14.14	68.72	3.04	16.01	49.07	5.06	26.10

Best case is	Absolute formula using Phase + RSS
Worst case is	Square root formula using RSS

Table4.15 reveals the result after calculated by those 3 formulas, As for this condition (rotate antenna, antenna set at 360°) the result show that square formula using phase + RSS x 10 gives the best result and square root formula using RSS only gives the worst result.

Chapter 5

Conclusion and Recommendation

5.1 Research Summary

There are three major purposes of the experiments as follow

1. To check any effect of with and without wave absorbers.
2. To compares the measurement with two difference interval.
3. To check any effect when antenna being rotated.

According the experimental result we can concludes as follow conditioning with the above mentioned purposes

1. In the case of measuring 2.5 cm interval with and without wave absorbers setup 1 and setup 2, we compare result about with and without wave absorbers. Wave absorbers are used for absorbing the wave from antenna at the edge of 2DC sheet.

In this cooperative education report, we evaluate position estimation method using phase and power level difference of electrode array with and without absorber. Using the method with absorber gives the best result in the case with using square formula and phase + RSS x 10. On the other hand, the result that is obtained from square root formula by using level only yielded the most inaccurate outcome. Using the method without absorber gives the best result in the case with using absolute formula and phase + RSS x 10, and worst result is obtained by square root formula and RSS only, which is aligned with the result from using the method with absorber.

2. In the case of measuring 2.5cm interval average 20 times for first measurement and 1cm interval for second measurement, this is to compare the measurement with 2 different intervals, numerous red lines can be observed from the result due to the fact that they are measured from many different positions. The most accurate result is remained when calculated by using phase + RSS x 10, and most inaccurate case is calculated by using RSS only.

3. In the case of rotated antenna setup 4, we would like to know if there are any effect to the change of the degree of antenna rotating.

In this part of the experiment that used 2.5cm interval average 20 times measurement for first measurement and rotate antenna measurement, observations pointed out that in some cases (i.e. 45 degrees and 180 degrees) numerous redlines are shown in the X-axis. This is because an antenna that is not aligned in the center. As well as the former parts of the experiment, results calculated by absolute formula and phase + RSS x 10 gives the best outcome, while results calculated by square root formula and RSS only yielded the worst outcome.

5.2 Identified Experimental issue and possible solution

Issued identified in this experiment was the antenna has failed to remain in the center. This can be solved by making a new base for the antenna which can be attached to an arm of the robot firmly which will effectively solve the problem.

5.3 Additional Comment

Additional scenario should be integrated in future experiments. One of interesting scenarios is to measure every other point. For instance, first measurement starting point at (0,0) then move on to measure (0,2) then (0,4) so on and so forth, and second measurement staring point at (0,1) then move on to measure (0,3) then (0,4) so on and so forth shows in Figure 5.1.

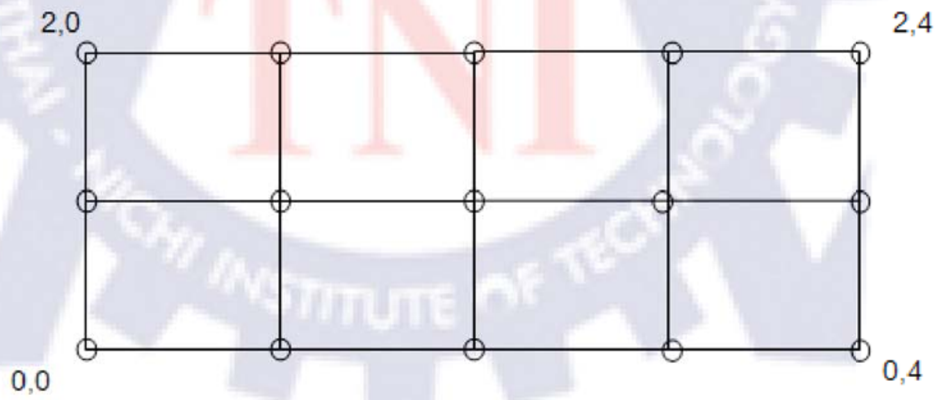


Figure5.1 Position estimation

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2007	:	Universiade Bangkok (Volunteer)
2005	:	Bangkok International Film Festival (Volunteer)
2004	:	XV International AIDS Conference (Volunteer)
2003	:	ABU Robocon (Volunteer)

