Department of Electronic Engineering

FINAL YEAR PROJECT REPORT

BEngECE-2008/09-CHC-01

Circularly-polarized annular-ring patch antennas with size reduction

Student Name: CHEUNG, Yuen Wai
Student ID:
Supervisor: Prof. CHAN, Chi Hou
Assessor: Prof. LUK, Kwai Man

Bachelor of Engineering (Honours) in
Electronic and Communication Engineering (Full-time)

Student Final Year Project Declaration

I have read the student handbook and I understand the meaning of academic dishonesty, in particular plagiarism and collusion. I declare that the work submitted for the final year project does not involve academic dishonesty. I give permission for my final year project work to be electronically scanned and if found to involve academic dishonesty, I am aware of the consequences as stated in the Student Handbook.

Project Title : Circularly-polarized annular-ring patch antennas with size reduction

Student Name : CHEUNG, Yuen Wai

Student ID:

Signature

Date : 24th April , 2009

Table of Contents

Page

CHAPTER4: Design and Result

CHAPTER 5: Size Reduction

CHAPTER 6: Enhancement

Page

CHAPTER 7: Conclusion

Abstract

Circularly-Polarized Annular-Ring Patch Antennas with Size Reduction

尺寸縮小的圓極化環型貼片天線

by

Dennis, Y.W. CHEUNG

Department of Electronic Engineering

City University of Hong Kong

The demand of antenna elements is rapidly increasing recently due to varieties of wireless communication systems launched into the market; for instances, 2G/3G mobile services, marine or land vehicle navigations (GPS), wireless LANs access, remote sensor with monitoring systems, and many small devices embedded with Bluethooth, UWB, Zigbee, DVB and etc. Among many types of antennas, they can be classified into two categories which are linearly-polarized and circularly-polarized elements. For majorities of wireless applications, the linearly-polarized antennas are good enough for transmitting as well as receiving the RF signals. However, for satellite communication and high sensitivity systems like as GPS, satellite phone and the space-to-earth communication, then the circularly-polarized antennas must be used in order to maintain a good capability of signals strength. Therefore, in this project, a study of development of new circularly-polarized (CP) microstrip antenna elements is carried out.

The aims of this project are to design a small CP annular ring patch antenna (ARPA) which targets to use in satellite communications. A novel techniques for size reduction in the microstrip ring patch is proposed. Firstly, a comparison between the annular-ring patch with conventional square / circular patch antennas is shown. Then, a technique for exciting CP radiation of the annular-ring patch by adding an L-sharp strip is introduced. Furthermore, a novel size reduction by employing "compact microstrip resonant cells" (CMRC) into the microstrip antenna is described. Finally, a bandwidth enhancement for the small antenna, with CMRC embedded, by using an L-probe fed and metallic wall are inaugurated.

All antenna designs are studied by IE3D and HFSS simulation, and then confirmed by measurements. In the finalized design, it is found that the size reduction of patch is around 40~50% when compared with a conventional antenna with the same center frequency. And the impedance bandwidth (BW) and 3dB axial ratio BW are above 10% and 1.5%, respectively. And the gain of this antenna is 6.8dBi. These result are meet the specified requirement and in good agreement.

Acknowledgement

"Channel all your efforts into a project, and you will succeed."

To begin with, I am willing to express gratitude to my supervisor, Prof. C.H. Chan, Professor (Chair) of Department of Electronic Engineering, Dean of Faculty of Science and Engineering, City University of Hong Kong, for his support, mercy and encouragement. He was my first teacher to initiate me into antenna industry. It is my honor to be a final year project student under Prof. Chan. Apart from my supervisor, I would also like to thank my assessor, Prof K.M. Luk, Professor (Chair) and Head of Department of Electronic Engineering, for his help, guide and opinion.

I wish to especially thank Dr. Steve H. Wong, Senior Engineer and Miss. Jovi W.C. Mok, Scientific Officer, City Univesity of Hong Kong. They taught me much technical knowledge for the purpose of the design, simulation, fabrication and measurement. With their instruction and suggestion, my project has been done very well. To sum up, there are no words to express the full measure of my appreciation.

Last but not least, I also thank to all technicians and colleagues in the Applied Electromagnetics Laboratory (P7822), City University of Hong Kong, for their pleasantness and support throughout my successful final year project. I would like to encourage all brothers and sisters to work hard in project. Because you just need to know many people are supporting behind you.

List of figures

Page

Page

Page

List of Tables

Chapter 1

Introduction

1.1 Background of study

Nowadays, the demand of antennas is rising because of the rapidly growth of wireless communication. It especially likes satellite communication system. Such as navigation hand held devices fitted to car, ship and aircraft. And it usually uses in civil and military application such things as: search and rescue.

Fig.1.1 (a) Examples of satellite communication system

However, for satellite communication systems and high sensitivity systems, the circularly-polarized antennas must be used in order to maintain and keep a good capability of signals strength. Therefore, in this project, a study of development of new (CP) microstrip antennas is carried out.

The aims of this project is to design a CP annular ring patch antenna (ARPA) which use in satellite communication, to investigate the influence of various parameters on the antenna performance, to integrate novel techniques for further size reduction & enhancement of annular-ring patch antennas and to fabricate the antenna & obtain good agreement in both measured and simulated results.

Fig.1.1 (b) Example of disadvantage of using large size antenna

Now, I would like to explain why we need to reduce size of antenna. We all know that smaller antennas can easily fit in smaller and finite size products. And it is one of increasing beamwidth methods. In case, size reduction is mainly considerable interest in developing microstrip antennas for wireless communication systems. There are several techniques that can be used to reduce the size. Such as use of capacitive and inductive loading, increase of the electrical length and change of antenna's topology (use high and expensive dielectric constant material).

1.2 Layout of the REPORT

Chapter 1 briefly describes the objective and background of this project and layouts the structure of this report.

Chapter 2 roughly introduces general parameters and circularly polarized (CP) characteristic of annular ring patch antenna (ARPA), and depicts the theory of related design and enhancement techniques. All of general antenna design knowledge is also given in this chapter, such as design guidelines and methodology.

Chapter 3 introduces the methodology of simulation and measurement. All simulation tools and measurement tools are presented in this chapter.

Chapter 4 shows the first proposed design of circularly polarized annular ring patch antenna by using L-shaped strip on inner ring boundary. The export of this L-shaped strip which connected to the edge of inner ring boundary excited 90 degree out of phase in order to produce circularly polarization. The performance results are presented. All parameters which influence of the result are also discussed in this chapter.

Chapter 5 shows the second to fourth proposed design of circularly polarized annular ring patch antenna with further size reduction. The performance results and main parameters study are also discussed in this chapter.

Chapter 6 shows the fifth and sixth (last) design of circularly polarized annular ring patch antenna with further size reduction and enhancement. By using L-probe feeding and metallic wall technique, the effective impedance and CP BW enhancement is achieved. All performance results and significant parameters study are also in this chapter.

Chapter 7 draws the conclusion and summary of this project.

Chapter 2

Antenna Theory

In the following chapter, I would like to give you a brief introduction of antenna. It covers the part of annular-ring patch antenna, compact microstrip resonant cell, L-probe fed technique and all significant parameters in antenna design. After you read this chapter, you will more and more understand related antenna theory.

2.1 Annular-Ring Patch Antenna

The annular ring patch antenna (ARPA) is popular microstrip antenna due to their benefits. It offers performance similar to that of rectangular shape antenna. And because of its large resonant length, it has a small size and bandwidth compared to other microstrip antennas resonant at the same given frequency in the fundamental TM11 mode. Nowadays, many applications require even small size antenna. For example, something likes hand-held device and motive device. ARPA also offers certain benefit in array. It can be easily modified to produce operation frequency. In order to fit in smaller and finite size devices, the further size reduction is need.

Consider an example of probe-fed annular ring patch antenna with the coordinate system as shown in Fig.2.1 (a). It comprises a ring metal on top side of dielectric substrate and with a ground plane on bottom side. The outer and inner radius are b and a, respectively. The length from center to probe fed position point is ℓ. Dielectric substrate is ε_r and thickness of substrate is h. And in Fig.2.1 (b) show all definition.

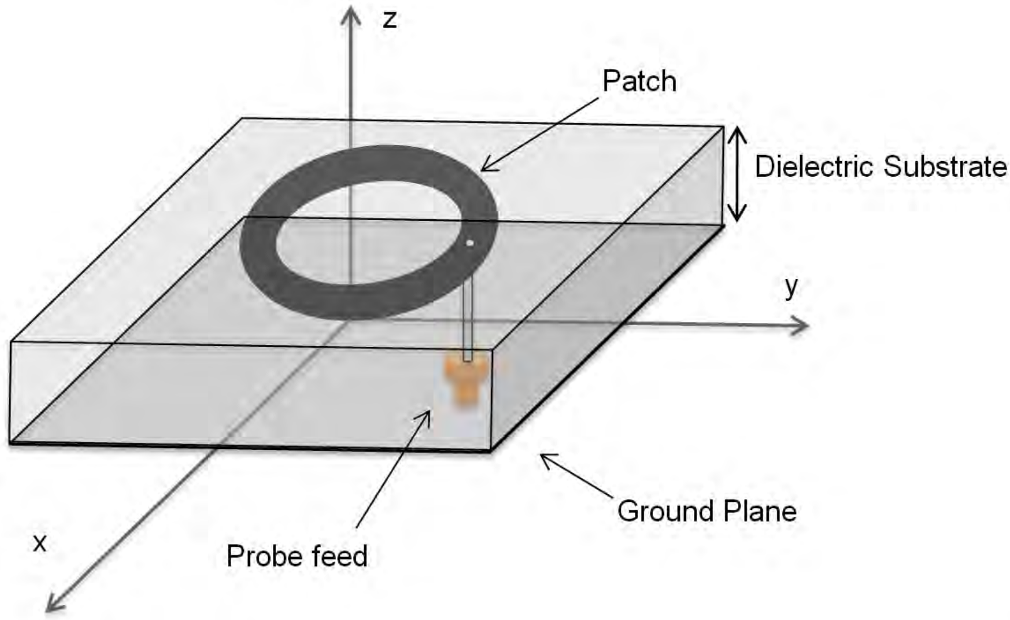


Fig.2.1 (a) Annular ring patch antenna with the coordinate system

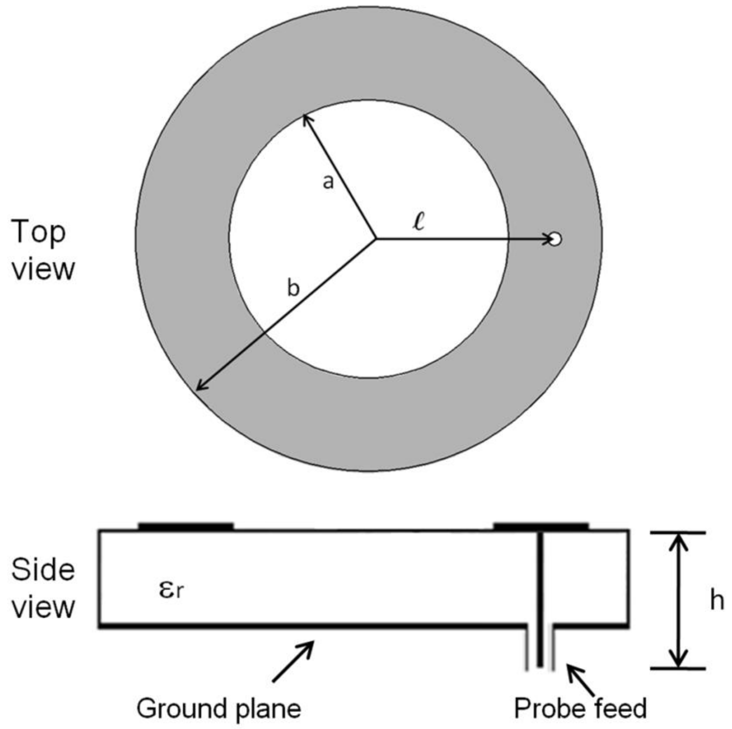


Fig.2.1 (b) Top view and side view of annular ring patch antenna

2.2 Compact microstrip resonant cell

Compact microstrip resonant cell (CMRC) is a planar printed one dimensional phonic band gap. CMRC exhibited slow wave property. And its characteristics like PBG structure which can be integrated to reduce the dimension of microstrip structure. Theoretically, C and L are the capacitance and inductance per unit length, respectively. CMRC was well developed by City University of Hong Kong.

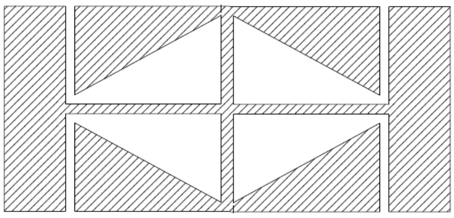


Fig. 2.2 (a) Geometry of Compact microstrip resonant cell (CMRC)

From above picture, its narrow connecting lines lead to increase the series inductance and gap across leads to increase the shunt capacitance. We can adjust these two parameters to attain slow eave effects for size reduction at specified frequency. In this project, by integrating CMRC for LC loading, further size reduction is obtained.

