

ANTENNA GAIN MEASUREMENT USING IMAGE THEORY

SANDRAWARMAN A/L BALASUNDRAM

A project report submitted in partial fulfillment of the
requirement for the award of the degree
Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JANUARY 2014

ABSTRACT

This report presents the measurement result of a passive horn antenna gain by only using metallic reflector and vector network analyzer, according to image theory. This method is an alternative way to conventional methods such as the three antennas method and the two antennas method. The gain values are calculated using a simple formula using the distance between the antenna and reflector, operating frequency, S-parameter and speed of light. The antenna is directed towards an absorber and then directed towards the reflector to obtain the S_{11} parameter using the vector network analyzer. The experiments are performed in three locations which are in the shielding room, anechoic chamber and open space with distances of 0.5m, 1m, 2m, 3m and 4m. The results calculated are compared and analyzed with the manufacture's data. The calculated data have the best similarities with the manufacturer data at distance of 0.5m for the anechoic chamber with correlation coefficient of 0.93 and at a distance of 1m for the shield room and open space with correlation coefficient of 0.79 and 0.77 but distort at distances of 2m, 3m and 4m at all of the three places. This proves that the single antenna method using image theory needs less space, time and cost to perform it. The method used can be improved by considering the uncertain elements such as losses, reflections sources, optimize far field distance and reflector size required in calculating the gain.

ABSTRAK

Laporan ini membentangkan hasil pengukuran gandaan antenna tanduk pasif dengan hanya menggunakan reflektor logam dan *vector network analyzer*, mengikut teori imej. Kaedah ini adalah cara alternatif kepada kaedah konvensional seperti kaedah tiga antenna dan kaedah dua antenna dengan mengira gandaan antenna menggunakan formula mudah. Pertama, antenna tersebut dihadap ke arah bahan penyerap isyarat atau kawasan terbuka, dan kemudian menghadap reflektor logam untuk mendapatkan parameter S_{11} untuk digunakan dalam formula mengira gandaan antenna. Eksperimen ini dilakukan dalam tiga persekitaran yang berbeza iaitu *shielding room*, kebuk tak bergema dan kawasan terbuka dengan jarak yang berbeza iaitu 0.5m, 1m, 2m, 3m dan 4m. Keputusan gandaan antenna yang dikira dibanding dan dianalisis dengan data yang diperolehi daripada pengilang. Data yang dikira hampir sama dengan data dari pengilang pada jarak 0.5m untuk kebuk tak bergema dengan pekali korelasi 0.93 dan 1m dalam *shielding room* dan di kawasan terbuka dengan pekali korelasi 0.79 dan 0.77 tetapi memesong jauh daripada data pengilang pada jarak 2m, 3m dan 4m di ketiga-tiga tempat. Ini membuktikan bahawa kaedah ini menggunakan ruang bilik yang kecil, menjimatkan masa dan kos. Kaedah ini boleh diperbaiki dengan mempertimbangkan elemen yang menghasilkan data yang salah seperti kehilangan isyarat, mengenalpasti sumber refleksi, mencari jarak yang optimum antara antenna dan reflektor dan saiz reflektor dalam pengiraan gandaan antenna.

TABLE OF CONTENTS

TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	x
LIST OF TABLES	xiii
LIST OF SYMBOLS AND ABBREVIATIONS	xiv
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Objective	3
1.3 Scope	3
1.4 Problem Statement	4
CHAPTER 2 LITERATURE REVIEW AND THEORY	
2.1 Introduction	6
2.2 Single Antenna Method for Traceable Antenna Gain Measurement	7
2.3 New Results of Antenna-Calibration in a Single- Antenna Set-Up	8
2.4 Antenna Measurement using the Mirror with Gating in a Time Domain	9
2.4.1 Mirror Method of Antenna Radiation Patterns Measurement with Gating in the Time Domain	9

2.4.2	Mirror Method of Gain Measurement with Gating in the Time Domain	11
2.5	Antenna Gain Measurement in the V-band: A Single Antenna Method	12
2.5.1	Measurement Result	12
2.5.1.1	On-chip Mounted Patch Antenna	13
2.5.1.2	Coplanar Fed Loop Slot Antenna	14
2.6	Theoretical Development	16
2.6.1	Introduction	16
2.6.2	Scattering Parameter	16
2.6.3	Gain	17
2.6.4	Friis Transmission Equation	18
2.6.5	Near and Far Field	19
2.6.6	Image Theory	21
2.6.7	Mean	22
2.6.8	Standard Deviation	22
2.6.9	Correlation Coefficient	23
CHAPTER 3 METHODOLOGY		
3.1	Introduction	24
3.2	System Overview	25
3.3	Overall Methodology	26
3.4	Procedure Methodology	27
3.5	Equipment Selection	28
3.5.1	Introduction	28
3.5.2	Pyramidal Horn Antenna	28
3.5.3	Vector Network Analyzer	29
3.5.4	Reflector	30
3.5.5	Absorber	31
3.5.6	Cable	32
3.5.7	Measuring Tools	32
3.5.8	Calibration Kit	33
3.6	Derivation formula using Friis Equation and S_{11} Parameter	34

3.7	Method in Collecting Data	37
3.7.1	The procedure of single antenna method	37
3.7.2	The procedure to calibrate the Vector Network Analyzer	39
3.8	Method in Calculating data	40
CHAPTER 4 RESULT AND ANALYSIS		
4.1	Introduction	41
4.2	Calculated far field of the Antenna	42
4.3	Results from the experiment in Shielding Room	43
4.3.1	Summary of results in Shielding Room	48
4.4	Results from the experiment in Anechoic Chamber	49
4.4.1	Summary of results in Anechoic Chamber	54
4.5	Results from the experiment at Open Space	56
4.5.1	Summary of results at Open Space	61
4.6	Comparison between best results from Shielding Room, Anechoic Chamber and Open Space	62
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS		
5.1	Conclusion	63
5.2	Recommendations	64
REFERENCES		65
APPENDIX A: Calculated Gain table in Shielding Room		67
APPENDIX B: Calculated Gain in Shielding Room plotted against Manufacturer's Data		68
APPENDIX C: Calculated Gain table in Anechoic Chamber		69
APPENDIX D: Calculated Gain in Anechoic Chamber plotted against Manufacturer's Data		70
APPENDIX E: Calculated Gain table at Open Space		71
APPENDIX F: Calculated Gain at Open Space plotted against Manufacturer's Data		72
APPENDIX G: Manufacturer's Data for Antenna Factor		73
VITA		

LIST OF SYMBOL AND ABBREVIATIONS

M	<i>Meters</i>
GHz	<i>Giga Hertz</i>
MHz	<i>Mega Hertz</i>
RF	<i>Radiofrequency</i>
DB	<i>Decibel</i>
NS	<i>Nanoseconds</i>
MM	<i>Millimetres</i>
PEC	<i>Perfect Electric Conductor</i>
DBI	<i>Decibel isotropic</i>
AUT	<i>Antenna Under Test</i>
VNA	<i>Vector Network Analyzer</i>
EMC	<i>Electromagnetic Compatibility</i>
λ	<i>Wavelength</i>
<i>F</i>	<i>Frequency</i>
<i>R</i>	<i>Distance</i>
<i>E</i>	<i>Electric Field</i>
<i>H</i>	<i>Magnetic Field</i>
V	<i>Voltage</i>
W	<i>Watt</i>
VNA	<i>Vector Network Analyzer</i>
UHF	<i>Ultra High Frequency</i>
TV	<i>Television</i>
Ω	<i>Ohm</i>
%	<i>Percentage</i>
>	<i>More than</i>