Appendix A

C Program Source Code for Calculating Measure Data

```
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <string.h>

#define MAX_LEN 256
#define MAX_LINE 5000

int main(void)
{
        FILE* fp1;
        FILE* fp2;
        char fname[80];
        char *ch1;
        char *ch2;
        char* buf1;
        char* buf2;
        int num1 = 0;
        int num2 = 0;
        int i;

        double** data1;
        double** data2;
        char* name1;
        char* name2;
        char** name1_list;
        char** name2_list;
```

```
buf1 = (char*)malloc(sizeof(char)*MAX_LEN);
buf2 = (char*)malloc(sizeof(char)*MAX_LEN);
data1 = (double**)malloc(sizeof(double*)*MAX_LINE);
data2 = (double**)malloc(sizeof(double*)*MAX_LINE);
for(i=0;i<MAX_LINE;i++){
        data1[i] = (double*)malloc(sizeof(double)*8);
        data2[i] = (double*)malloc(sizeof(double)*8);
}
name1_list = (char**)malloc(sizeof(char*)*MAX_LINE);
name2_list = (char**)malloc(sizeof(char*)*MAX_LINE);

printf("Input phase file name 1:");
gets_s(fname);
```

Input phase file 1

```
fp1 = fopen(fname, "r");
if(fp1 == NULL){
        printf("Can't open file\n");
        exit(1);
}
int flag;

while(fgets(buf1, MAX_LEN-1, fp1) != NULL){

        ch1 = strtok(buf1, " ");
        i = 0;
        flag = 0;
        while(ch1 != NULL){
```

```
                if(flag == 0){
                        name1_list[num1] = strdup(ch1);
                        flag = 1;
                }else{
                        data1[num1][i] = atof(ch1);
                        i++;
                }
                ch1 = strtok(NULL, " ");
        }
        num1++;


}
fclose(fp1);
free(buf1);

printf("Input phase file name 2:");
gets_s(fname);

fp2 = fopen(fname, "r");
if(fp2 == NULL){
        printf("Can't open file\n");
        exit(1);
}

while(fgets(buf2, MAX_LEN-1, fp2) != NULL){

        flag = 0;
        ch2 = strtok(buf2, " ");
        i = 0;
```

Input phase file 2

```
        while(ch2 != NULL){
            if(flag == 0){
                name2_list[num2] = strdup(ch2);
                flag = 1;
            }else{
                data2[num2][i] = atof(ch2);
                i++;
            }
            ch2 = strtok(NULL, " ");}
        num2++;


    }

    fclose(fp2);
    free(buf2);

    printf("Input level file name 1:");
    gets_s(fname);

    FILE* fp3;

    fp3 = fopen(fname, "r");
    if(fp3 == NULL){
        printf("Can't open file\n");
        exit(1);
    }

    char* buf3;
    char* ch3;
```

Input level file 1

```
char** name3_list;
double** data3;
int num3 = 0;

buf3 = (char*)malloc(sizeof(char)*MAX_LEN);
data3 = (double**)malloc(sizeof(double*)*MAX_LINE);
for(i=0;i<MAX_LINE;i++){
        data3[i] = (double*)malloc(sizeof(double)*8);
}
name3_list = (char**)malloc(sizeof(char*)*MAX_LINE);


while(fgets(buf3, MAX_LEN-1, fp3) != NULL){

        flag = 0;
        ch3 = strtok(buf3, " ");
        i = 0;
        while(ch3 != NULL){
                if(flag == 0){
                        name3_list[num3] = strdup(ch3);
                        flag = 1;
                }else{
                        data3[num3][i] = atof(ch3);
                        i++;
                }
                ch3 = strtok(NULL, " ");}
        num3++;


}
```

```
fclose(fp3);
free(buf3);

printf("Input level file name 2:");
gets_s(fname);

FILE *fp4;

fp4 = fopen(fname, "r");
if(fp4 == NULL){
        printf("Can't open file\n");
        exit(1);
}
char* buf4;
char* ch4;
char** name4_list;
double** data4;
int num4 = 0;

buf4 = (char*)malloc(sizeof(char)*MAX_LEN);
data4 = (double**)malloc(sizeof(double*)*MAX_LINE);
for(i=0;i<MAX_LINE;i++){
        data4[i] = (double*)malloc(sizeof(double)*8);
}
name4_list = (char**)malloc(sizeof(char*)*MAX_LINE);


while(fgets(buf4, MAX_LEN-1, fp4) != NULL){

        flag = 0;
```