2.3 L-probe feeding technique

L-probe technique was invented by City University of Hong Kong in 1998. And it is made by bending a straight wire. Practically, L-probe is no connection between the probe and the patch. It is one of coupling fed techniques. It consists of vertical and horizontal portion. The geometry of the typical L-probe is shown as follow:

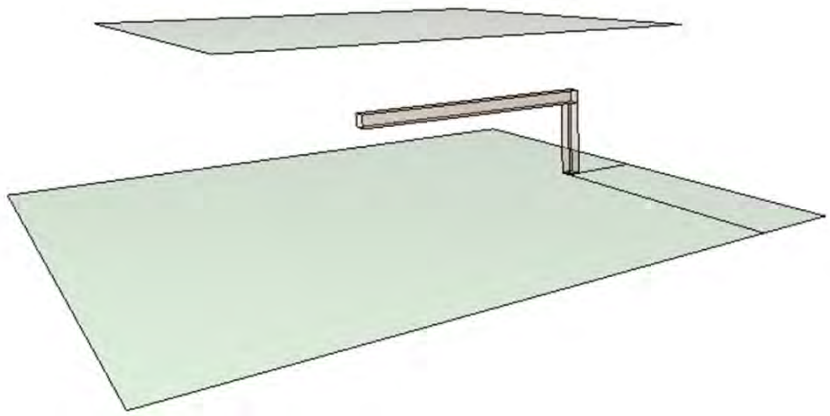


Fig. 2.3 (a) 3D view of tradition L-probe

Typically, the thickness of air substrate is 0.1 λ . By using L-probe technique, it can improve the impedance bandwidth effectively. The improvement of impedance bandwidth is achieved around 50 to 60%. Increasing the length of horizontal portion introduces capacitance to cancel out the inductance from vertical portion. In this project, a novel type of L-probe.is proposed, I try to modify the horizontal portion as shown in Fig.2.3 (b). The function of Y horizontal portion is also introduces capacitance to cancel out the inductance from vertical portion.

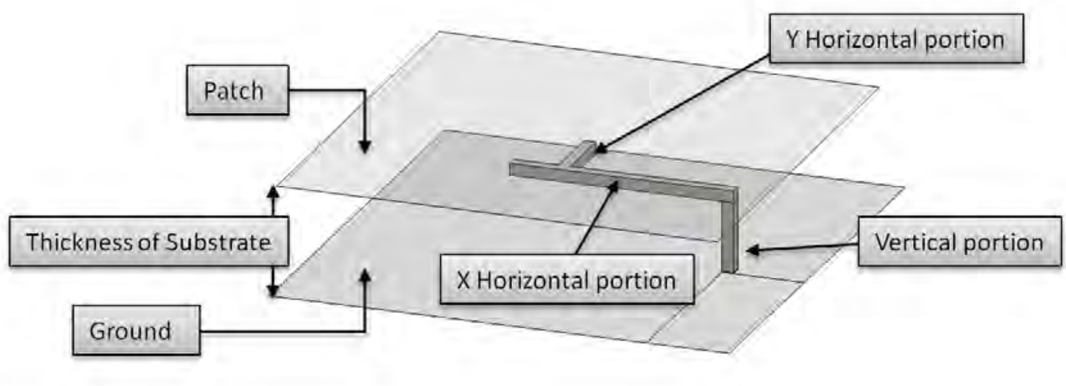


Fig. 2.3 (b) 3D view of novel L-probe

2.4 Antenna Parameters

Antenna parameters are the main concern in all antennas design. For this project, the following parameters must be considered: resonant frequency, input impedance, voltage standing wave ratio (VSWR), return loss, bandwidth, radiation pattern, polarization and antenna gain.

2.4.1 Resonant frequency

Resonant frequency means that antenna operates on electromagnetic wave frequencies. Electromagnetic waves propagate with velocity of light. For antenna design, we can refer the approximation equation as follow:

$$f = \frac{c}{\lambda\sqrt{\varepsilon}} \quad \text{and} \quad L = \frac{\lambda}{2\sqrt{\varepsilon}}$$

Where f and L are resonant frequency and physical length of antenna, respectively

2.4.2 Return loss

Return loss (RL) represents the amount of power which is reflected back to the source due to impedance mismatching. It is a ratio of electric field strength of the reflected wave to incident wave. It is usually expressed as a ratio in dB. For good power transfer, the RL (a ratio of electric field strength of the reflected wave to incident wave) should be as small as possible.

For example, -20dB is better than -10dB. We defined that the standard merit of return loss is -10dB in this project, and -14dB in production. Return loss can be expressed in dB as follow:

$$\text{Return loss(dB)}=-20\log_{10}|\Gamma| \quad \text{and} \quad \Gamma=\frac{V^-}{V^+}$$

Where V^- and V^+ are incident and reflected wave, respectively.

2.4.3 Voltage standing wave ratio

Voltage standing wave ratio (VSWR) is like return loss. CSWR is also a measure of the impedance mismatch between the transmitter and the antenna. For example, if the antenna is not match, some of the power would be reflected back and it would produce a standing waves. We can express it as follow:

$$VSWR=\frac{1+|\Gamma|}{1-|\Gamma|} \quad \text{and} \quad \Gamma=\frac{V^-}{V^+}=\frac{Z_{in}-Z_s}{Z_{in}+Z_s}$$

Γ is reflection coefficient, where Z_s and Z_{in} are transmitter and antenna impedance, respectively, also V^- and V^+ are incident and reflected wave, respectively. Practical antenna designs usually have an input impedance of either 50ohms or 75 ohms.

According to maximum power transfer theorem, it can be transferred if:

$$Z_{in}=Z_s^*$$

2.4.4 Bandwidth

The term of bandwidth in antenna means the usable frequency range with reasonable performance and specified standard. It is usually defined as the percentage of the frequency difference between highest and lower frequency with specified standard and divided by center frequency. The specified standard is -10dB in this project and -14dB in production. The return loss below this standard ensures good performance in operation. The equation of bandwidth can be expressed as below:

$$\text{Bandwidth}(\%)=\frac{f_H - f_L}{(f_H + f_L)/2}\times 100\%$$

Where f_H and f_L are upper and lower frequency at specified S11 requirement -10dB for this project and -14dB for production.

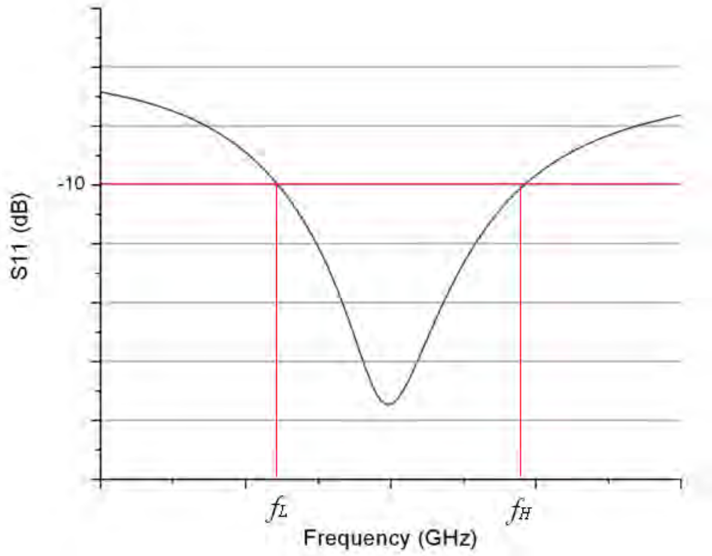


Fig.2.4 (a) Example of bandwidth measurement with specified standard -10dB

We can also judge the antenna performance by measuring its VSWR<2. It is another method to ensure the antenna is good performance.

2.4.5 Radiation Pattern

The radiation pattern describes the relative strength or radiated energy of the radiated field from the antenna. We can use this pattern to draw the radiation property of the antenna which energy out into space. And these patterns are usually presented in polar format. In this project, it is an important parameter to state that an antenna exists circularly polarization or not.

By observing the E-left and E-right, we can define the CP performance of the antenna. In the pattern, we can also observe half power (3dB) beamwidth of the antenna. And the 3dB beamwidth is defined as the angle degree between the main lobe to that are down from the maximum gain by 3 dB. Antennas with wide beamwidth usually have low gain and narrow beamwidth.

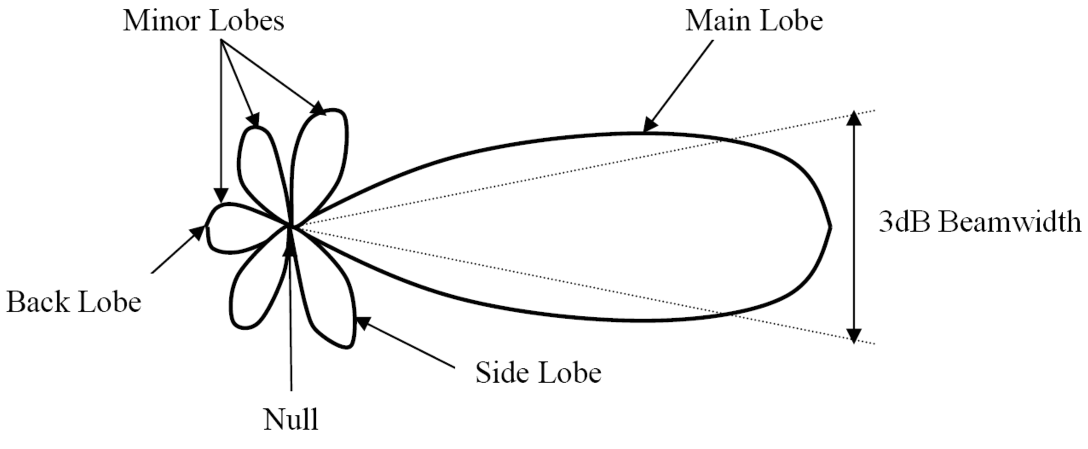


Fig. 2.4 (b) Example of radiation pattern structure

For above example, different parts of radiation pattern, which include main lobe, minor lobes, side lobe and back lobe, are showed.

2.4.6 Polarization

Polarization of radiation represents the property of an electromagnetic wave describing magnitude of the electric field vector as the time varying direction. The most common types of polarization are the linear polarization (LP) and left / right hand circular polarization (LHCP/RHCP). Circular polarization is resolved into two LP waves with equal amplitude and 90 degree phase difference. In this project, the right hand circularly polarized antenna is performed. The electric filed vector rotates in clockwise direction

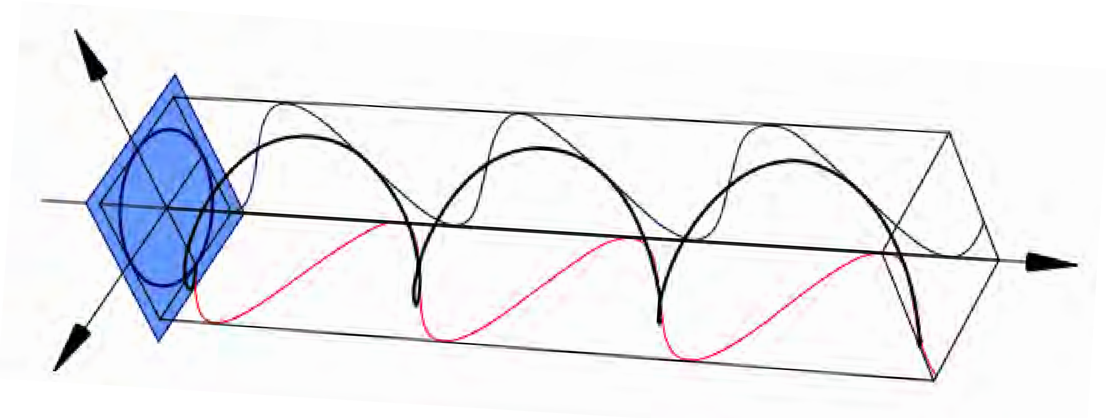


Fig. 2.4 (c) Example of wave with circularly polarization (CP)

2.4.7 Gain

Antenna gain is defined as the ratio of the intensity radiated by the antenna in the maximum direction. It is also related to the directivity of the antenna. Directivity of an antenna states how much of energy concentrates in one direction an antenna in preference to radiate in other directions. If the antenna is fully efficient, then the directivity would be equal to the antenna gain.

The equation of gain is as follow: Antenna gain = efficiency x directivity

Practically,

$$\text{Antenna Gain(dBi)} = \text{AUT-SGH} + \text{Factor}$$

Where AUT=antenna under test, SGH=power gain of standard horn

2.5 References

[1] Deschamps, G.A., *"Mircrostrip mircowave antennas",* 3rd USAF Symposium on antennas, 1953.

[2] John D. Kraus and Ronald J. Marhefka, *"Antennas for all Applications"*, McGraw-Hill, 2002

[3] Constantine Balanis, *"Antenna Theory",* John Wiley & Sons, 1997

[4] Quan Kue, Kam Man Shum, Wing Nam Chau, and Chi Hou Chan, *"Compact mircrostrip resonating cells and their applcation in mircowave circuits"* Recent research development in mircowave theory & techniques, vol.2, Transworld Research Network.