LIST OF FIGURES

1.1	Setup of one antenna method	2
1.2	Image theory concept for PEC	2
1.3	The arrangement for two-antenna method experiment	4
1.4	The set-up for three-antenna method	5
2.1	The hardware setting for single antenna method	7
2.2	The time domain data responses of double-ridged waveguide horn DRH20 without gating	10
2.3	The time domain data responses of double-ridged waveguide horn DRH20 with gating from 35.5ns to 37.5ns	10
2.4	Gain comparison of double-ridged waveguide horn DRH18E using the two antenna method (gray line) and the mirror method with gating in the time domain (black line)	11
2.5	Gain and reflection coefficient, $ S_{11} $ of an on-chip mounted and antenna	13
2.6	Gain and reflection coefficient, $ S_{11} $ of coplanar-fed loop slot antenna	15
2.7	Two port network diagram	16
2.8	The radiation pattern and the gain value of an antenna	17
2.9	Two antenna method	18
2.10	The near field and far field of the antenna	19
2.11	Spherical Phase Front Tangent to a Plane Antenna Aperture	20
2.12	Image theory	21
3.1	Connection of the equipment	25
3.2	Simplified connection of the equipment	25
3.3	Process flow of the project	26

3.4	Technical flow of the project	27
3.5	BHA 9118 Horn Antenna	28
3.6	Vector network Analyzer	29
3.7	Anechoic Chamber Absorber	31
3.8	Cable connected to horn antenna	32
3.9	Measurement tape	32
3.10	Rhode & Schwarz ZV-Z21 calibration kit	33
3.11	Diagram of Thevenin Equivalent Circuit Model for an Antenna	34
3.12	Antenna on the tripod	37
3.13	Position of horn antenna and the absorber at 0.5m in the shielding room	38
3.14	Position of horn antenna and the metal reflector at 1m	38
3.15	Connection between the calibration kit, cable and VNA	39
4.1	Calculated data at 0.5m in shield room against manufacturer's data	43
4.2	Calculated data at 1m in shield room against manufacturer's data	44
4.3	Calculated data at 2m in shield room against manufacturer's data	45
4.4	Calculated data at 3m in shield room against manufacturer's data	46
4.5	Calculated data at 4m in shield room against manufacturer's data	47
4.6	Calculated data at 0.5m in anechoic chamber against manufacturer's data	49
4.7	Calculated data at 1m in anechoic chamber against manufacturer's data	50
4.8	Calculated data at 2m in anechoic chamber against manufacturer's data	51
4.9	Calculated data at 3m in anechoic chamber against manufacturer's data	52
4.10	Calculated data at 4m in anechoic chamber against manufacturer's data	53

4.11	Calculated data at 0.5m at open space against manufacturer's data	56
4.12	Calculated data at 1m at open space against manufacturer's data	57
4.13	Calculated data at 2m at open space against manufacturer's data	58
4.14	Calculated data at 3m at open space against manufacturer's data	59
4.15	Calculated data at 4m at open space against manufacturer's data	60
4.16	Comparison between best results from shield room, anechoic chamber, open space	62

LIST OF TABLES

3.1	Summary of Horn Antenna characteristic	29
3.2	Summary of Vector Network Analyzer characteristic	30
4.1	The far field distance for different frequency ranges	42

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

An antenna is an essential part of the wireless radio frequency communication system. The system could not operate properly without an antenna causing lot of problems in the real life situation. The antenna works as a transformer between the guided electromagnetic wave inside the terminal and wave propagating in the air to send and receive the signals. Every wireless portable device that has data transmission capability using electromagnetic waves must have at least an antenna. An antenna often has sources of error in radiating its emission. Using an inaccurately calibrated antenna may result in erroneous rejection. The calibration of an antenna is very important in the real environment. Various methods exist to calibrate an antenna.

During an antenna calibration, it is useful to know the antenna's characterization such as the gain of an antenna over the entire frequency range of interest. Furthermore, to test and measure accurately the gain of antenna there are few methods that may be implemented such as the two antenna method and the three antenna method[1]. Both of the methods find the gain value by analyze the measured data for the antenna under test (AUT) to a reference antenna that the gain value is already known. There is another method that is less costly and has almost the same outcome as the two other methods mentioned. This method is called single antenna method[2].

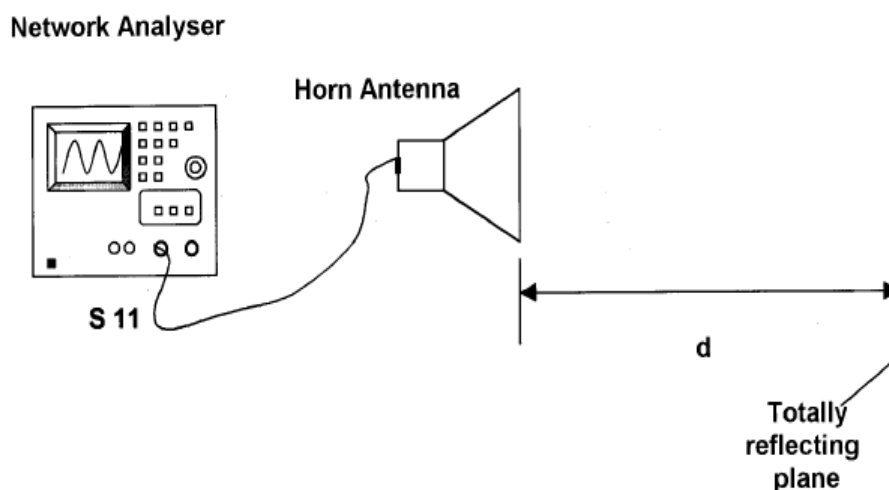


Figure 1.1: Setup of one antenna method.

Figure 1.1 shows the arrangement for single antenna setup. This method applies the applications in the communication theory called image theory. Image theory is a concept that can be explained using a mirror. The mirror produces an image of the object in front of it, and the image is located at the distance behind the mirror as same as the object is in front of the mirror [1]. Figure 1.2 shows the image theory concept for magnetic field [2]. It is model of as two-antenna method but the reference antenna is replaced by large reflecting surface with the distance reduced by half. Only the antenna that needs to be calibrated is needed and used to evaluate its gain measurement.

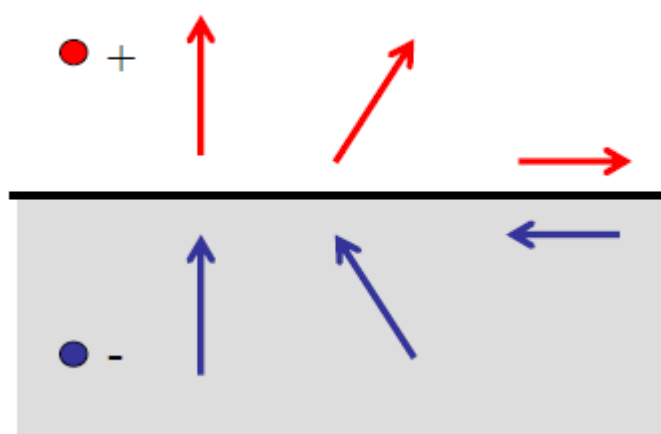


Figure 1.2: Image theory concept for PEC.