Input level file 2

```
        ch4 = strtok(buf4, " ");
        i = 0;
        while(ch4 != NULL){
                if(flag == 0){
                        name4_list[num4] = strdup(ch4);
                        flag = 1;
                }else{
                        data4[num4][i] = atof(ch4);
                        i++;
                }
                ch4 = strtok(NULL, " ");}
        num4++;
}
fclose(fp4);
free(buf4);

int j, k;

double** d1;
d1 = (double**)malloc(sizeof(double*)*MAX_LINE);
for(i=0;i<MAX_LINE;i++){
        d1[i] = (double*)malloc(sizeof(double)*7);
}

char si[3];
int start;
int end;
printf("Input start sink number(0 - 7) :");
gets_s(si);
start = atoi(si);
```

Input start sink number from sink 0-7.

```
if(start < 0 || start >= 7){
        printf("Input start sink number error. start sink num set to 0\n");
        start = 0;
}
printf("Input end sink number(start+1 - 7):");
gets_s(si);
end = atoi(si);
if(end <= start || end > 7){
        printf("Input end sink number error. end sink num set to 7\n");
        end = 7;
}

for(k=0;k<num1;k++){
        for(j=start;j<end;j++){
                if(abs(data1[k][j] - data1[k][j+1])<180){
                        d1[k][j] = abs(data1[k][j] - data1[k][j+1]);
                }else{
                        d1[k][j] = abs(abs(data1[k][j] - data1[k][j+1])-360);
                }
        }
}

double** d2;
d2 = (double**)malloc(sizeof(double*)*MAX_LINE);
for(i=0;i<MAX_LINE;i++){
        d2[i] = (double*)malloc(sizeof(double)*7);
}

for(k=0;k<num2;k++){
        for(j=start;j<end;j++){
```

Input end sink number from start+1 - 7.

```
                    if(abs(data2[k][j] - data2[k][j+1])<180){
                              d2[k][j] = abs(data2[k][j] - data2[k][j+1]);
                    }else{
                              d2[k][j] = abs(abs(data2[k][j] - data2[k][j+1])-360);
                    }
          }
}

double min;
int min_num;
double buf_min;
int l;
double x_s;
double y_s;
double x_e;
double y_e;

char* a;
char* reg;

double td;
int td_num;
double e_max;

FILE* afp;
FILE* wfp;
FILE* xfp;
afp = fopen("result.txt", "w");
wfp = fopen("result_phase.plt", "w");
xfp = fopen("phase.dat", "w");
```

```
fprintf(wfp, "reset\n");
fprintf(wfp, "set term post eps color \"Arial\"\n");
fprintf(wfp, "set output \"phase_arrow.eps\"\n");
fprintf(wfp, "set xrange[25:125]\n");
fprintf(wfp, "set yrange[12:52]\n");
fprintf(wfp, "set xtics 5\n");
fprintf(wfp, "set ytics 17, 5\n");
fprintf(wfp, "set mxtics 4\n");
fprintf(wfp, "set mytics 4\n");
fprintf(wfp, "set nokey\n");
fprintf(wfp, "set size square\n");
fprintf(wfp, "set grid xtics ytics mxtics mytics\n");

printf("Input number(1:Power, 2:Abs, 3:Sqrt) : ");
gets_s(fname);
```