[5] Nakar, Punit Shantilal . *"Design of a compact Microstrip Patch Antenna for use in Wireless/Cellular Devices."*, Florida State University.

Chapter 3

Methodology

In chapter 3, I would like to introduce the simulation and measurement method. Let you know more about the methodology of antenna design. The following procedures are all successfully accomplished in my antennas design project

1. Paper and information study
2. Simulation in IE3D and HFSS
3. Draw in AutoCAD
4. Fabrication of the antenna
5. Measure the resonant frequency, return loss and BW are measured by using network analyzer. Measure the axial ratio, gain, beam width and radiation pattern are measured by compact range chamber.
6. Modification
7. Workout (report and presentation)

3.1 Simulation method

By using the well-known simulation software IE3D and HFSS, the antenna characteristics have been simulated and analyzed. IE3D is a full-wave, method of moments based electromagnetic simulation software. It uses to solve the current distribution on 3D layer and multiple layer general structures. Not only use in the design of antenna, but also widely use in the design microwave circuits and filter.

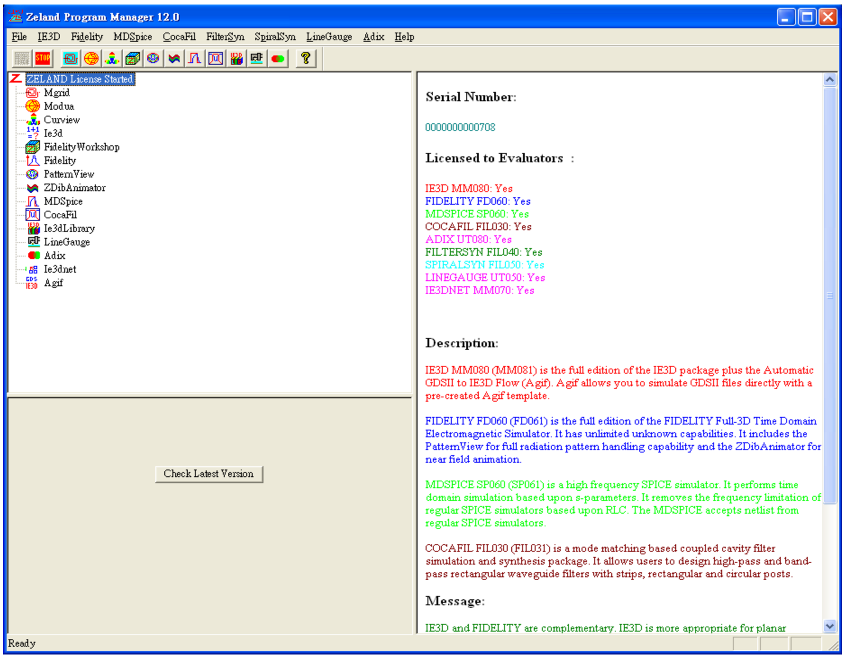


Fig. 3.1(a) Screen of Zeland Program manger version.12.0

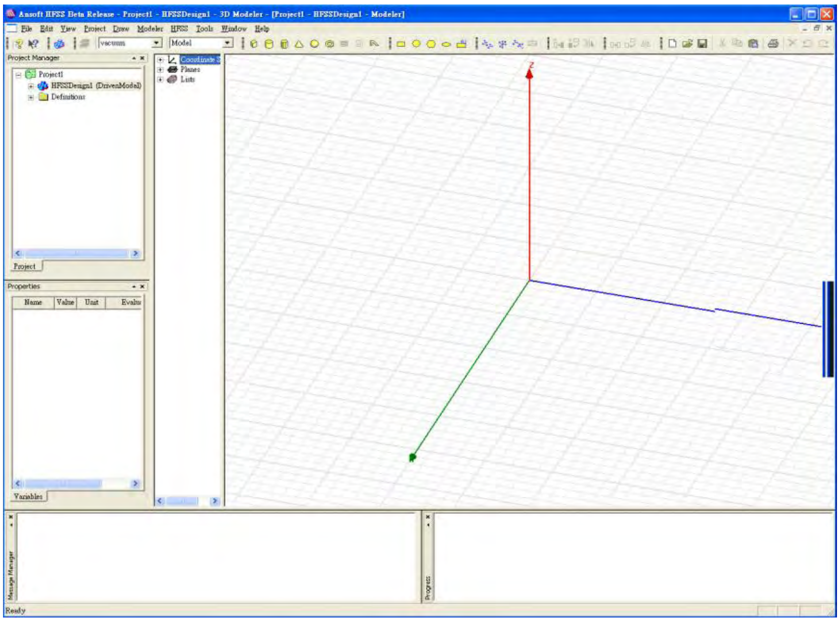


Fig. 3.1(b) Screen of Ansoft HFSS

Different from IE3D, HFSS improves engineering productivity, reduces development time, better assures first-pass design success. And HFSS can also solve complex geometries 2-5X faster and use less memory. I would use HFSS for later part.

3.2 Measurement method

For return loss and input impedance, network analyzer had been used to record. For axial ratio and gain, the chamber room with network analyzer had been used to measure. For radiation pattern, the chamber room with software MidAS3 had been used to measure.

Fig. 3.2 (a) Network analyzer HP8753

The input impedance of the antenna can be simply used by Network analyzer HP8753. Only one port is measured which is represented as S11. We also can observe Bandwidth, VSWR, real and imaginary impedance. Before I start to measure, the prior calibration should be finished. It is proper calibration of open circuit, short circuit and 50ohms load that can ensure all results are more accurate.

Radiation pattern of antennas can be measured by compact-range chamber room. The basic setting is shown as Figure 3.2(c). In conjunction with the software MidAS3 (refer to Fig 3.2 (b)), radiation pattern is obtained.

Fig.3.2 (b) Using the chamber room with software MidAS3 in P7822 AE Lab

For CP antenna, the (Right-Hand) and (Left-Hand) transmitting horn is located at the focal point of the parabolic reflector separately and then the horn produces a plane wave at the location of the antenna under test (AUT). When it applies reciprocity, the radiation pattern of the AUT can be obtained by the associated software MidAS3. Left and right picture at Fig.3.2 (d) are sample of AUT and RH/LH transmitting horns, respectively.

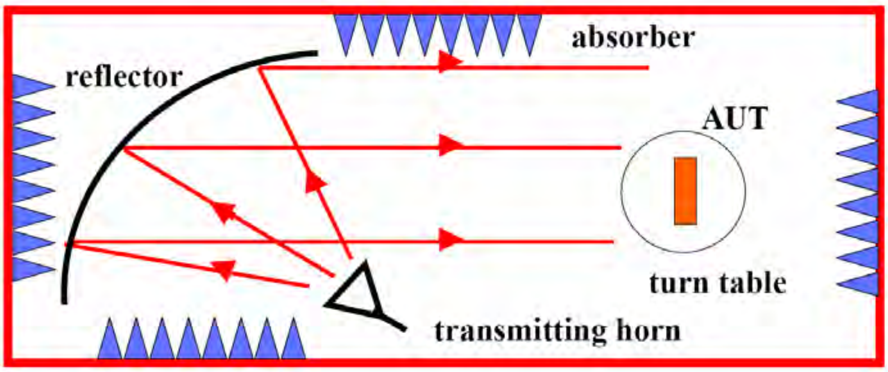


Fig.3.2(c) Basic setting captured from the note of EE4036, Antenna part, Prof K.M.Luk

Fig.3.2 (d) Setting up in chamber room in P7822 AE Lab

3.3 References

[1] Zeland Software, Inc. *"IE3D manual*", http://www.zeland.com/

[2] Sam Siu Yuen, *"Antennas Design - IE3D design handbook"*, Chuan Hwa Book Co., Ltd

[3] Wong Chi Yu, Ling Chi Wai, *"Microstrip antennas design- How to use IE3D"*, Chuan Hwa Book Co., Ltd

[4] Ansoft - HFSS *"HFSS manual*", http://www.ansoft.com

[5] Prof. K.M.Luk, *"Antenna"* EE 4036, EE department. CityU of Hong Kong

Chapter 4

Design and Results

In the first place, I would like to show the flow of antenna design. As you can see the following chart, I specially highlight the part of antenna design, simulation, measurement and enhancement which I would focus on.

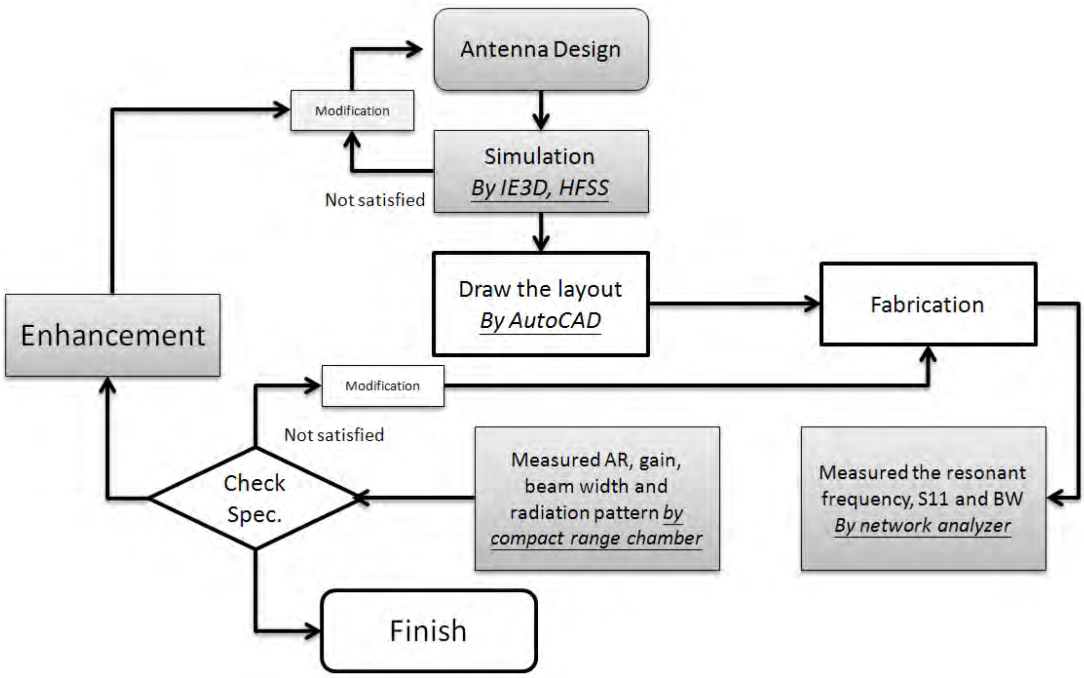


Fig.4 (a) Flow chart of antenna design

Typically, we spend so much time on simulation because the running time of simulation is too long and we also have a detail analysis and investigation. The output of analysis and investigation is used for tuning and adjusting in order to obtain better results of the proposed antenna.

4.1 Design Considerations

In antenna designs, there are many different feeding techniques to transfer the power from source to antenna patch. And also, there are different types of single and dual-fed technique to obtain circular polarization.