1.2 Objectives.

The aim of this experiment is to study the effectiveness of image theory in antenna gain measurement. The specific objectives that are as follows:

- I) To develop a set-up consists of a vector network analyzer, metallic reflector and the horn antenna to calculate the gain using image theory.
- II) To study the variation of the gain calculated in different places such as shielding room, anechoic chamber and open space.
- III) To propose the optimum set-up for antenna gain measurement using image theory.

1.3 Scope

To complete this project successfully with the time constraint and budget, there are a few things defined in the scopes of the project that need to be outlined. The scope is divided into two main types which is the mathematical analysis and experimental analysis. There are:

- I) Derive the formula to calculate the gain of the AUT used in this project based on S parameter.
- II) Perform the experiment in three different conditions, non ideal (shielding room), free space (open space) and ideal (anechoic chamber)
- III) Perform the calculation to find the gain value of the AUT based on the S parameter value obtained during experiment.
- IV) Analysis the gain value obtained from the calculation with the gain value from the manufacturer.

1.4 Problem Statement

The most commonly used methods for antenna calibration is the two-antenna method and the three-antenna method. The two-antenna method is known as reference antenna method in some studies[3]. The two-antenna method requires two identical test antennas, one used as a transmitter and the other one used as a receiver. Both the antennas must be well matched in terms of impedance and polarization. The main disadvantage of this method is that it is difficult to find two antennas of identical gains. This element may induce errors in the measurement of the results. Figure 1.3 shows two-antenna method arrangement.

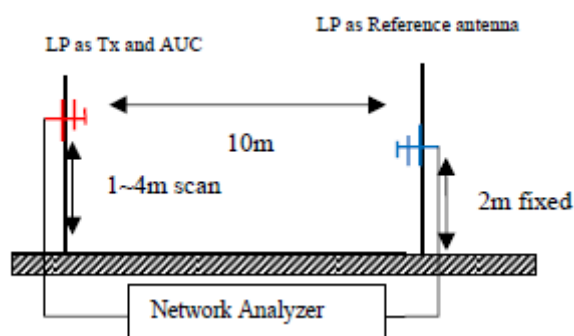


Figure 1.3: The arrangement for two-antenna method experiment.

The three-antenna method is used when the two antennas in the measuring system are not identical. Another antenna must be employed and the three-antenna method measurements must be implemented [3]. The antenna is needed to be characterized and two extra antennas that operate over a same range of frequencies are selected. Figure 1.4 shows the arrangement for three-antenna method, the antennas used to transmit, reflector and receiver the signal [4]. This method is used to measure the antenna gain without using a reference antenna.

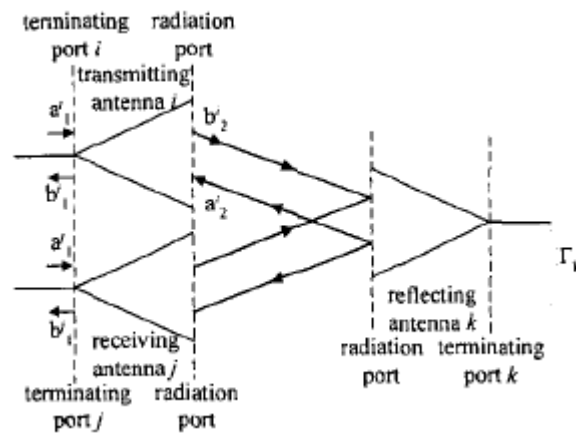


Figure 1.4: The set-up for three-antenna method.

The disadvantage of both methods is involvement of the extra antennas. The involvement of the extra antennas will make the cost to execute the experiments to increase. The extra antennas needed have to be bought for the experimental purpose. More antennas suggest the expansion of workplace to run these experiments because for three-antenna method the workplace is bigger than the two-antenna method. This indirectly will affect the time used to set-up the workplace, more time consuming for the bigger work place. The main advantage of these methods are the calculation involved for the gain and power calculation. The gain and power of the extra antennas must be involved when doing the calculation. The residual gain differences among the antennas must be considered in the calculation.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Introduction

This literature review studies some works previously done by other researcher. It involves the aspects of the project or research which are available in the outside world. This research not only focused directly to the previous research done but it also focused on factual data and references of its field of study.

The source of information can be obtained from the internet, library, and also from people who have a high knowledge about the study. This review is important because it is the starting point to create, upgrade and produce a quality research with accurate results.

Through past research, a lot can be learnt about the equipment to be used, the type of disadvantages to be expected, the basic knowledge needed so that the experiment can be carried out with the expected result obtained. This will help to reduce the time and cost to conduct the research.

2.2 Single Antenna Method for Traceable Antenna Gain Measurement.

The first concept of the single antenna method is to find the different approach of antenna calibration without using conventional method [1]. Numerous experiments had been completed regarding the single antenna method. The experiments were executed to find the difference between the gain measurement in conventional method and in single antenna method. The experiments were done by using the wave-guided horn antenna with frequency range of 12GHz to 18 GHz which is connected to the directional coupler. The output of the coupler is connected to the horn antenna, the input is connected to RF sweep generator act as RF supply and the reflected side is connected to spectrum analyzer which acts as the measurement equipment. The horn antenna is placed in front of a brass reflector with measurement 1m by 1m. Figure 2.1 shows the completed set-up diagram [1].

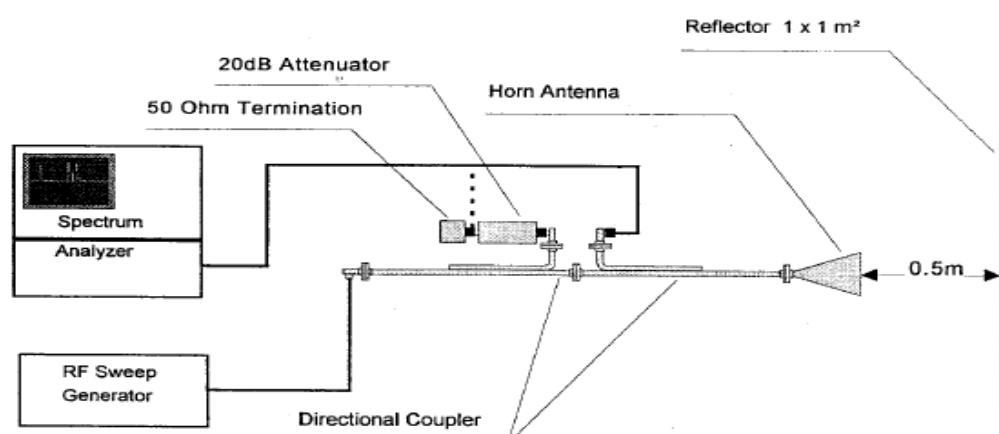


Figure 2.1: The hardware setting for single antenna method.

This method can be used to reduce the cost of the experiment and there are few adjustments needed to implement the single antenna method fully. Further experiments and numerical calculation are needed to identify clearly the disturbing reflections from sources, due to the results of experimental and theoretical method which show a margin of a few tenth decibels. The disadvantage discovered is that this method should not be executed in a reflecting environment which distorts the reading.