Input formula by choosing number.

```
int form;
form = atoi(fname);

if(form != 1 && form != 2 && form !=3){
        printf("wrong input number!\n");
        exit(0);
}

td = 0.0;
td_num = 0;
e_max = 0;

int m;
```

```
for(k=0;k<num2;k++){
        min = 10000000;
        min_num = 0;
        for(j=0;j<num1;j++){
                buf_min = 0;
                for(l=start;l<end;l=l+1){
                        if(form == 1){
                                buf_min += pow((d1[j][l] - d2[k][l]), 2);
                        }else if(form == 2){
                                buf_min += abs(d1[j][l] - d2[k][l]);
                        }else if(form == 3){
                                buf_min += sqrt(abs(d1[j][l] - d2[k][l]));
                        }

                }
                if(min > buf_min){
                        min = buf_min;
                        min_num = j;
                }
        }
                        reg = strdup(name2_list[k]);
        a = strtok(reg, ",");
        if(a != NULL){
                x_s = atof(a);
        }else{
                printf("input file error 1 %s!\n", name2_list[k]);
        }
        a = strtok(NULL, ",");
        if(a != NULL){
                y_s = atof(a);
```

```
        }else{
            printf("input file error 2 %s!\n", name2_list[k]);
        }
        reg = strdup(name1_list[min_num]);
        a = strtok(reg, ",");
        if(a != NULL){
            x_e = atof(a);
        }else{
            printf("input file error 3! %s\n", name1_list[min_num]);
        }
        a = strtok(NULL, ",");
        if(a != NULL){
            y_e = atof(a);
        }else{
            printf("input file error 4! %s\n", name1_list[min_num]);
        }

        if(x_s == x_e && y_s == y_e){
            fprintf(xfp, "%f  %f\n",x_s, y_s);
        }else{
            if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 10){
                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 1);
            }else if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) >= 10 &&
sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 20){
                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 2);
            }else{
                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 3);
```

```
                    }
                    td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
                    if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
                            e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
                    }
                    if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e),2))>=2.5){
                    td_num++;
                    }
            }
    }

    fprintf(afp, "**** using phase only ****\n");

    fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
    fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
    fprintf(afp, "maximum error distance = %.2fcm\n", e_max);
    fprintf(wfp, "plot \"phase.dat\" w p ps 2 pt 6\n");
    fprintf(wfp, "set output\n");
    fclose(wfp);
    fclose(xfp);

    double min2;
    int min_num2;
    double buf_min2;

    FILE* wfp2;
    wfp2 = fopen("result_level.plt", "w");
```

```
FILE* xfp2;
xfp2 = fopen("level.dat", "w");

fprintf(wfp2, "reset\n");
fprintf(wfp2, "set term post eps color \"Arial\"\n");
fprintf(wfp2, "set output \"level_arrow.eps\"\n");
fprintf(wfp2, "set xrange[25:125]\n");
fprintf(wfp2, "set yrange[12:52]\n");
fprintf(wfp2, "set xtics 5\n");
fprintf(wfp2, "set ytics 17, 5\n");
fprintf(wfp2, "set mxtics 4\n");
fprintf(wfp2, "set mytics 4\n");
fprintf(wfp2, "set nokey\n");
fprintf(wfp2, "set size square\n");
fprintf(wfp2, "set grid xtics ytics mxtics mytics\n");


td = 0.0;
td_num = 0;
e_max = 0.0;

for(k=0;k<num4;k++){
        min2 = 10000000;
        min_num2 = 0;
        for(j=0;j<num3;j++){
                buf_min2 = 0;
                for(l=start;l<end;l=l+1){
                        if(form == 1){
                                buf_min2 += pow(((data3[j][l]-data3[j][l+1]) -
(data4[k][l]-data4[k][l+1])), 2);
```

```
                }else if(form == 2){
                        buf_min2 += abs((data3[j][l]-data3[j][l+1]) -
(data4[k][l]-data4[k][l+1]));
                }else if(form == 3){
                        buf_min2 += sqrt(abs((data3[j][l]-data3[j][l+1]) -
(data4[k][l]-data4[k][l+1])));
                }

        }

        if(min2 > buf_min2){

                min2 = buf_min2;
                min_num2 = j;
        }

}

reg = strdup(name2_list[k]);
a = strtok(reg, ",");
if(a != NULL){
        x_s = atof(a);
}else{
        printf("input file error 1 %s!\n", name2_list[k]);
}
a = strtok(NULL, ",");
if(a != NULL){
        y_s = atof(a);
}else{
        printf("input file error 2 %s!\n", name2_list[k]);
```

```
        }
        reg = strdup(name1_list[min_num2]);
        a = strtok(reg, ",");
        if(a != NULL){
                x_e = atof(a);
        }else{
                printf("input file error 3! %s\n", name1_list[min_num2]);
        }
        a = strtok(NULL, ",");
        if(a != NULL){
                y_e = atof(a);
        }else{
                printf("input file error 4! %s\n", name1_list[min_num2]);
        }

        if(x_s == x_e && y_s == y_e){
                fprintf(xfp2, "%f%f\n",x_s, y_s);
        }else{
                if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 10){
                        fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 1);
                }else if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) >= 10 &&
sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 20){
                        fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 2);
                }else{
                        fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 3);
                }
                td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
```

```
                    if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
                        e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
                    }
                    if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e),2))>=2.5){
                    td_num++;
                    }
            }
        }

        fprintf(afp, "**** using level only ****\n");

        fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
        fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
        fprintf(afp, "maximum error distance = %.2fcm\n", e_max);

        fprintf(wfp2, "plot \"level.dat\" w p ps 2 pt 6\n");
        fprintf(wfp2, "set output\n");

        fclose(wfp2);
        fclose(xfp2);

        printf("Input weight for level:");
        gets_s(fname);

        double weight;
        weight = atof(fname);

        double min3;
```