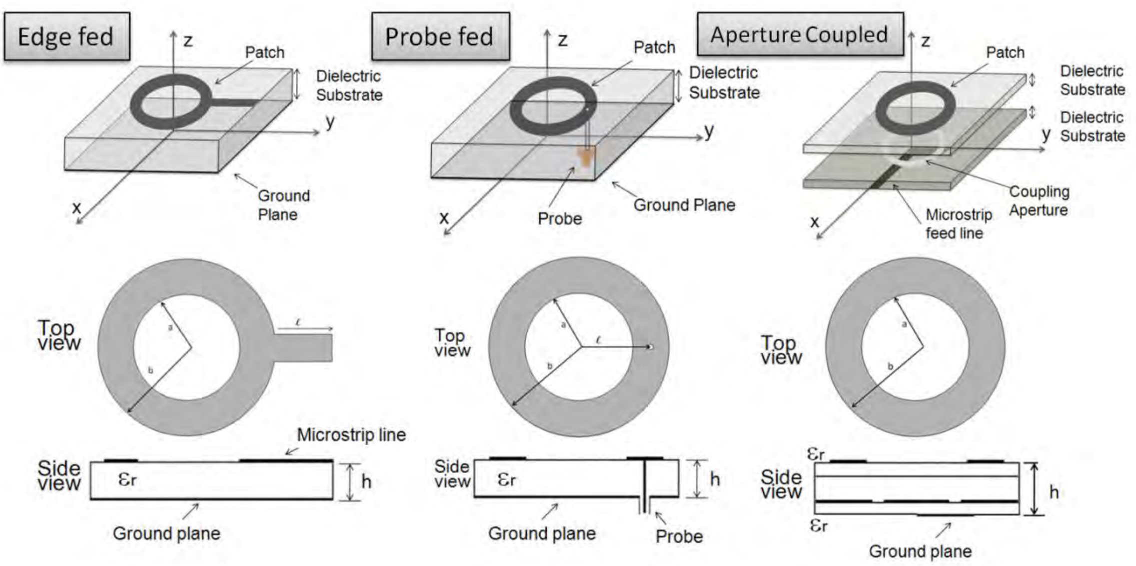


Fig.4.1 (a) Different feeding techniques applied in annular-ring patch antenna

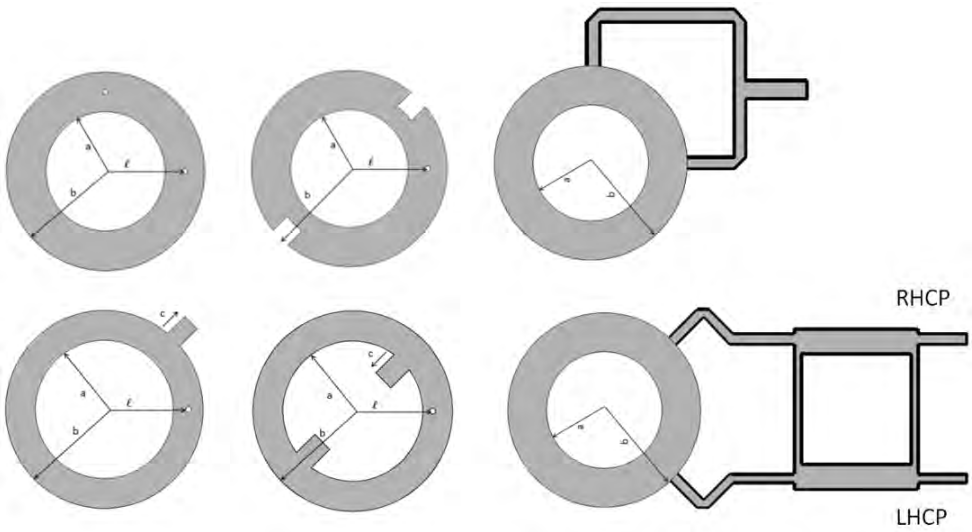


Fig.4.1 (b) Different types of single and dual-fed techniques to obtain CP

4.2 First proposed CP annular-ring patch antenna

The basic geometry of the antenna is shown in figure 4.2(a) and 4.2(b). The antenna consists of three layer which layer1 is Wangling (ε_r =2.65, thickness=0.8mm), layer 2 is 5mm foam or air and layer3 is Wangling (ε_r =2.65, thickness=2mm).

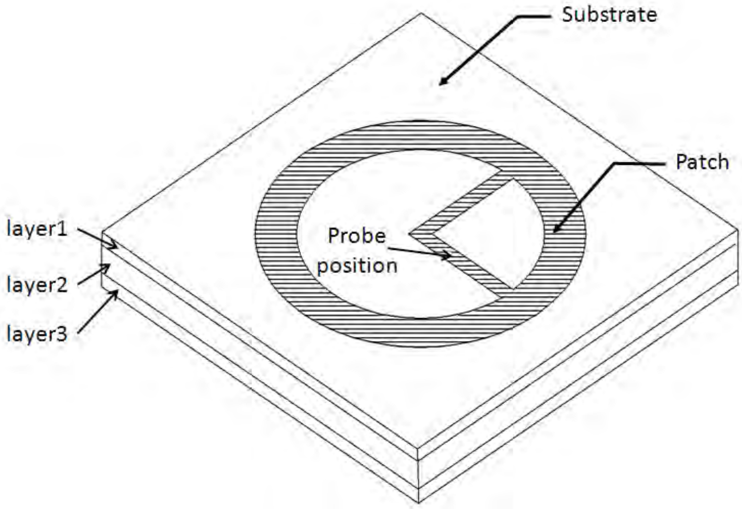


Fig. 4.2 (a) 3D view of first proposed antenna

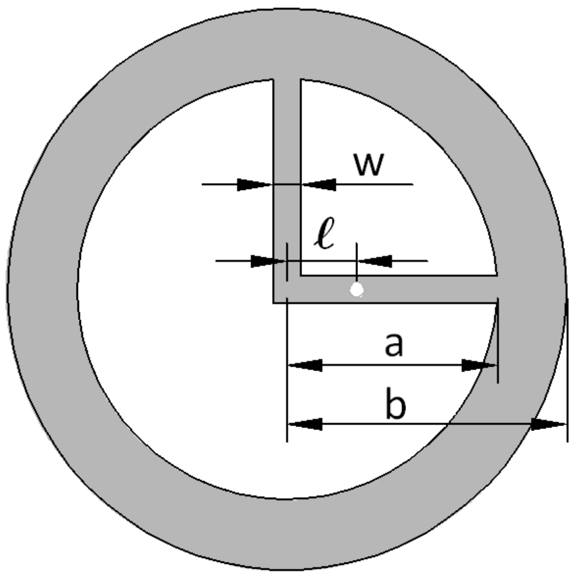


Fig. 4.2 (b) Top view of first proposed antenna (unit: mm)

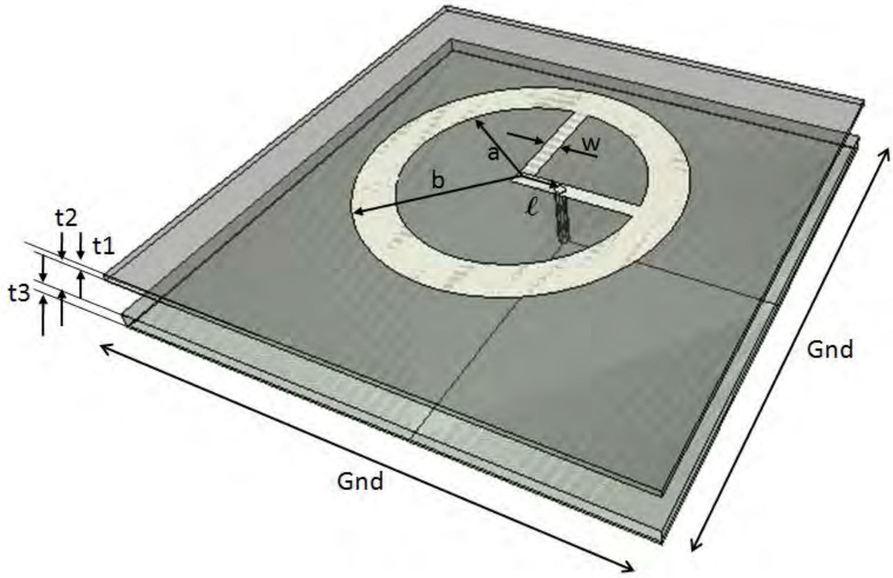


Fig. 4.2 (c) Geometry of first proposed antenna in IE3D

All parameter values are shown at table 4.2 (a). However, detail parameters study is must for designing antenna. And I would show in next section. With table shown as below, the diameter of the ring is 40mm. Approximately,

$$L \approx x\frac{\lambda_o}{2} \approx x\frac{c}{2f} \approx x\frac{3\times10^8}{2\times2.6\times10^9}$$

$$\because L = 0.04m \Rightarrow x \approx \frac{0.04}{0.05769} = 0.693$$

$$L \approx x\frac{\lambda_o}{2} \approx 0.347\lambda_o$$

Where L is the physical length of diameter of annular-ring

Parameters	a	b	w	ℓ	t1	t2	t3	gnd
Values(mm)	15	20	2	5	0.8	5	2	65
	$0.13\lambda_o$	$0.173\lambda_o$	$0.017\lambda_o$	$0.043\lambda_o$	$0.007\lambda_o$	$0.043\lambda_o$	$0.017\lambda_o$	$0.563\lambda_o$

Table. 4.2 (a) Parameter values of first proposed antenna

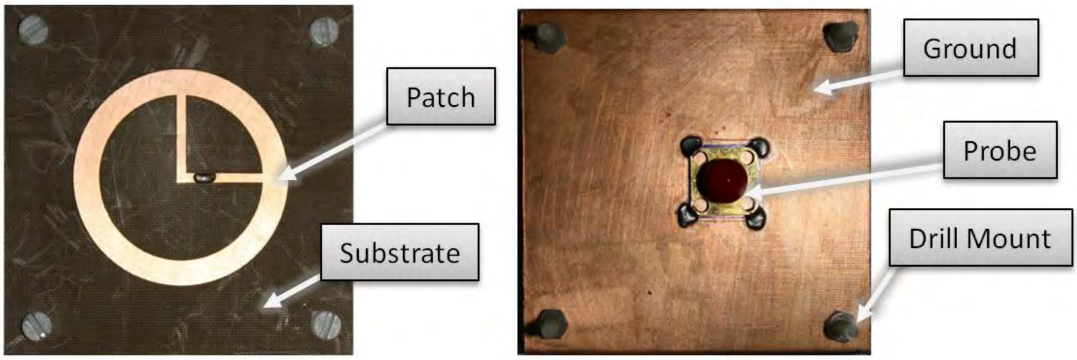


Fig.4.2 (d) Top and bottom view of prototyped first proposed antenna

Fig. 4.2 (e) Slant view of fabricated first proposed antenna

Fig. 4.2 (f) 3D view of fabricated first proposed antenna

4.2.1 Antenna description

In case, the target operating frequency is 2.6 GHz, desired impedance and axial ratio bandwidth is higher than 10% and 1.5% respectively, the gain is not less than 5dBi and use in satellite communication.

New method to obtain circularly polarization is shown. It uses one L-shaped strip placed inside the annular ring and its two ends connected to orthogonal side of inner boundary. And these two ends excited two modes with equal amplitude and 90degree phase difference. In order to have a good matching, it able to modify the feeding position on L-shaped strip.

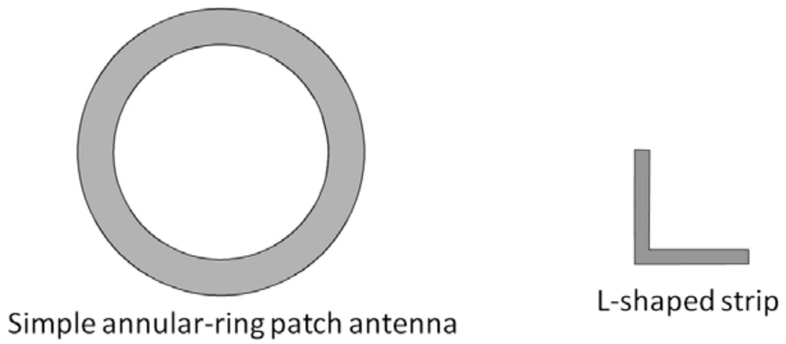


Fig. 4.2.1 (a) Simple annular ring patch antenna and L-shaped strip

Compare to commercial half-wavelength antennas, the first proposed antenna has 30.8% size reduction. At 2.6 GHz operating frequency, outer and inner radius are 20mm (0.173 λ_o) and 15mm (0.13 λ_o) respectively. The width of L-shaped strip is 2mm (0.017 λ_o) which placed at inner boundary. The feeding position is located on (5mm, 0mm) L-shaped strip away from center of antenna. The height and radius of probe are 7mm and 0.65mm, respectively. The size of ground plane is 65mm x 65mm.

4.2.2 Simulated and measured results

All simulated results are confirmed by measurement. Both simulated and measured results are not much different. We can say that both results are in good agreement. Figure 4.2.2 (b) and 4.2.2(c) show the measured return loss and voltage standing wave ratio (VSWR), respectively. For S11 < -10dB, the first proposed annular ring patch antenna can operated from 2.49 GHz to 2.67 GHz.

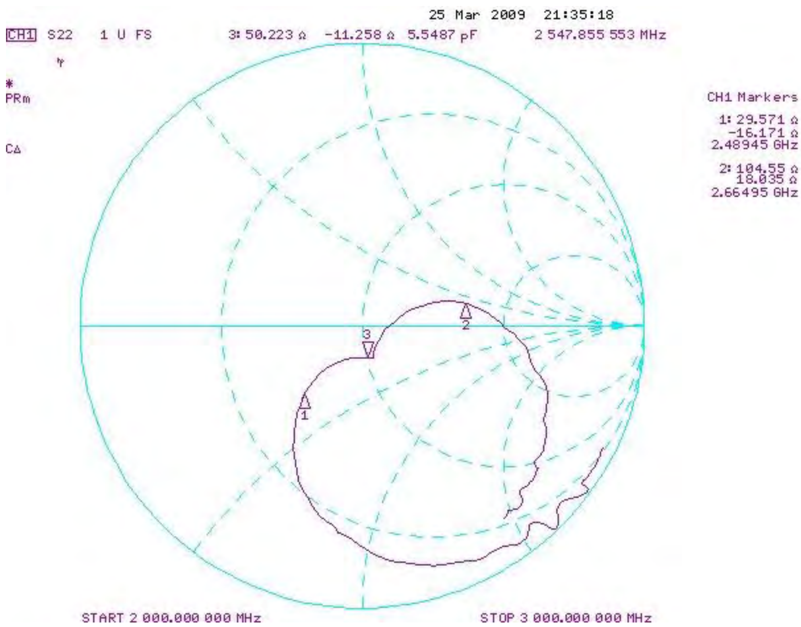


Fig. 4.2.2 (a) Measured impedance of the first proposed antenna

Above smith chart shows how capacitive or how inductive a load is across the frequency range. The impedance bandwidth is 6.8%. The result shows that the antenna is wider than commercial antenna which typically has 1~3% impedance bandwidth. In this report, I prefer to show the return loss rather than VSWR result. Typically, input impedance as good matching is 50 ohms. Now, I would like to compare all results with simulation as below.