2.3 New Results of Antenna-Calibration in a Single-Antenna Set-Up.

The concept of this method is to prove that the gain of a passive antenna can be measured without the conventional method [5]. The advantage of this single-antenna arrangement is that no longer the residual gain difference between 2 equal antennas will affect the result of the gain measured. The difference between this experiment and the previous one is the usage of the complex network analyzer and the team which performs this experiment is the same. The distance between the reflector and horn antenna varied due to the difference gain measured against the distance of separation. The experiment is executed using a horn antenna with frequency range of 1.7GHz to 18GHz, the reflector is stainless steel plates with 1m by 1m measurement and the distance range is from 1m to 2m [5].

$$G = |S_{11}| \frac{8\pi d}{\lambda} = |S_{11}| \frac{8\pi d f}{C_0} \quad (2.1)$$

where,

S_{11} = Reflection Coefficient

d = separation distance between the reflector and antenna

f = range of the operating frequency

λ = wavelength of the operating frequency

C_0 = speed of the light

The results obtained when compared with the manufacturer's typical antenna data found to have a deviation of not more than 0.25dB. The cause of the deviation is mainly from additional reflections from the ground, other objects in the chamber, the edges of the finite reflector and the antenna aperture itself.

2.4 Antenna Measurement Using the Mirror Method with Gating in a Time Domain.

The single antenna method can also be executed using time domain measurement instrument such as the Agilent PNA microwave network analyzer E8364A [6]. The advantage of this method is less time consuming and time gating instrumentation, which allows signals to be isolated and separated in time domain. The data obtained will be analyzed in time domain and not in the frequency domain as the previous author proposed using scalar or vector analyzers. This method is used not only to measure gain but it is also used to calculate the antenna radiation pattern. The result of its measurement is compared with the result of standard measurement. The only weakness of this method is its low practical value of precision gain measurement. To overcome that weakness, a mirror method (single antenna method) can be used to increase the accuracy of the readings obtained during the experiment [6].

2.4.1 Mirror Method of Antenna Radiation Patterns Measurement with Gating in the Time Domain.

A double-ridged waveguide horn DRH20 is placed at 5.35m from the plane reflector with the dimension of 2m by 2m. The measurement starts from angle 0° oriented backward to the reflector. The frequency used for this horn antenna is 2GHz to 19GHz and the vector analyzer is set to antenna coefficient S_{11} . The signal is send and received at the port one of the port system network.

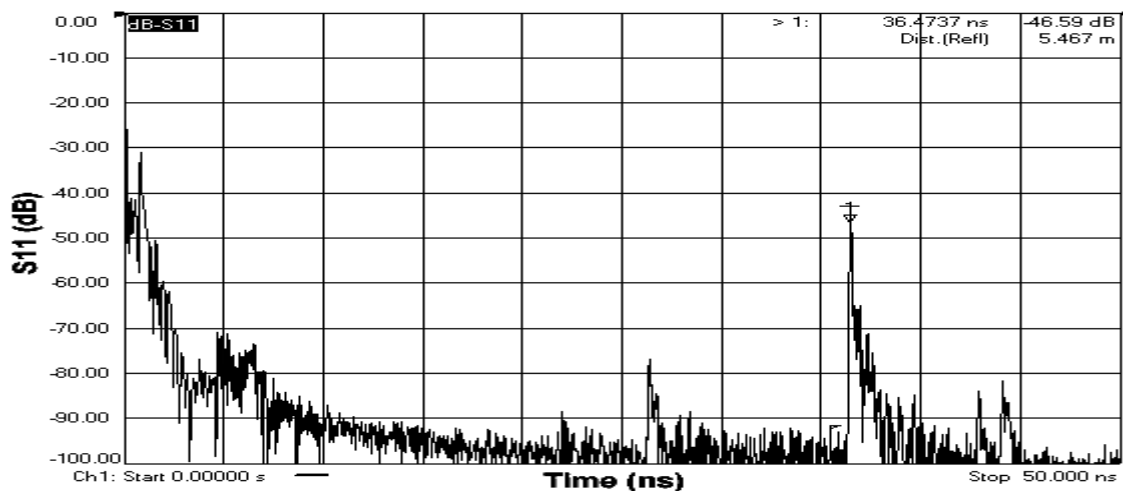


Figure 2.2: The time domain data responses of double-ridged waveguide horn DRH20 without gating.

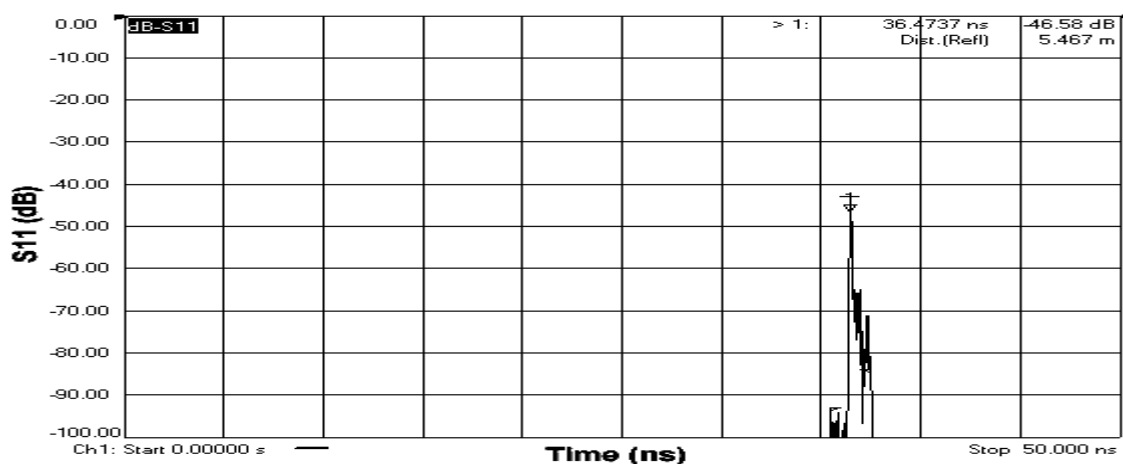


Figure 2.3: The time domain data responses of double-ridged waveguide horn DRH20 with gating from 35.5ns to 37.5ns.

Figure 2.2 shows the measurement without gating when the vector analyzer is used. It can be stated that a lot of peaks are due to the reflections inside the antenna or reflection from the surrounding area. Figure 2.3 shows the measurement with the gating method used from 35.5ns to 37.5ns. The time gating measurement is taken when the main lobe of the antenna is directly perpendicular to the reflector plane. During the time 36.4737ns, the peak is caused by reflection originated from the plane reflector. The distance of 5.467m is more than the distance of horn antenna from the reflector because the distance of the antenna to the antenna connector is included.

2.4.2 Mirror Method of Gain Measurement with Gating in the Time Domain.

A double-ridged waveguide horn DRH18E is placed at a distance of 2.56m from the plane reflector with measurement 2m by 2m. The experimental technique of the gating interval can be widened but for this experiment, the gating interval is chosen from 17.6ns to 19.6ns. The results obtained are compared with two antenna method and shown in figure 2.4.