Input weight number.

```
int min_num3;
double buf_min3;

FILE* wfp3;
wfp3 = fopen("result_total.plt", "w");
FILE* xfp3;
xfp3 = fopen("total.dat", "w");

fprintf(wfp3, "reset\n");
fprintf(wfp3, "set term post eps color \"Arial\"\n");
fprintf(wfp3, "set output \"total_arrow.eps\"\n");
fprintf(wfp3, "set xrange[25:125]\n");
fprintf(wfp3, "set yrange[12:52]\n");
fprintf(wfp3, "set xtics 5\n");
fprintf(wfp3, "set ytics 17, 5\n");
fprintf(wfp3, "set mxtics 4\n");
fprintf(wfp3, "set mytics 4\n");
fprintf(wfp3, "set nokey\n");
fprintf(wfp3, "set size square\n");
fprintf(wfp3, "set grid xtics ytics mxtics mytics\n");

td = 0.0;
td_num = 0;
e_max = 0.0;

for(k=0;k<num2;k++){
        min3 = 10000000;
        min_num3 = 0;
        for(j=0;j<num1;j++){
                buf_min3 = 0;
```

```
                for(l=start;l<end;l=l+1){
                        if(form == 1){
                                buf_min3 += pow((d1[j][l] - d2[k][l]), 2) +
pow(((data3[j][l]-data3[j][l+1]) - (data4[k][l]-data4[k][l+1])) * weight, 2);
                        }else if(form == 2){
                                buf_min3 += abs(d1[j][l] - d2[k][l]) + abs((data3[j][l]-
data3[j][l+1]) - (data4[k][l]-data4[k][l+1])) * weight;
                        }else if(form == 3){
                                buf_min3 += sqrt(abs(d1[j][l] - d2[k][l])) +
sqrt(abs((data3[j][l]-data3[j][l+1]) - (data4[k][l]-data4[k][l+1]))) * weight;
                        }
                                                        }
                if(form == 1){
                        buf_min3 += pow((data3[j][l] - data4[k][l]) * weight, 2);
                }else if(form == 2){
                        buf_min3 += abs(data3[j][l] - data4[k][l]) * weight;
                }else if(form == 3){
                        buf_min3 += sqrt(abs(data3[j][l] - data4[k][l])) * weight;
                }

                if(min3 > buf_min3){

                        min3 = buf_min3;
                        min_num3 = j;
                }
        }
        reg = strdup(name2_list[k]);
        a = strtok(reg, ",");
        if(a != NULL){
                x_s = atof(a);
```

```
}else{
        printf("input file error 1 %s!\n", name2_list[k]);
}
a = strtok(NULL, ",");
if(a != NULL){
        y_s = atof(a);
}else{
        printf("input file error 2 %s!\n", name2_list[k]);
}
reg = strdup(name1_list[min_num3]);
a = strtok(reg, ",");
if(a != NULL){
        x_e = atof(a);
}else{
        printf("input file error 3! %s\n", name1_list[min_num3]);
}
a = strtok(NULL, ",");
if(a != NULL){
        y_e = atof(a);
}else{
        printf("input file error 4! %s\n", name1_list[min_num3]);
}

if(x_s == x_e && y_s == y_e){
        fprintf(xfp3, "%f%f\n",x_s, y_s);
}else{
        if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 10){
                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 1);
```

```
                        }else if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) >= 10 &&
sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) < 20){
                                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 2);
                        }else{
                                fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n",
x_s, y_s, x_e, y_e, 3);
                        }

                        td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
                        if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
                                e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
                        }
                        if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e),2))>=2.5){
                        td_num++;
                        }


                }
        }

        fprintf(afp, "**** using phase and level*%.2f ****\n", weight);

        fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
        fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
        fprintf(afp, "maximum error distance = %.2fcm\n", e_max);
        fprintf(wfp3, "plot \"total.dat\" w p ps 2 pt 6\n");
        fprintf(wfp3, "set output\n");
```

```
fclose(afp);
fclose(wfp3);
fclose(xfp3);

for(i=0;i<MAX_LINE;i++){
        free(d1[i]);
        free(d2[i]);
        free(data1[i]);
        free(data2[i]);
        free(data3[i]);
        free(data4[i]);
}
free(d1);
free(d2);

free(data1);
free(data2);
free(data3);
free(data4);

free(name1_list);
free(name2_list);
free(name3_list);
free(name4_list);
}
```