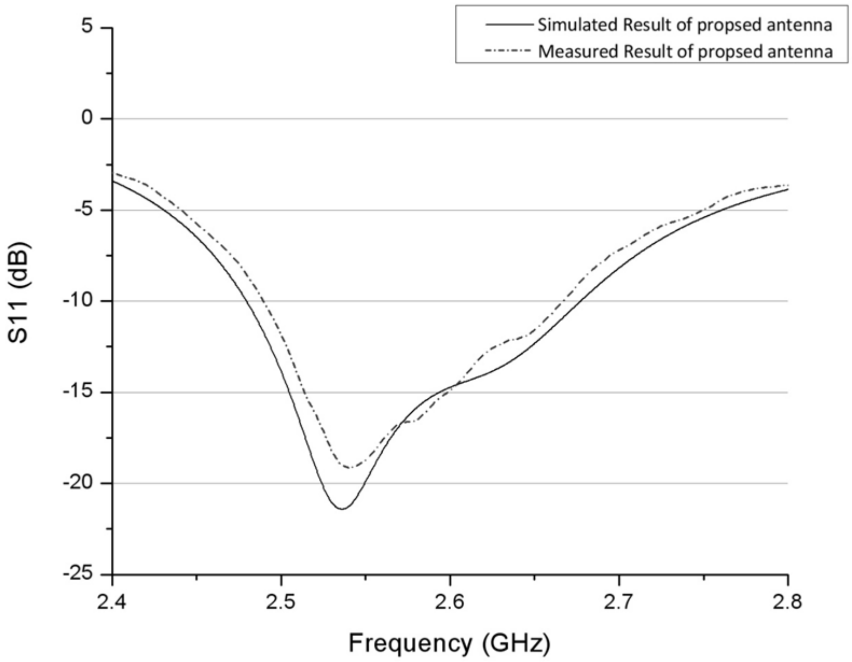


Fig. 4.2.2 (b) Simulated and measured return loss of the first proposed antenna

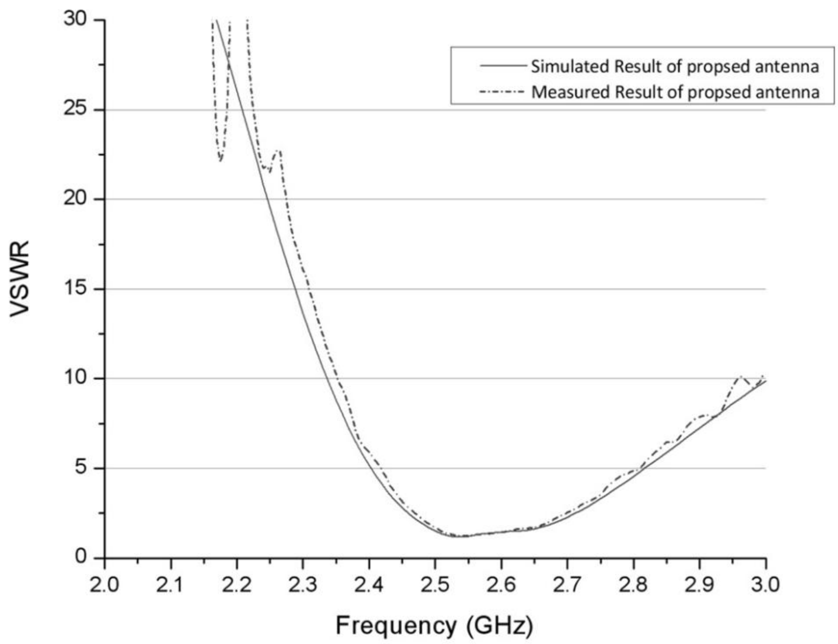


Fig. 4.2.2 (c) Simulated and measured VSWR of the first proposed antenna

As you can see from the figure 4.2.2 (d), the antenna performs circularly polarization when the axial ratio is less than 3dB. The measured axial ratio bandwidth of the first proposed annular-ring patch antenna covers the range of frequency from 2.57 GHz to 2.62 GHz. And axial ratio bandwidth is fully under cover impedance bandwidth (refer to figure 4.2.2 (b)). It actually covers in desired operating frequency 2.6 GHz.

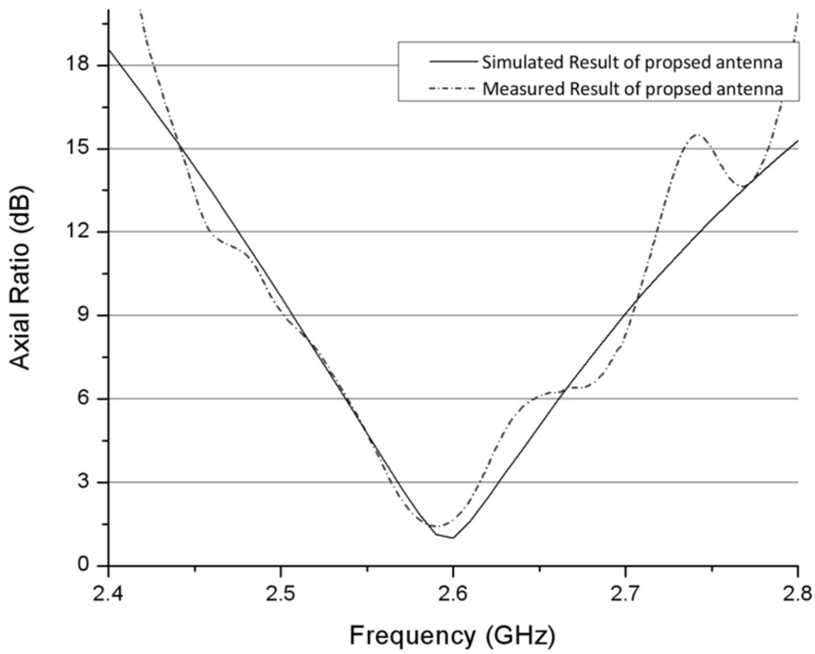


Fig.4.2.2 (d) Simulated and measured axial ratio of the first proposed antenna

For good level of capable tolerance, the axial ratio bandwidth is as large as possible. But it is a big challenge to small size antenna. And in this project, due to fabricated tolerance and measured error, the measured results are slightly shifted. But the results are also satisfied.

The gain of first proposed annular-ring patch antenna also showed as Fig. 4.2.2 (e). At desired operating frequency 2.6 GHz, the gain is found about 7.06dBi.

The gain is smooth, stable and linear in the range of axial ratio bandwidth.

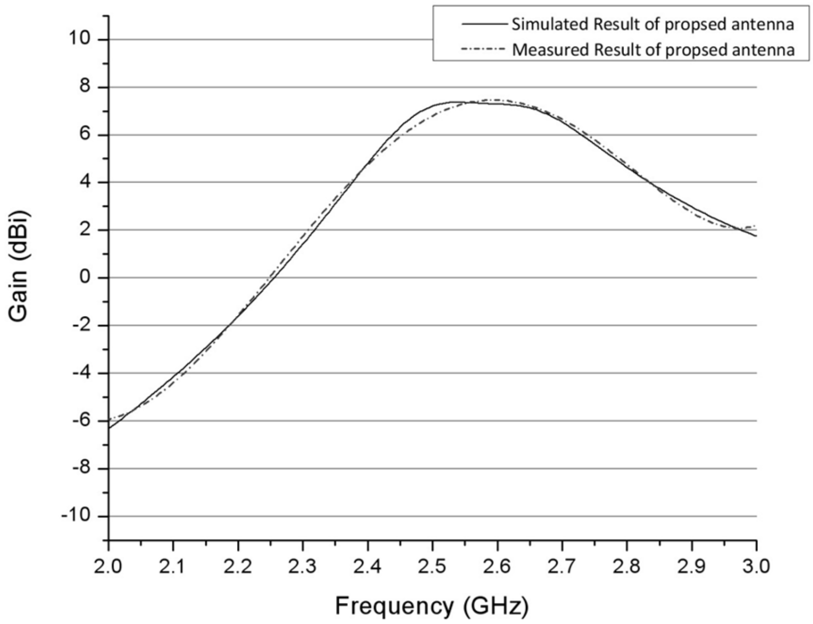


Fig. 4.2.2 (e) Simulated and measured gain of the first proposed antenna

Fig. 4.2.2 (f) and Fig. 4.2.2 (g) show simulated and measured result of radiation pattern (phi=0) and (phi=90), respectively. By observing the radiation pattern, the antenna is found as right hand circularly polarization. In the experiment, the pattern of (phi=0) is better than (phi=90). It seems that pattern of (phi=90) is much different than simulation because of unsymmetrical geometry of patch and measured tolerance. The 3db beamwidth of the polarization is around 89 degree.

From all above experimental study, you may see most of results are in good agreement due to the pattern is simple. The measured and simulated will be normally different if little more parameter is preformed. So adjustment of parameter is required in order to obtain comparable performance.

Simulation and Measurement of operating frequency 2.6 GHz:

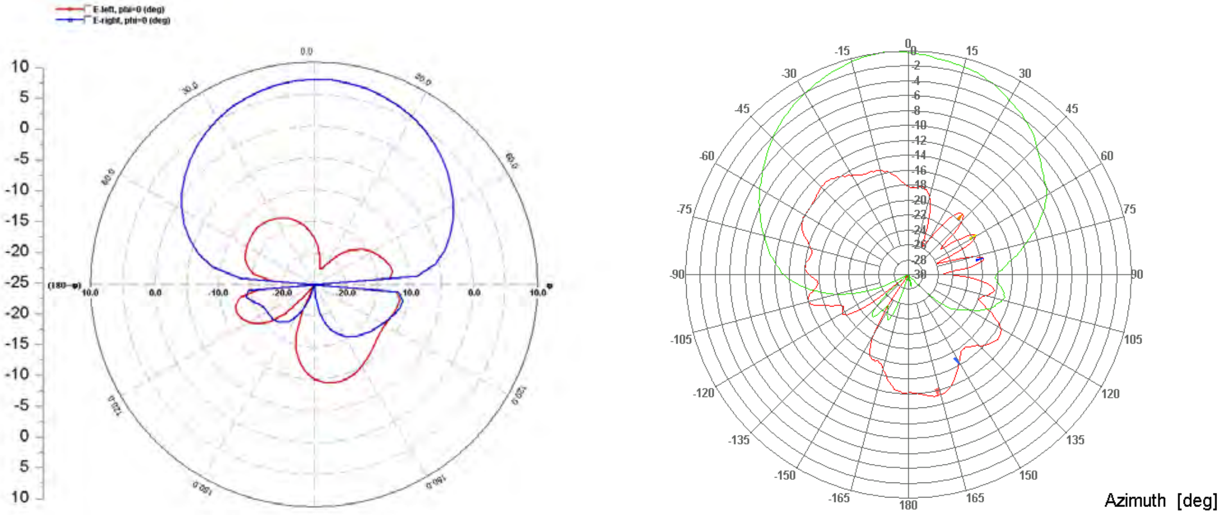


Fig.4.2.2 (f) Simulated and measured radiation pattern (phi=0) of first proposed antenna

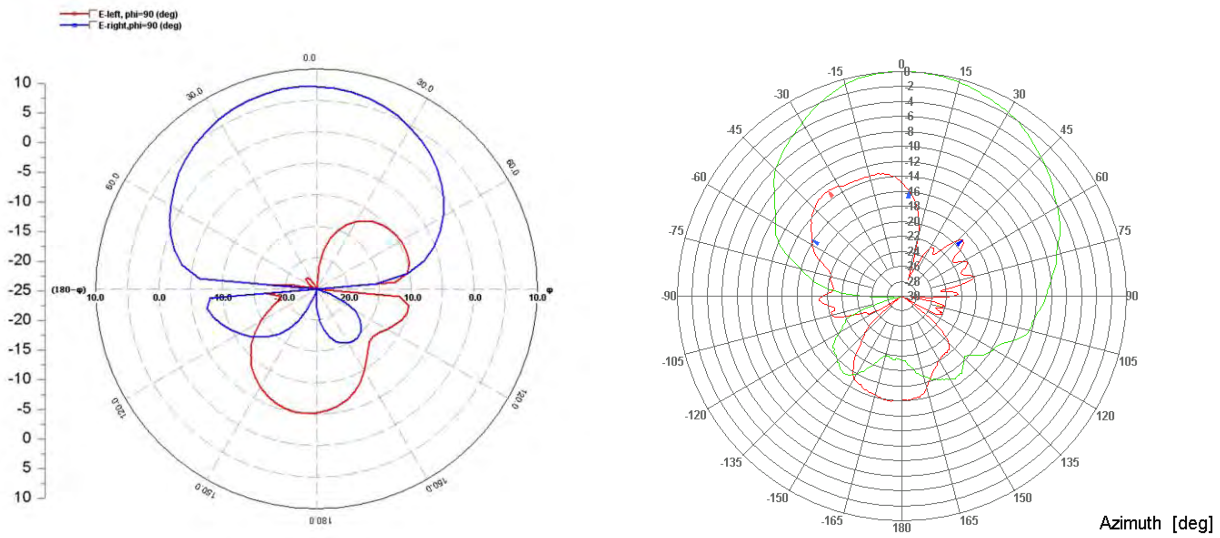


Fig.4.2.2(g) Simulated and measured radiation pattern (phi=90) of first proposed antenna

4.2.3 Analysis and investigation

It no doubt that different parameters will affect the results. By modifying the width of L-shaped strip can help matching the operating frequency, return loss and axial ratio. Fig. 4.2.3 (b) and Fig. 4.2.3 (c) show the relationship of S11 and axial ratio against frequency with different width of L-strip. The width of L-strip varies from 1.5mm to 4mm. With longer width of the L-shaped strip (refer to Fig. 4.2.3 (a)), the return loss and axial ratio results are better. But the range is shifted to higher frequencies that the antenna needs to scale up to obtain lower frequency.