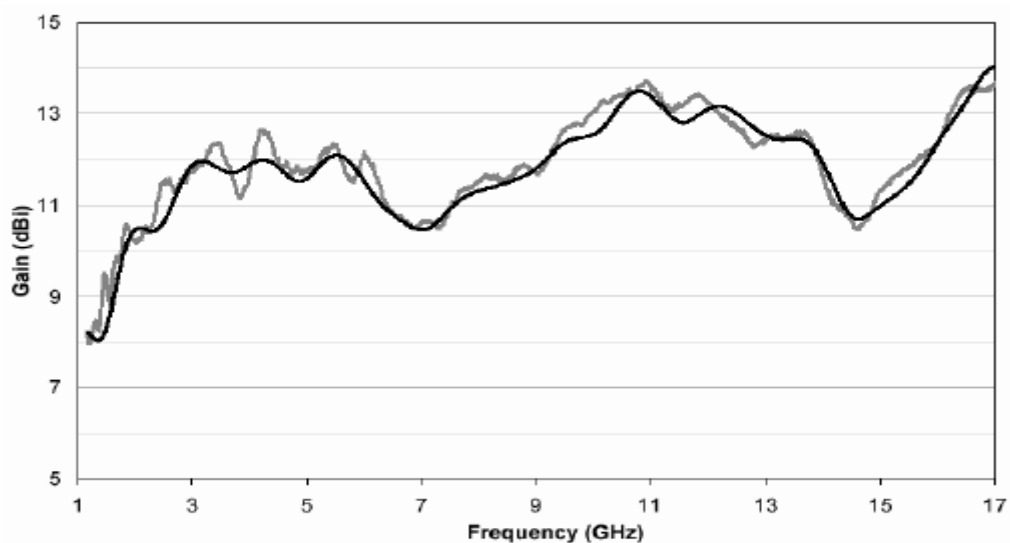


Figure 2.4: Gain comparison of double-ridged waveguide horn DRH18E using the two antenna method (gray line) and the mirror method with gating in the time domain (black line).

The conclusion is that the results show a good agreement with two-antenna method for gain measurement. The first results show a relatively good agreement with the two-antenna method. The time domain mirror method of gain measurement helps to eliminate some of the errors of frequency in the domain mirror method. The advantage of this method is that the experiment need not be executed in an anechoic chamber. This method can filter out the undesired reflected signals itself. The disadvantage noted is that there is the necessity to use a sufficiently large flat reflector and additional equipment for the time domain measurement and it is not suitable to measure circularly-polarized.

2.5 Antenna Gain Measurement in the V-band: A Single-Antenna Method.

A single antenna measurement technique in the V-band is presented. The technique is simple and inexpensive as it uses standard antenna measurement equipment and it does not require the antenna range calibration procedure [7]. The high frequency capabilities of complementary metal oxide-semiconductor (CMOS) technology and the availability of the 7GHz of unlicensed spectrum around 60GHz have made highly integrated radio circuits available at mm-wave frequencies, which reduce the cost and power consumption of mm-wave radios. The ability to test and characterize mm-wave antennas operating in the V-band is essential for a successful design. However, in the V-band, the high cost of radio frequency electronic equipment and absorbing materials make this task very challenging. An alternative method for antenna gain measurements is to use two identical test antennas placed face to-face and separated by a distance equal to a far-field separation of reference planes. In this set one antenna functions as a transmitting antenna, the other as a receiving antenna and the antenna gain is estimated from the transmission measurements. The objective is to validate the method and to investigate how the separation between the antenna device and planar electric conductor together with size of the planar electric conductor affect the measurements. Two mm-wave antennas are tested using the single antenna method and when compared to the electromagnetic simulations resulted in reasonable agreements [7].

2.5.1 Measurement Result

The antenna gain measurements for two different mm-wave antennas designed for the 60GHz band is presented. One of the designs is on-chip mounted and integrated patch antenna shown in figure 2.5 and another is coplanar fed loop slot antenna shown in figure 2.6. The first antenna is a low gain antenna with uni-directional radiation pattern in the upper half hemisphere. The second antenna has a more directional radiation pattern and medium gain.

2.5.1.1 On-chip Mounted Patch Antenna

The aperture dimension $D=1.8\text{mm}$ of the on-chip mounted antenna and the wavelength λ_{min} which equals 4.6mm at 66GHz (highest required operating frequency) distance from the antenna to reflector (r) of more than 1.41mm is required. The measured data presented in this paper are for a distance (d) which equals 7mm . The size of the reflector is chosen to be 40mm which is more than a few wavelengths at the operating frequencies. Figure 2.5 shows the measured and simulated gain and reflection coefficients of the integrated patch antenna. The gain of 2.4dBi inside the -10dB impedance bandwidth was measured. The fabricated prototype achieves 50Ω input impedance matching (reflection coefficient) which equals to or less than -10dB at frequencies from 60GHz to 66GHz . Therefore, the validity of comparison between the measured and simulated gains is limited to these frequencies. The results show that the prototype antenna is much better matched to 50Ω impedance than the simulation model antenna at frequencies from 63.5GHz to 66GHz . The difference between the measured and simulated gain at these frequencies is within 0.7dB . Gain variation at other frequencies is mainly due the limited dynamic range of the network analyzer, high noise level and high path loss at 60GHz . Since the microwave probe is not shielded, it also radiates some energy which limits the measurement set-up of the dynamic range. When the distance between the antenna and reflector is increased to 10mm the difference between the S_{11} and S_{11c} becomes too small to accurately calculate the gain.

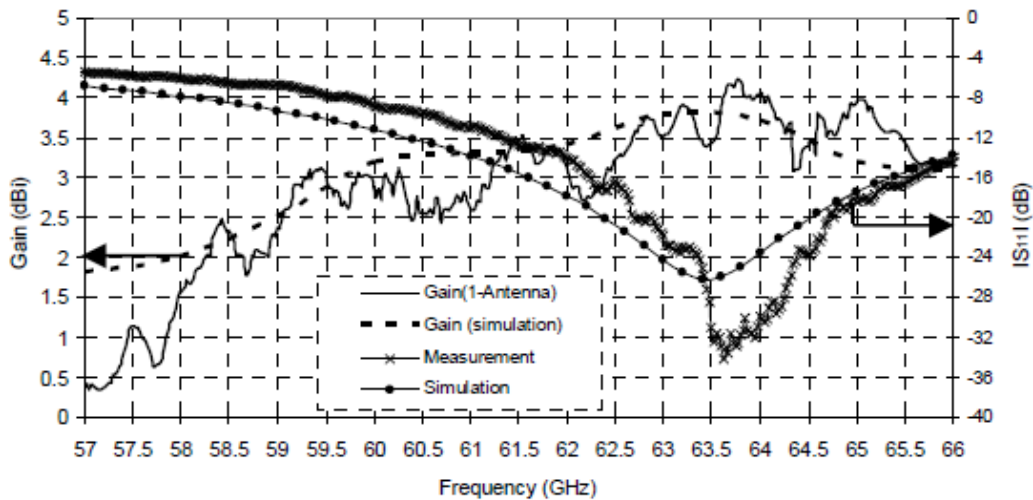


Figure 2.5: Gain and reflection coefficient, $|S_{11}|$ of an on-chip mounted and antenna.

2.5.1.2 Coplanar Fed Loop Slot Antenna

Figure 2.6 shows the measured gain versus frequency achieved using single-antenna method, three-antenna method and simulated gain of coplanar fed loop slot antenna. The conventional 3-antennas measurement set-up are calibrated using coaxial V-band VNA calibration kit and two standard rectangular horn V-band antennas (23dBi gain). And, one of the input ports is connected to the V-band connector and test antenna.