Appendix B

Gnuplot Program for plotting graph of the result data

"Gnuplot" is a command-line program that can generate two and three dimensional plots of functions, data, and data fits. It is frequently used for publication quality graphics as well as educational purposes. The program runs on all major computers and operating systems (GNU/Linux, UNIX, Microsoft Windows, Mac OS X and others). It is a program with a fairly long history, dating back to 1986. This software is not distributed under the GPL license, opting for its own open source license instead. Gnuplot can produce output directly on screen, or in many formats of graphics files, including PNG, EPS, SVG, JPEG and many others. It is also capable of producing LaTeX code that can be included directly in LaTeX documents, making use of LaTeX's fonts and powerful formulae abilities. The program can be used both interactively and in batch mode using scripts. In this section, we will present how to use Gnuplot program in this experiment.

1) Screen after start up

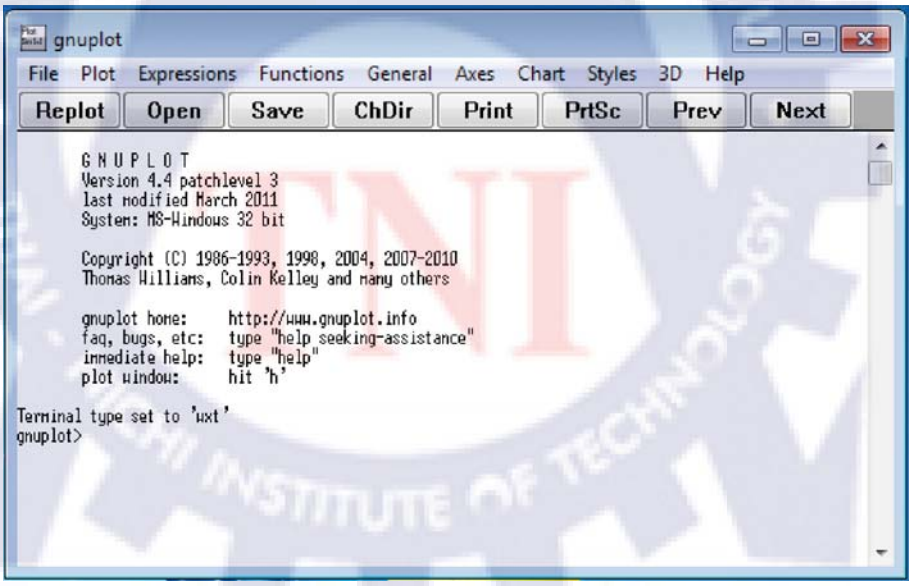

Figure B.1 Screen display after start up program

2) Insert experiment data after calculate

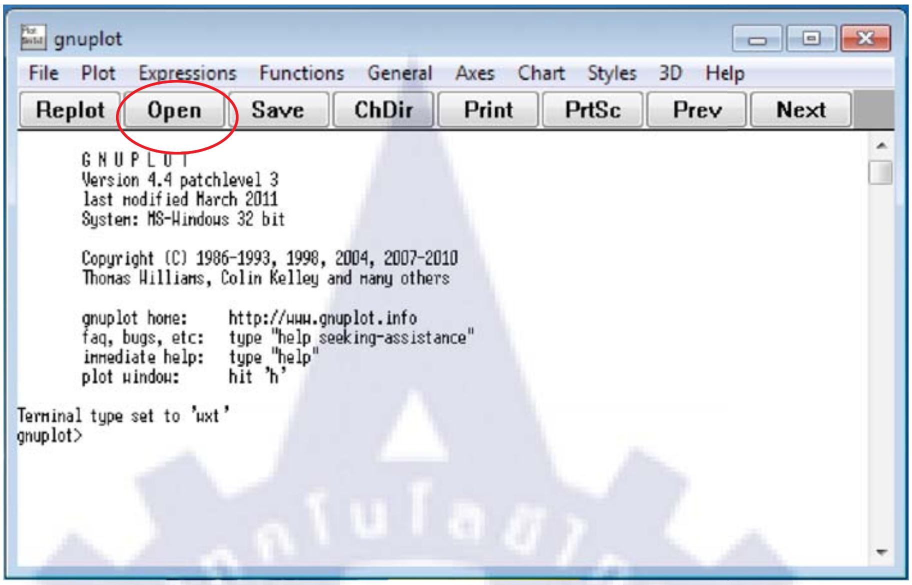

Figure B.2 Click open to choose file name

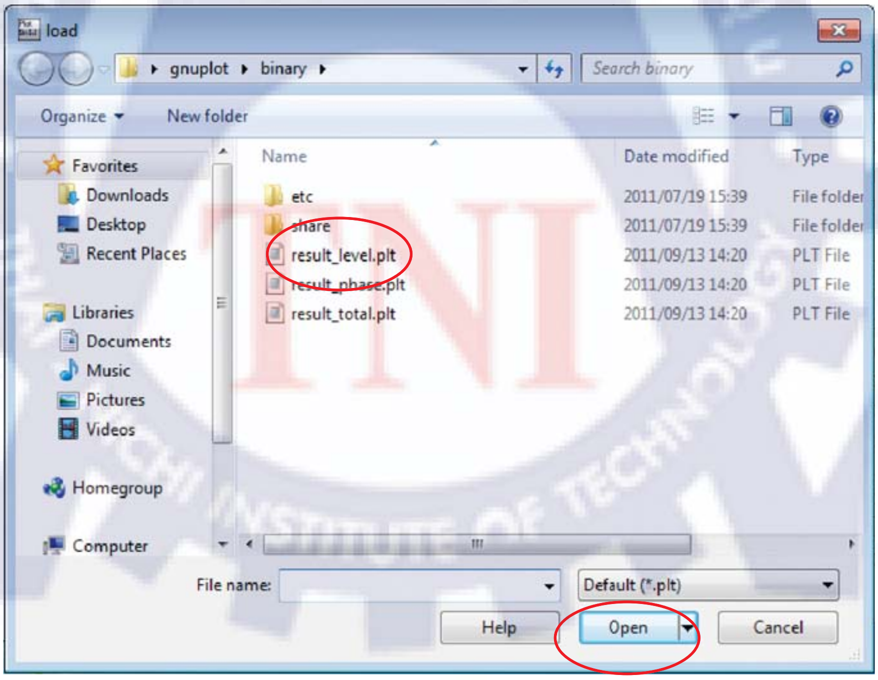

Figure B.3 Choose file name and click open

3) Plot an evaluation graph.