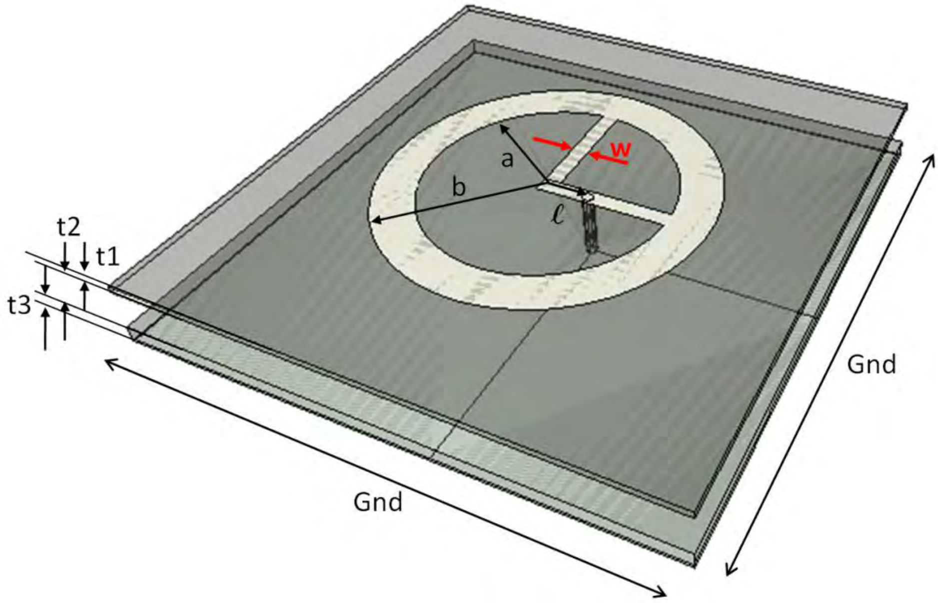


Fig. 4.2.3 (a) Parameter study of different width of L-strip

By observing the results from Figure 4.2.3 (b) and (c), 2mm width of L-shaped strip has good matching in both return loss and axial ratio at operating frequency 2.6 GHz. The S11 value is -16dB.

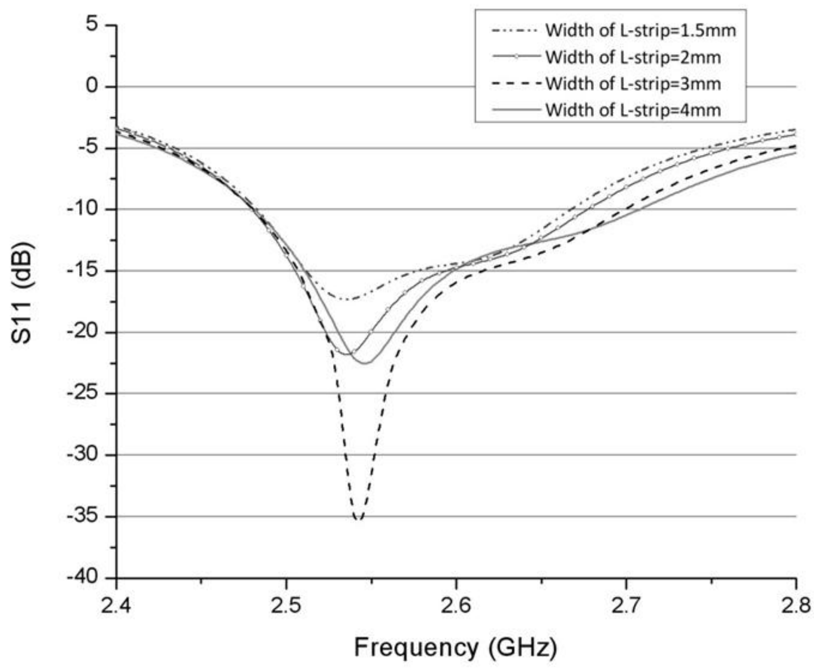


Fig.4.2.3 (b) Parameter study of S11 against frequency with different width of L-strip

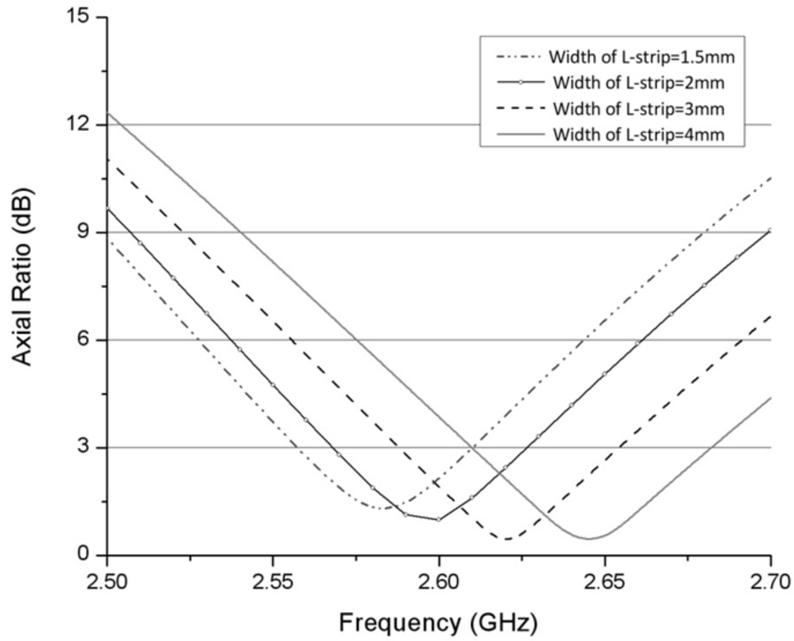


Fig.4.2.3 (c) Parameter study of AR against frequency with different width of L-strip

From table 4.2.3 (a), we can observe that when the width is increased, both impedance and AR bandwidth is increased but the operating frequency range is shifted. The suitable width is 2mm for operating frequency 2.6 GHz. As the gain is not changed so much with different parameter, result of gain just shows in this example.

Width of L-shaped strip	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
1.5mm	2.483-2.667	7.14%	2.557-2.61	2.05%
2mm	2.48-2.675	7.56%	2.567-2.627	2.31%
3mm	2.482-2.697	8.29%	2.588-2.654	2.51%
4mm	2.481-2.697	8.34%	2.61-2.683	2.76%

Table.4.2.3 (a) Impedance and AR BW with different width of L-strip

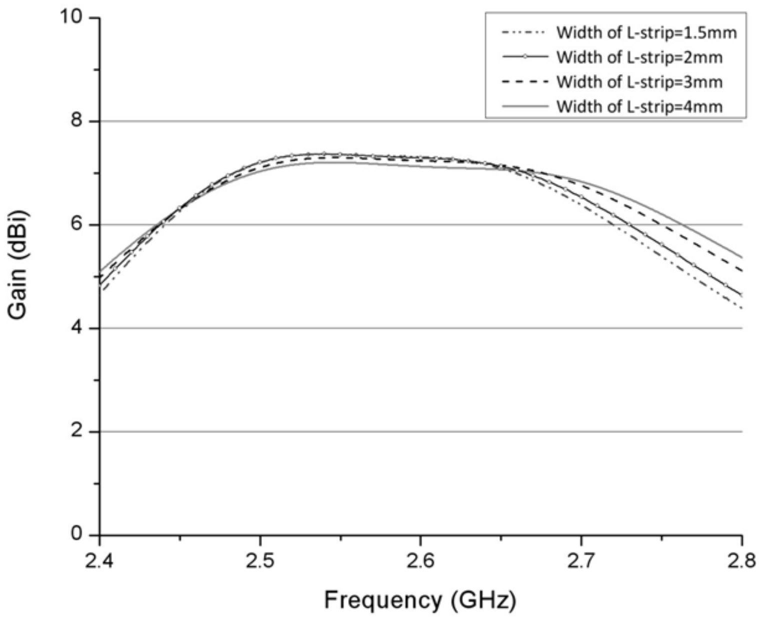


Fig.4.2.3 (d) Parameter study of gain against frequency with different width of L-strip

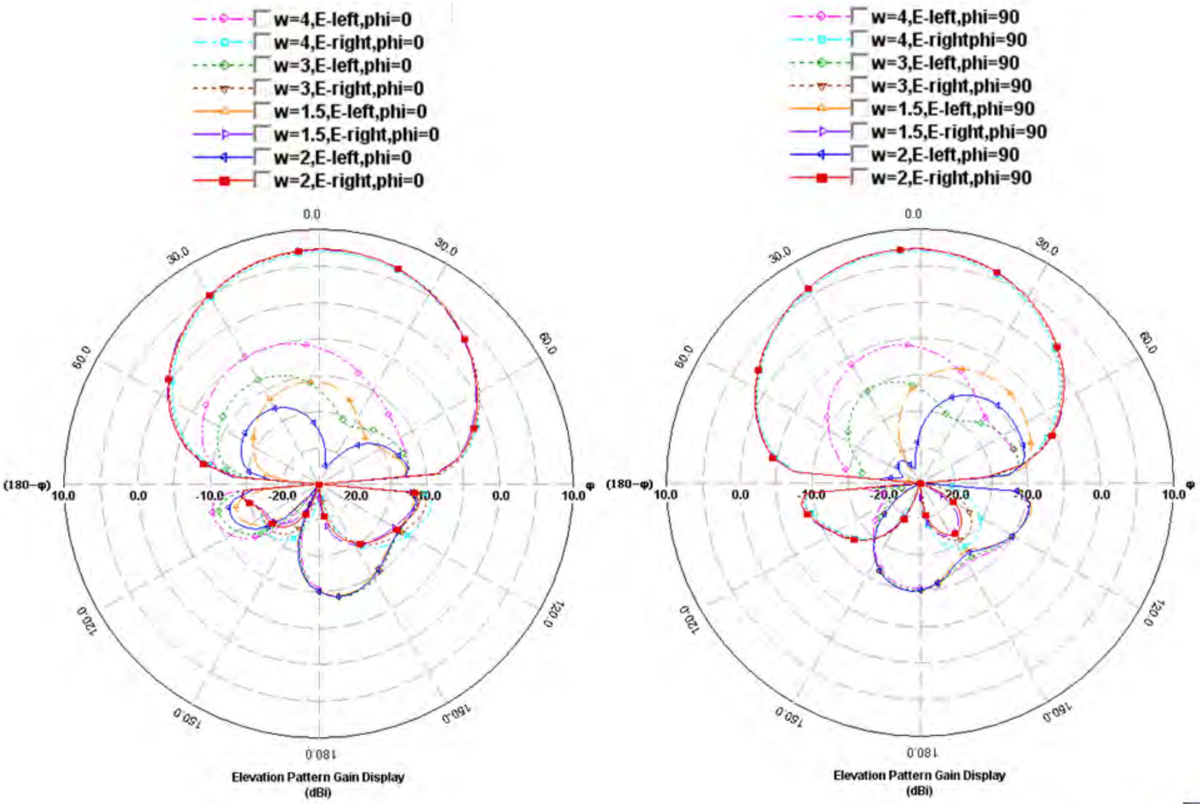


Fig.4.2.3(e) Parameter study of radiation pattern (phi=0 & 90) at 2.6GHz with different width of L-strip

Figure 4.2.3 (e) depicts the radiation pattern found from simulated results which are simulated by IE3D. The performance of different width of L-shaped strip is presented. Those patterns are captured at operating frequency 2.6 GHz. E-right is similar and E-left is change with different width. In other word, the effect of the width of L-shaped strip is small for E-right and obvious for E-left.

By modifying the ratio of radius a/b can help matching the operating frequency, return loss and axial ratio. Fig. 4.2.3 (g) and Fig. 4.2.3 (h) show the relationship of S11 and axial ratio against frequency with different ratio of radius a/b. The ratio varies from 0.74 to 0.77. With lower ratio, both impedance and axial ratio bandwidth is wider.