The measured results (three-antenna method) show that fabricated coplanar fed loop antenna achieves gain of 7dBi to 8dBi within the -10dB input impedance matching bandwidth. The -10dB input impedance matching bandwidth is achieved at frequencies from 57.5GHz to 65GHz. For the same frequency bandwidth V-band reference horn antennas are also matched and $|S_{11}| < -15\text{dB}$. The gain difference between single antenna method and three antenna method is within 1.7dB. The discrepancy is mainly due to impedance mismatch, possible antenna misalignment and measurement errors of the VNA. The reference horn antenna is matched for the bandwidth from 50GHz to 75GHz, however, the antenna under test has -10dB input impedance matching bandwidth from 57.5GHz to 65GHz. Thus, the validity of the measured antenna gains for both methods is limited to the bandwidth from 57.5GHz to 65GHz. It should also be noted that the measurements and gains of the single antenna method are also affected by the proximity of the V-connector to the PEC reflector.

Since the V-connector housing and acrylic support of the prototype antenna is not included in the simulation there is a discrepancy between the measurement and simulation results at around 57.5GHz and 61GHz. Although, the gain discrepancies between the three-antenna method and single-antenna method for the CPW-fed loop slot antenna is about 1.7dB considering 8dBi antenna gain (medium gain), the single-antenna method is still acceptable for quick gain measurements during the antenna design development stage.

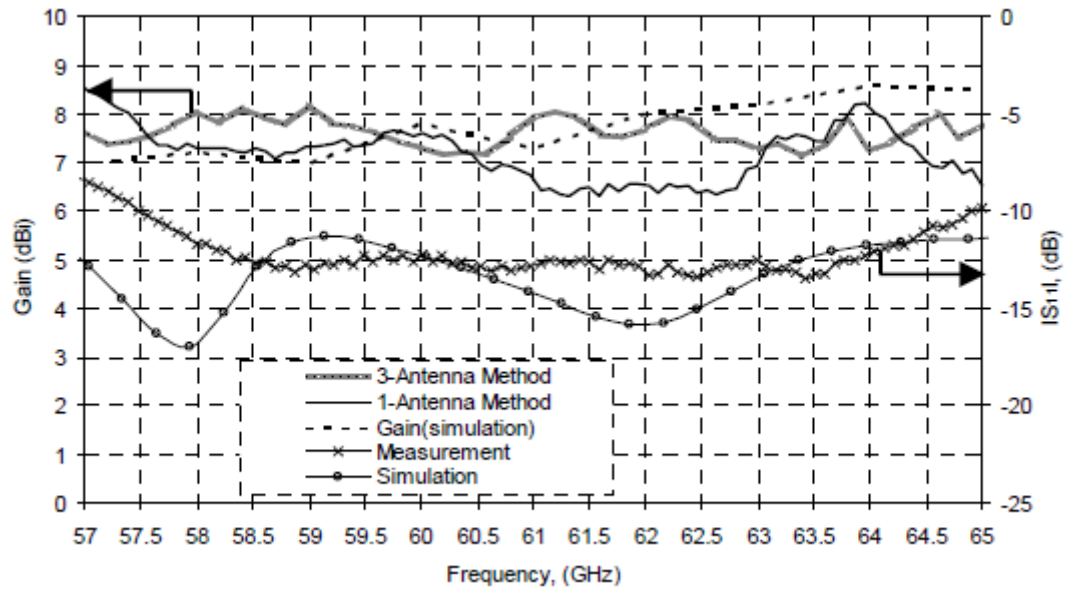


Figure 2.6: Gain and reflection coefficient, $|S_{11}|$ of coplanar-fed loop slot antenna.

This experiment examines the usage of a single-antenna gain measurement method for the mm-wave antennas in the V-band. Two mm-wave antennas are measured using the single antenna method and the simulation results are compared to standard three-antenna method. The achieved results confirm the suitability of the single-antenna method for measuring antenna gain in the V-band. However, the measurements of the low gain V-band antennas suffer from limited dynamic range of the network analyzer, high path losses and noise. This measurement method is suitable for quick measurements of medium to high gain directional antennas.

2.6 Theoretical Development

2.6.1 Introduction

The theoretical method used throughout the project is briefly discussed in this sub topic. The theoretical method must be related to the experiment prepared. This Theoretical method is to ensure that the attained data is calculated using a correct practical practice for a better end result. This sub topic helps to focus on the objective of this project which is to calculate the gain of the antenna. The important theoretical part of this experiment consists of the following important parameter such as S parameter, gain and far field region.

2.6.2 Scattering Parameter

Scattering parameter is also known as s-parameter in communication term. S-parameter is used to describe the input/output relationship between the port networks. S-parameter is measured by sending a single frequency signal into the network and detecting the kind of what signal exit from each port. S parameter is used to replace the parameter admittance and impedance [8]. This is because measuring travelling signal waves is easier compared to measuring total voltages and current. A harder cause for admittances and impedance short and open test need to be performed. Figure 2.7 shows the schematic of two port networks and its port parameters [9].

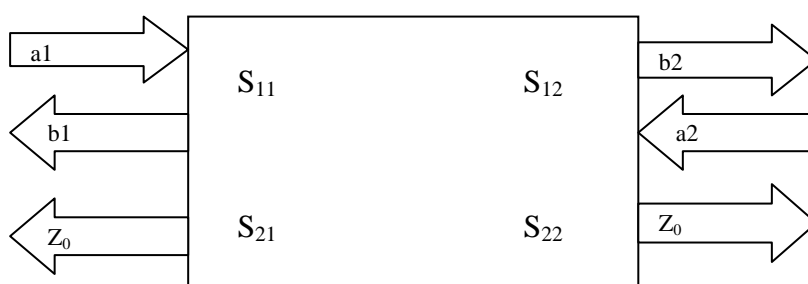


Figure 2.7: Two port network diagram.

a_i = Power wave travelling towards 2 port gate.

b_i = Power wave reflected back from 2 port gate.

Z_0 = Matching impedance, 50 ohm.

2.6.3 Gain

The important thing about the antenna is its time passive elements, and ensuring that no additional power is injected apart from the RF signal. This can be concluded that gain depends on radiation pattern. Usually the gain's unit is in dBi, meaning that the gain of the antenna is compared with a perfect round object and the energy radiating from such object is the same in all directions. Gain always refers to the increase of signal strength in the main direction or in one particular direction compared to the round object. Sometime gain unit is in dBd, which means the gain is compared with dipole antenna not with the perfect round object. For example, if an antenna has gain 5.1dBi it means that the antenna is having a forward gain of 5dB compared to a perfect round object [9].

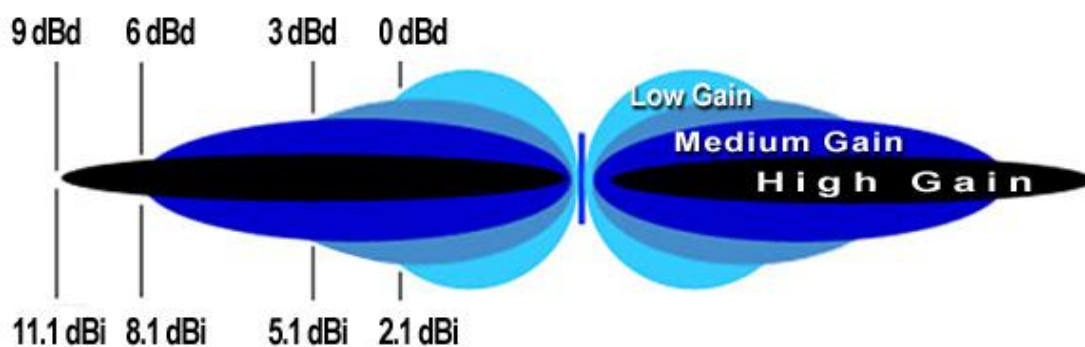


Figure 2.8: The radiation pattern and the gain value of an antenna.