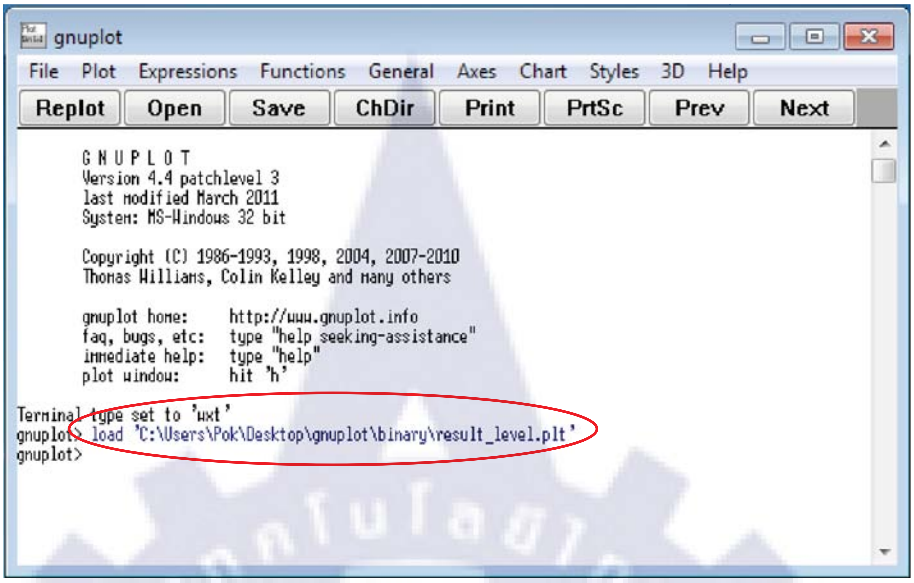

Figure B.4 File path name of experiment data

4) Display result in Microsoft PowerPoint or other program

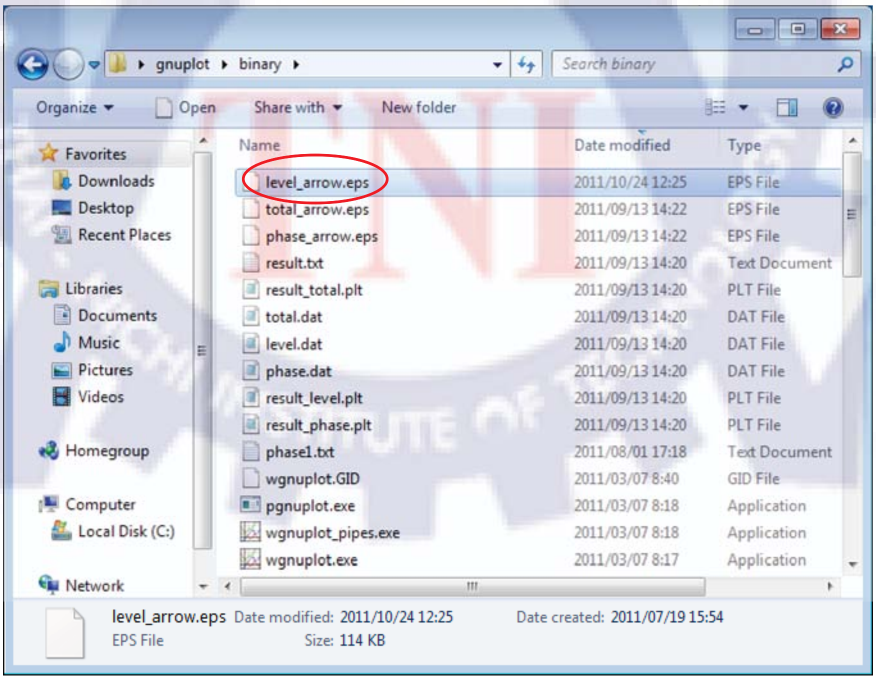

Figure B.5 File result

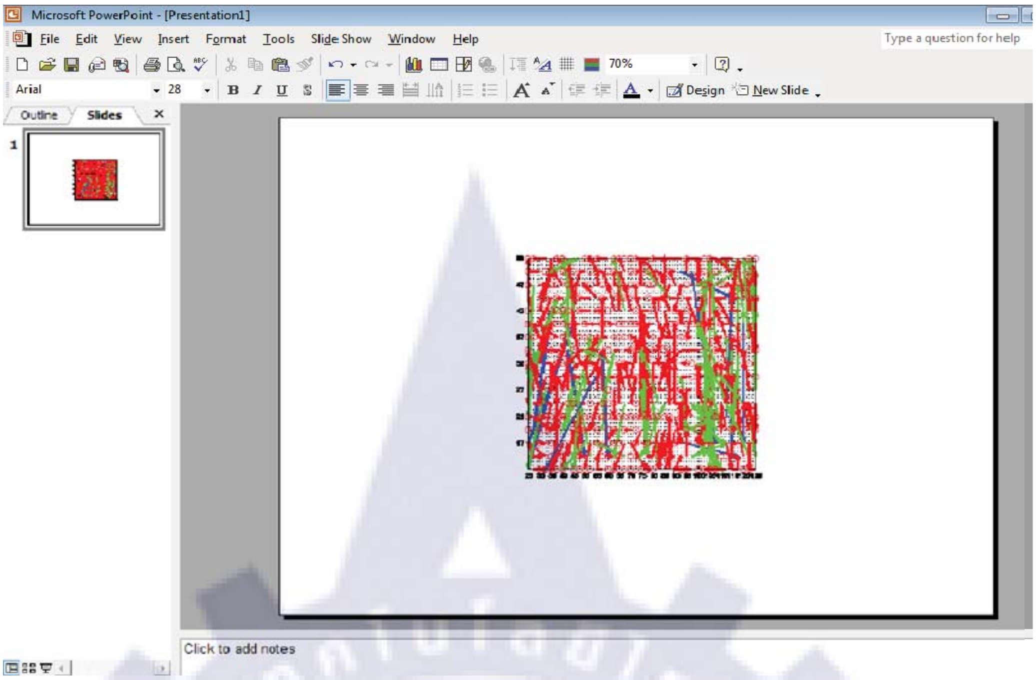

Figure B.6 Experiment data graph