The results indicate that the matching is not very much sensitive to the ratio of radius a/b. And the bandwidth shifts to higher frequencies as ratio increase.

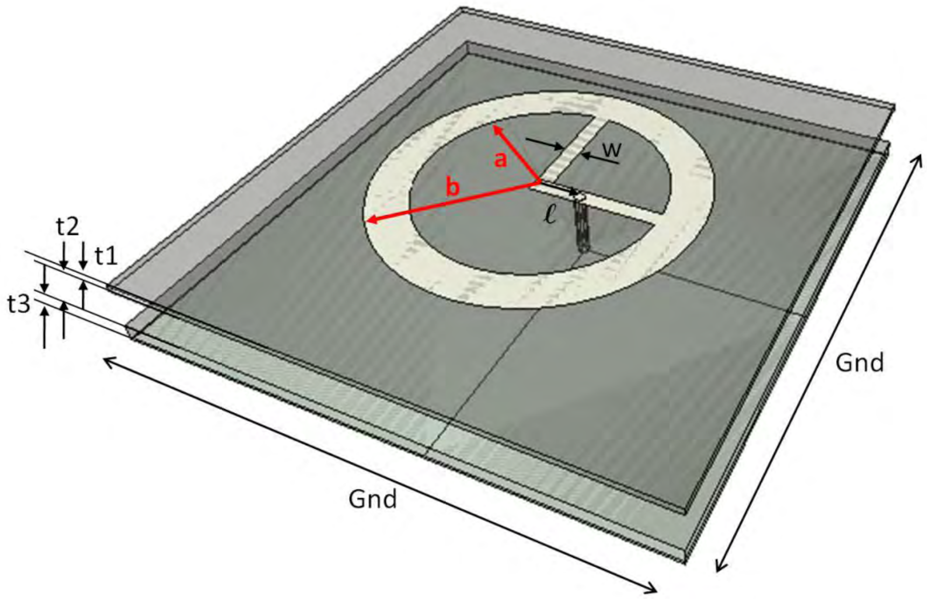


Fig. 4.2.3 (f) Parameter study of different ratio of a/b

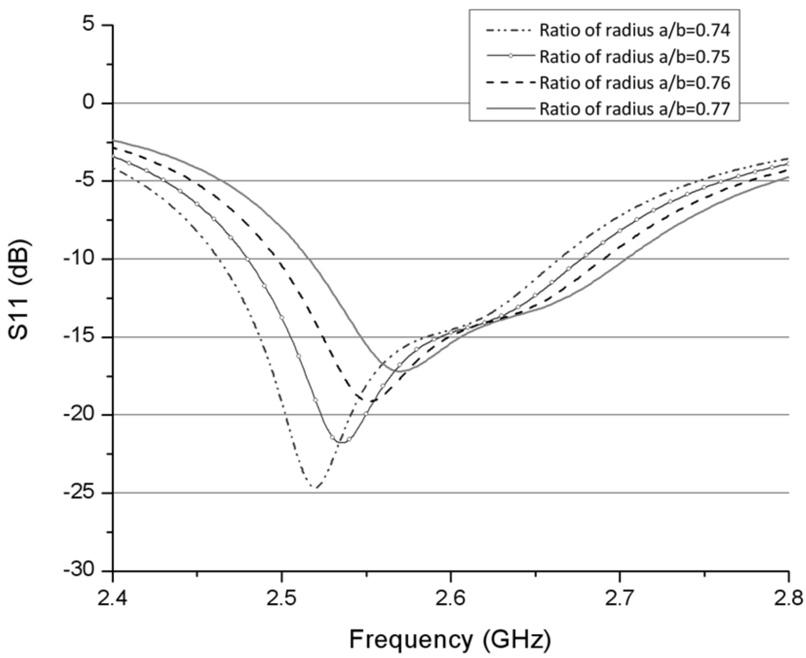


Fig.4.2.3 (g) Parameter study of S11 against frequency with different ratio of a/b

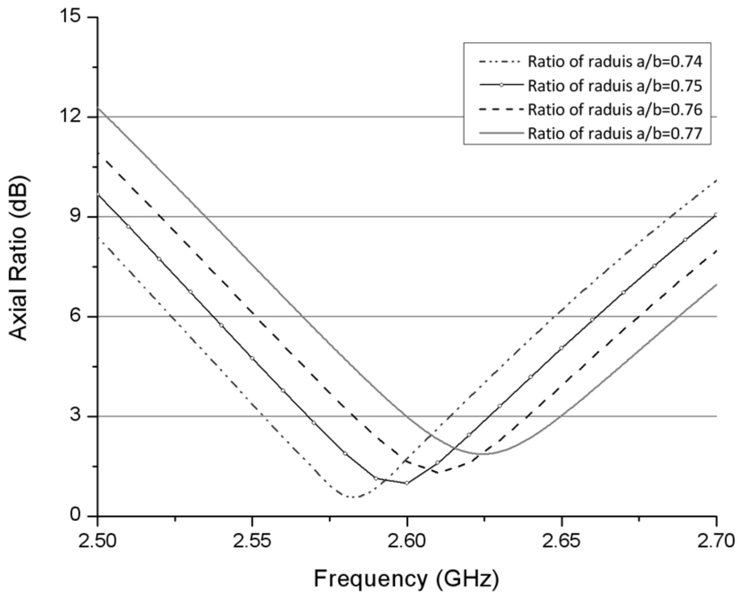


Fig.4.2.3 (h) Parameter study of AR against frequency with different ratio of a/b

Figure 4.2.3 (h) and (i) depicts the effect of S11 and axial ratio with different ratio of radius a/b, respectively. As you can see the result as above, the better ratio of radius of a/b is 0.75. Therefore, the inner and outer radii are 15mm and 20mm respectively for obtaining operating frequency 2.6 GHz.

Ratio of radius a/b	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
0.74	2.462-2.663	7.83%	2.553-2.614	2.38%
0.75	2.48-2.675	7.56%	2.567-2.627	2.31%
0.76	2.497-2.689	7.41%	2.582-2.639	2.19%
0.77	2.519-2.705	7.14%	2.599-2.615	1.95%

Table.4.2.3 (b) Impedance and AR BW with different ratio of radius a/b

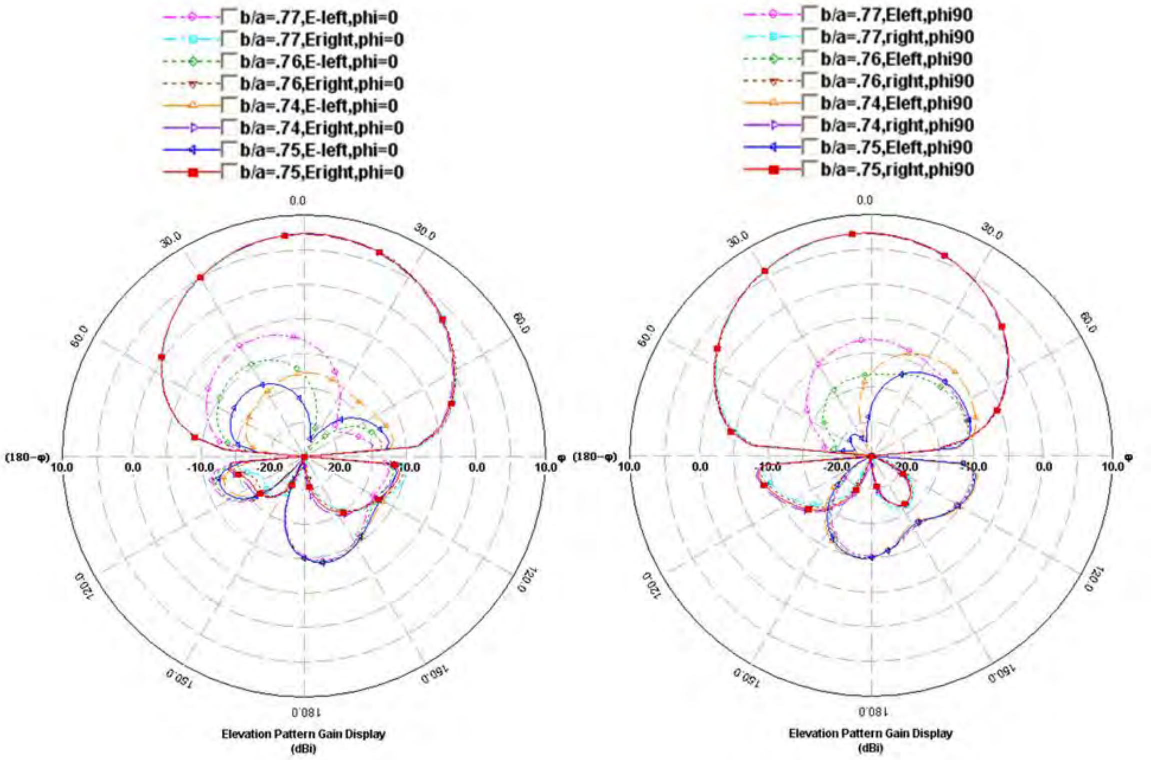


Fig.4.2.3 (i) Parameter study of radiation pattern (phi=0 & 90) at 2.6GHz with different ratio of a/b

Figure 4.2.3 (k) depicts the radiation pattern. The performance of different ratio of a/b is presented. Those patterns are captured at operating frequency 2.6 GHz. E-right is similar and E-left is change with different ratio.

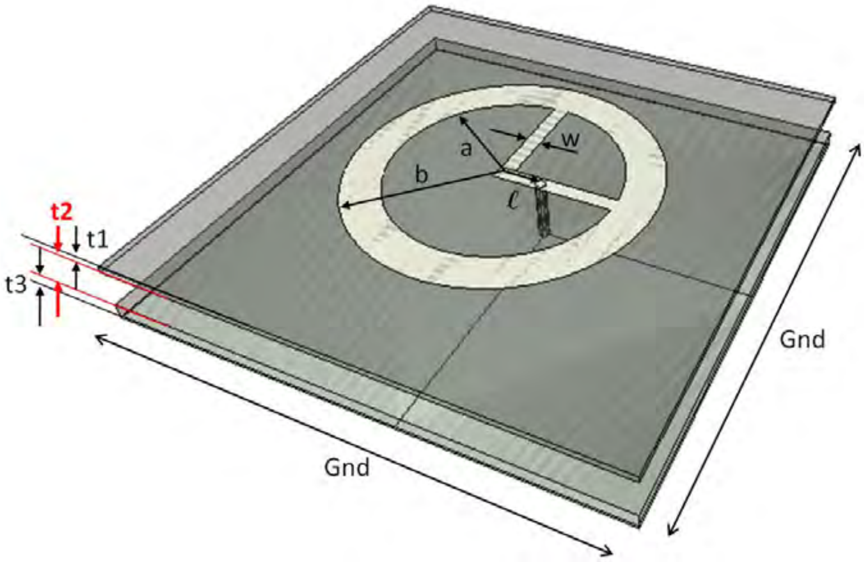


Fig. 4.2.3 (j) Parameter study of different thickness of foam

Actually, t2 represents the thickness of foam layer of the substrate. Refer to Figure 4.2.3(m) and (n), they show the relationship of S11 and axial ratio against frequency with different to thickness of foam. The thickness varies from 3mm to 9mm. And the results indicate that the matching is most sensitive to thickness of foam.

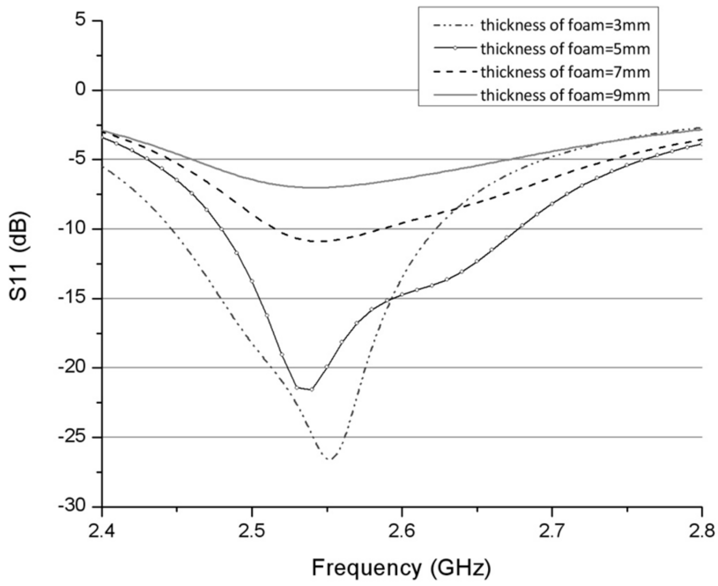


Fig.4.2.3 (k) Parameter study of S11 against frequency with different thickness of foam

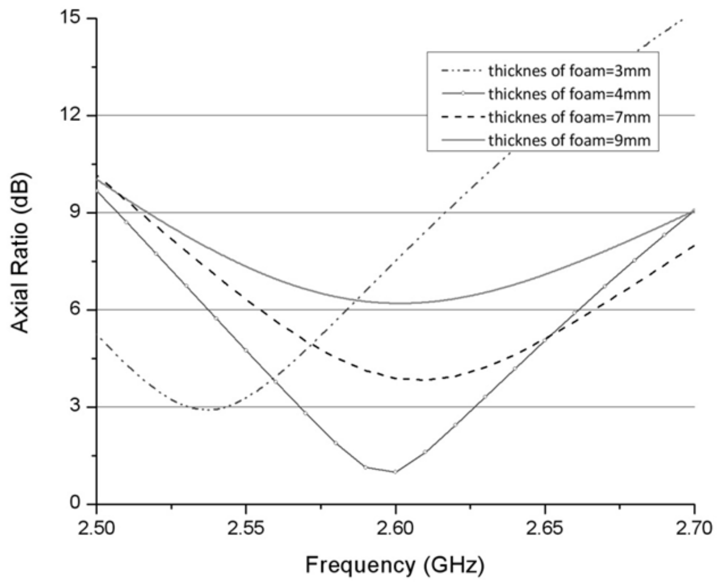


Fig.4.2.3 (l) Parameter study of AR against frequency with different thickness of foam

As you can see the result as above, the best thickness of foam should be 5mm. For 3mm, 7mm and 9mm thickness, it do not excited circularly polarization. And the gain become small (refer to Fig. 4.3.2 (o)).