In Technical term it means that the gain is referred as the ratio of the power required at the input of a loss-free reference antenna to the power supplied to the input of the antenna in producing, the same field strength in a given direction at the same distance. Figure 2.8 shows the radiation pattern diagram. Good antenna will have a higher gain because the higher the gain, the more susceptible the antenna signal is to obstruction and interference. The antenna's ability to focus the scattered radio frequency (RF) into a narrower plane is essential to make an antenna having higher gain value.

2.6.4 Friis Transmission Equation.

The Friis transmission equation is the power received from one antenna (with gain G_1), when transmitted from another antenna (with gain G_2), separated by the distance R , and operating frequency, f and wavelength, λ . Figure 2.9 shows the arrangement of hardware for Friis Transmission Equation [9].

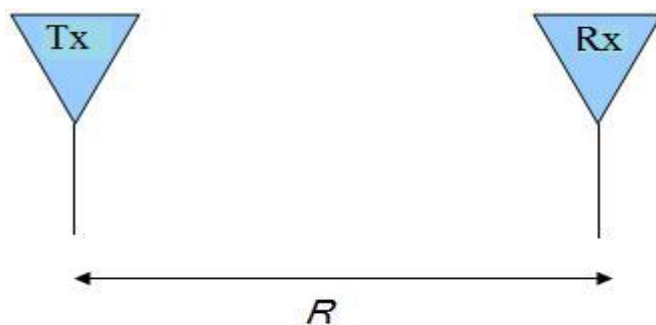


Figure 2.9: Two antenna method.

It relates the free space path loss, antenna gains and wavelength to the received and transmitted powers. This is one of the fundamental equations in antenna theory and design. This formula is known as Friis Transmission Formula.

$$P_R = \frac{P_T G_T G_R c^2}{4^2 \pi^2 R^2 f^2} \quad (2.2)$$

P_R = Power Received by antenna Rx (W)

P_T = Power Transmit by antenna Tx (W)

G_R = Gain Received by antenna Rx (dBi)

G_T = Gain Transmit by antenna Tx (dBi)

R = Distance between the antenna Rx an Tx (m)

c = Light speed (m/s) = 299 792 458 m / s

f = operating frequency (Hz)

2.6.5 Near and Far Field

Near field as the name suggest is the region close to the antenna and far field is the region far from the antenna. The two terms mention describes areas within an electromagnetic field formed around an antenna. Between these fields there is also an intermediate region known as transition zone. Transition zone retains the properties of both near and far field depending on the distance. The far field region of an electromagnetic field starts approximately two wavelengths from the antenna and extends outward. The near field region is found one wavelength or less from the transmitting antenna. . Unlike far field communication, the receiving antenna affects the transmitting antenna. This unique characteristic of the near field region allows near field communication to create a signal between a transmitting device and the receiving near field tag. The tag's field is powered by the transmitter and the tag's field can communicate back to the transmitter in sending information. This entire region is not permanent, meaning that it can be changed depending on the strength of the signal transmitted by the transmitting antenna. Figure 2.10 shows the region of the near and far field of an antenna.

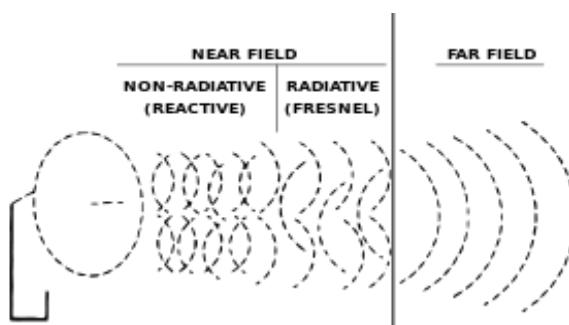


Figure 2.10: The near field and far field of the antenna.

The near field and far field can also be related using a formula below. This formula is commonly used to calculate the distance considered as far and near field.

For near field distance, R:

$$R = 0.62 \left(\frac{D^3}{\lambda} \right)^{\frac{1}{2}} \quad (2.3)$$

For far field distance, R:

$$R = \left(\frac{2D^2}{\lambda} \right) \quad (2.4)$$

D = Antenna aperture or antenna diameter (m^2)

λ = Wavelength of the antenna involved (m)

The reason for measuring gain in the far field region is to measure the gain as accurately as possible, by restricting the deviation of the phase of the field (E and H) across the antenna aperture. The general criterion used is at the constant of $\pi/8$ radian (22.5°). Figure 2.11 shows that in order to determine the minimum permissible value of R (far field value) it is necessary to hold the Δ (angle) to a maximum of $1/16$ wavelength (22.5° of phase deviation).

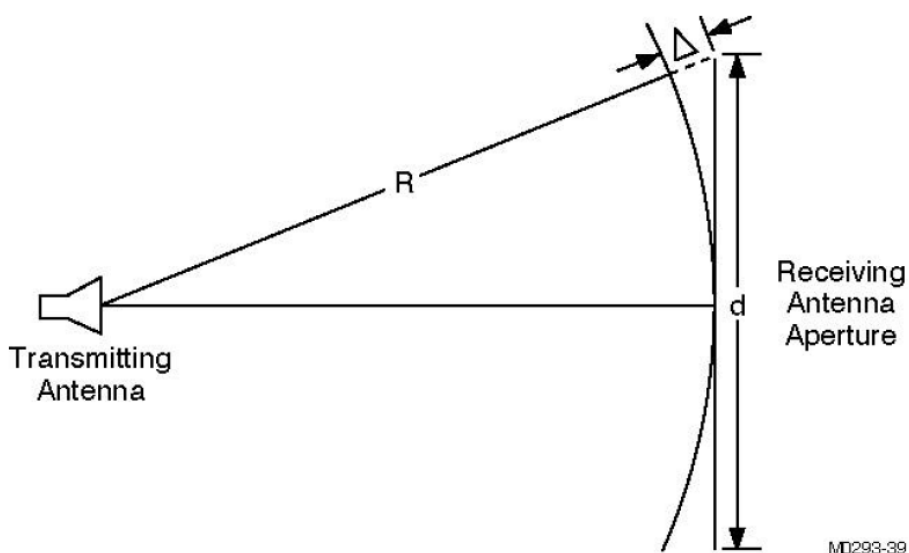


Figure 2.11: Spherical Phase Front Tangent to a Plane Antenna Aperture

2.6.6 Image Theory

The antenna is placed above a perfectly conducting plane surface (90°). Figure 2.12 shows the placement of an antenna on a perfectly conducting plane surface.

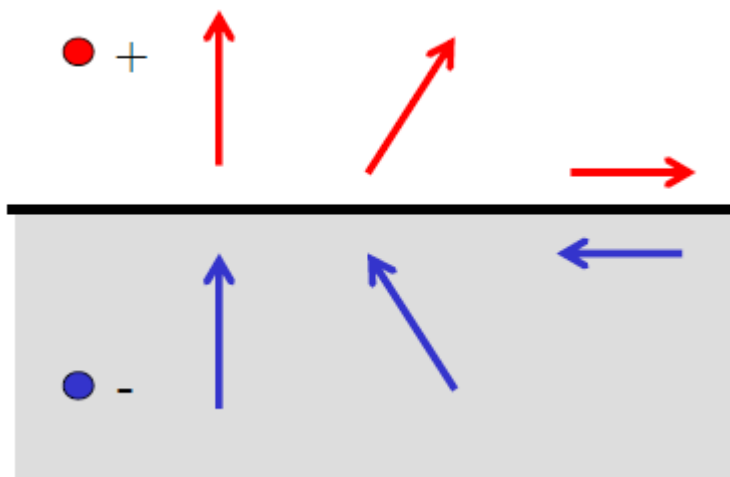


Figure 2.12: Image theory.

The tangential electric field component of an image theory is equal to 0. Figure 2.12 shows that when the component is placed vertically, the reflected signal is reflected back to the source. But if the components are placed horizontally the reflected signal will move away from the source. Image theory also stated that the field (above the ground) is the same as if the ground is replaced by the antenna image below. Usually image theory is used to predict the radiation pattern of a dipole antenna located at a specified distance from the plane and at a 90° corner planar of a perfect electrical conductor [2, 9].

2.6.7 Mean

In statistics, the mean is the mathematical average of a set of numbers. The average is calculated by adding up two or more scores and dividing the total by the number of scores [22].

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \dots + X_n}{n} \quad (2.5)$$

X_1, X_2, X_3, X_n = Samples/Data collected

\bar{X} = Mean/Average of the sample

N = Total number of the sample

2.6.8 Standard Deviation

The standard deviation is a measure of the numbers or data are spread out or the measure of dispersion of the number or data. If the standard deviation of a set of data is large it means that the data are widely scattered. If the standard deviation of a set of data is small it means that the data are tightly clustered [23].

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{X})^2} \quad (2.6)$$

s = Standard deviation of the sample

N = Total number of the sample

x_i = The sample numbering ($i=1,2,3,4,5 \dots n$)

\bar{X} = Mean of the sample

2.6.9 Correlation Coefficient

The correlation coefficient measures the strength of a straight line or linear relationship between two variables. A 0 indicates no linear relationship between the data, +1 indicates positive linear relationship between the data and -1 indicates negative linear relationship between the data [24].

$$r = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \sqrt{n(\sum y^2) - (\sum y)^2}} \quad (2.7)$$

r = Correlation coefficient of the sample

n = Total number of the sample

x = Sample number 1

y = Sample number 2

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the overall methods and hardware that are used for this project. It begins by understanding the specifications and the characteristics of the single antenna method. This project focuses on the gain measurement of the horn antenna, using the formula and S-parameter (S_{11}) that will be obtained during the experiment. The other methods that need to be understood are the correct ways to handle the vector network analyzer so as to obtain the best results. Before any action is taken for any project or experiment, proper planning must be done. This proper planning on the project or experiment is important. The project or the experiment can be defined with specific goals and datelines.

The methodology of this project is divided into three parts. Each part of the project is discussed as follows:

- a) List and decide the best method and strategy to design the system based on past project and reference.
- b) Decide to use the appropriate hardware based on information that have been gathered.
- c) Determine the formula and the parameter that will be useful in this experiment.

REFERENCES

1. J. Glimm, K. Munter, R. Pape and M. Spitzer, "New Results of Antenna Calibration In A Single Antenna Set-Up," XVI IMEKO World Congress, Austria, 2000, September 25-28.
2. Prof. Dr R. Struzak, "Antenna theory basics, "School on Digital Radio Communications for Research and Training in Developing Countries The Abdus Salam International Centre for Theoretical Physics ICTP Trieste ,2004 February 9-28.
3. Jungkuy Park, Guseon Mun, Daehoon Yu, Boveon Lee and Woo Nyun Kim, "Proposal of Simple Reference Antenna Method for EMI Antenna Calibration", Electromagnetic Compatibility(EMC), IEEE International Symposium, 2001, August 14-19.
4. Hsin-Chia Lu and Tah-Hsiung Chu, "A Quasi-Monostatic Reflective Three-Antenna Method for Antenna Gain and Scattering Measurement", volume 3, Antennas and Propagation Society International Symposium (IEEE), 2000.
5. J. Glimm, K. Munter, R. Pape and M. Spitzer, " A Single-Antenna Method for Traceable Antenna Gain," IEEE Transactions on Electromagnetic Compatibility , Vol 41, 1999, November.
6. Hyenek Bartik, "Antenna Measurement Using the Mirror Method with Gating in a Time Domain", Department of Electromagnetic Field, Czech Technical University in Prague.
7. Gordana Felic, " Antenna Gain Measurements in the V-band: A Single-Antenna Method", National ICT Australia (NICTA), Victoria Research Laboratory, The University of Melbourne, Parkville, 2009.
8. Yoshikazu Fujishiro, "Taking Advantage of S-Parameter", TDK Corporation Application Center, 2000.

9. C. Balanis, "Antenna theory, analysis and design," Wiley, Second Edition, 1997.
10. Internet resource "http://en.wikipedia.org/wiki/Near_and_far_field", Wikipedia Corporation, viewed on 2013 Mar 24.
11. Internet resource "www.teseq.com/products/downloads/datasheet/BHA_9118.pdf", Teseq GmbH Corporation, viewed on 2013 April 24.
12. Internet resource "<http://www.zcg.com.au/antenna-gain-explained.html>", ZCG Scalar Corporation, Victoria, Australia, viewed on 2013 April 27.
13. B.K Chung & H.T Chuah," Modelling of RF Absorber for Application in the Design of Anechoic Chamber", Faculty of Engineering Multimedia University,2003.
14. Internet resource "[http://www.metrictest.com/product_info.jsp?mfgmddl=RS%20ZV-Z21\(D\)](http://www.metrictest.com/product_info.jsp?mfgmddl=RS%20ZV-Z21(D))", MetricTest Engineering, Hayward, UK, viewed on 2013 May 27.
15. Hewlett Packard," S Parameter Technique for Faster, more Accurate Network Design", Test & Measurement, Application Note 95-1 pg 3, 1995.
16. Yenpao Albert Lu,"Design of Horn and Open Waveguide Antenna at 915 MHz" The Propagation Group, PG-TR-040813-YL, 2004 August 13.
17. Sana Naghipour, "ESE498 Patch Antenna", Washington University in St.Louis, School of Engineering and Applied Science, 2012 May.
18. B.N Prakash and K.R Suresh," A Practical Method For Calibrating Antennas", EMC Test Centre, QA Divisison Bharat Electronics LTD,Bangalore, 1999.
19. Pippard, A.B., Burell, O.J., Cromie, E.E.: "The Influence of Re-Radiation on Measurements of The Power Gain of an Aerial", JIEE 93 (1946) Pt IIIA N0.4, pp 720- 722.
20. Internet resource "<http://www.antenna-theory.com/basics/friis.php>", test equipment connection, viewed on 2013 April 30.
21. Internet resource "<http://www.sal2000.com/ds/ds3/Acoustics/Wave%20Reflection.html>",test equipment connection, viewed on 2013 April 30.
22. Internet resource "<http://www.purplemath.com/modules/meanmode.htm>",purplemath, Staple Elizabeth, viewed on 2013 September 28.
23. Internet resource "<http://www.mathsisfun.com/index.htm>", mathisfun, viewed on 2013 September 28.
24. Internet resource "<http://mathbits.com/MathBits/TISection/Statistics2/correlation.htm>",mathbits, viewed on 2013 September 28.