Thickness of foam	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
3mm	2.447-2.516	6.85%	2.528-2.546	0.75%
5mm	2.48-2.675	7.56%	2.567-2.627	2.31%
7mm	2.516-2.583	2.61%	/	/
9mm	/	/	/	/

Table.4.2.3 (c) Impedance and AR BW with different thickness of foam

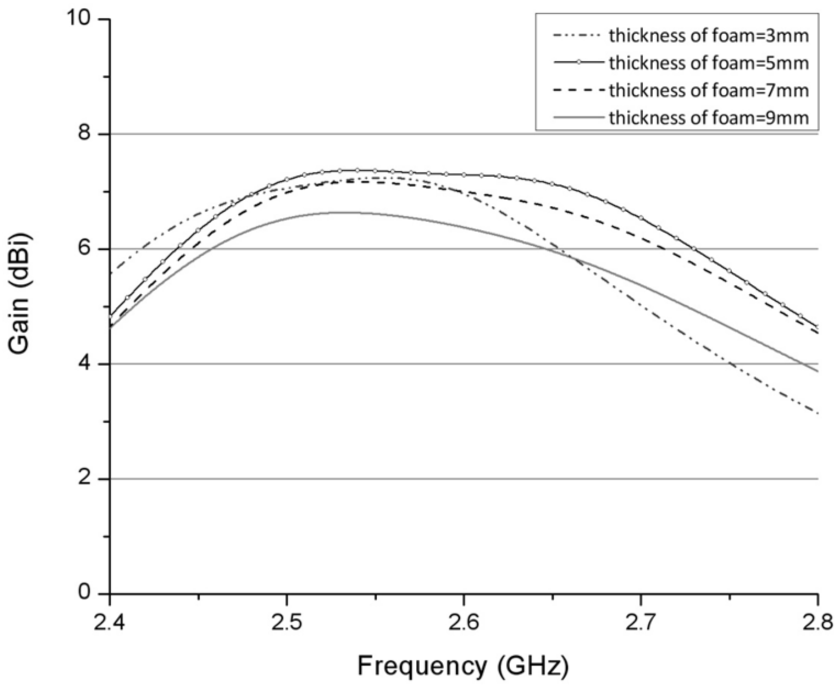


Fig.4.2.3 (m) Parameter study of gain against frequency with different thickness of foam

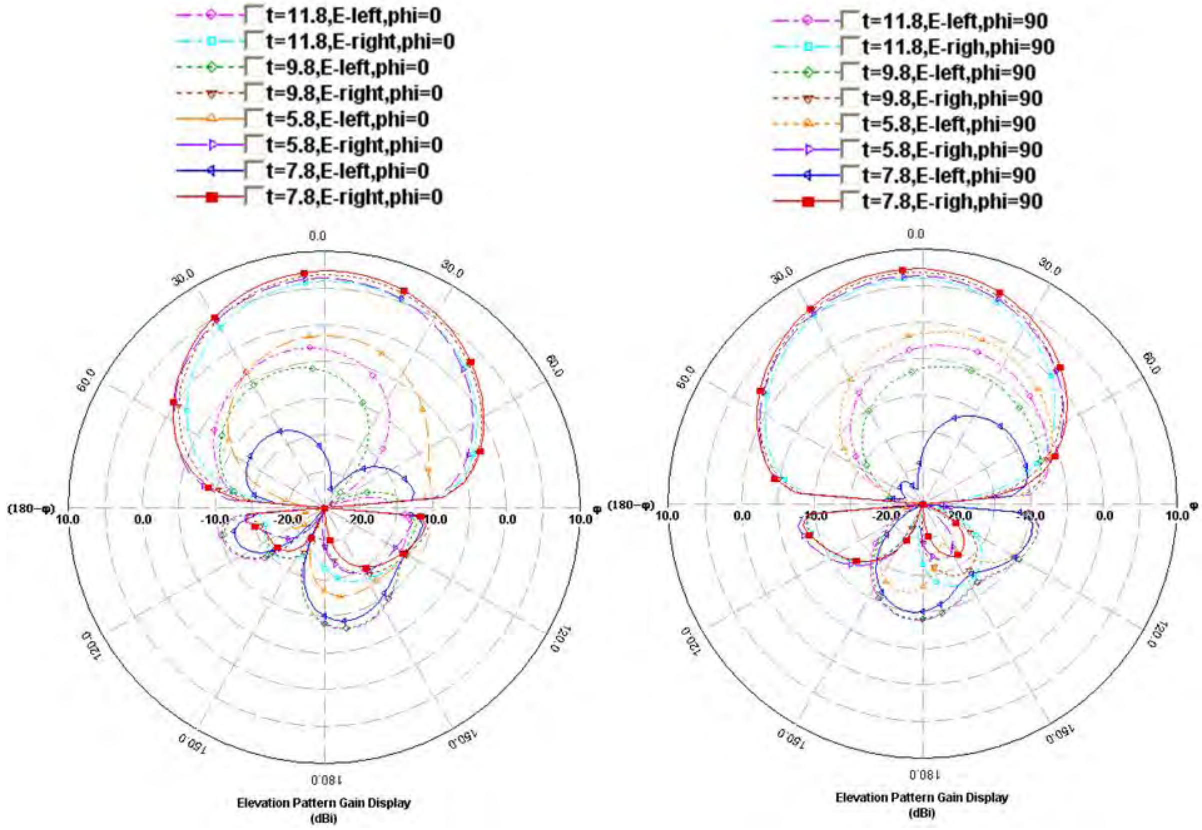


Fig.4.2.3(n) Parameter study of radiation pattern (phi=0 & 90) at 2.6GHz with different thickness of foam

In the end, the parameter study of different probe feeding position is shown as Figure 4.2.3 (q).

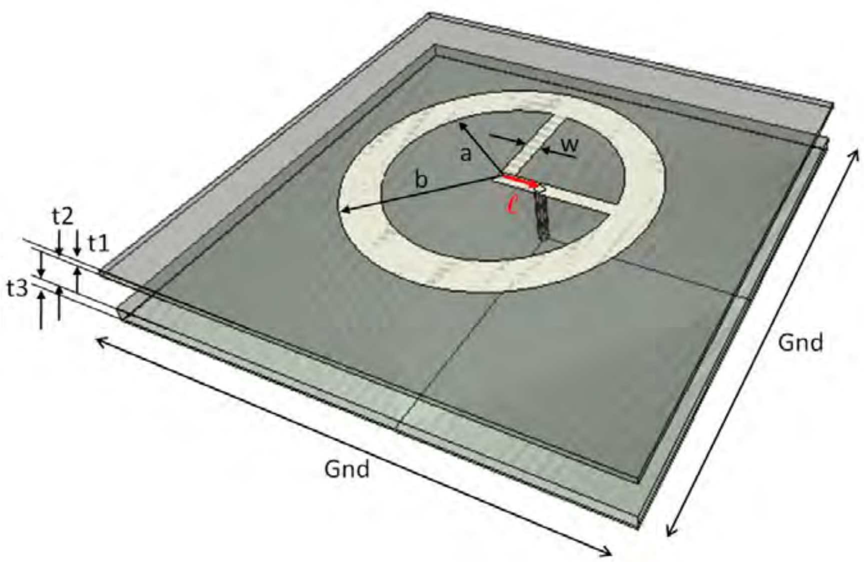


Fig. 4.2.3 (o) Parameter study of different probe feeding position

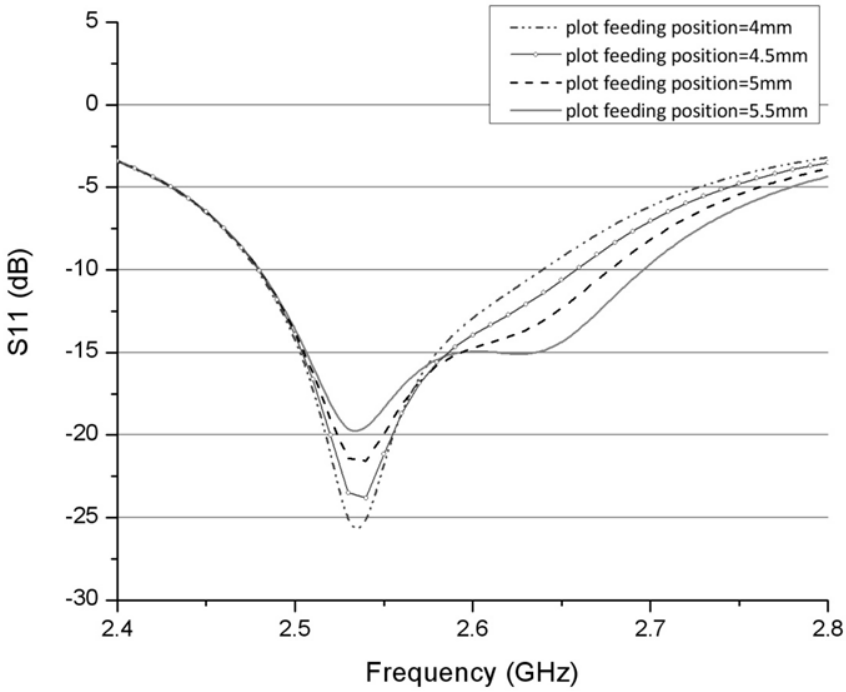


Fig.4.2.3 (p) Parameter study of S11 against frequency with different probe feeding position

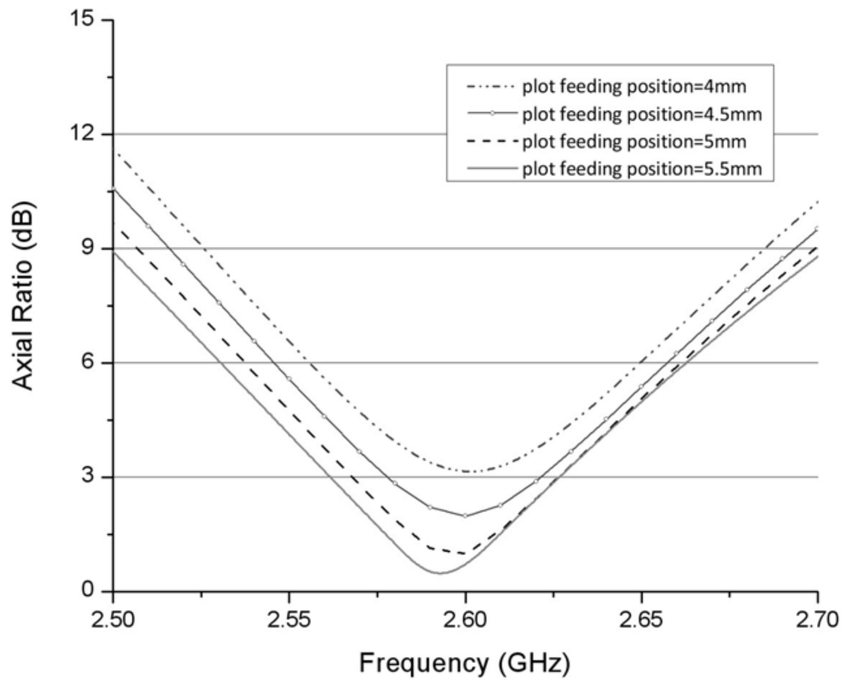


Fig.4.2.3 (q) Parameter study of S11 against frequency with different probe feeding position

Probe feeding position	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
(4mm,0mm)	2..479-2.638	6.22%	/	/
(4.5mm,0mm)	2.479-2.657	6.95%	2.577-2.622	1.7%
(5mm,0mm)	2.48-2.675	7.56%	2.567-2.627	2.31%
(5.5mm,0mm)	2.481-2.695	8.27%	2.562-2.627	2.51%

Table.4.2.3 (d) Impedance and AR BW with different probe feeding position

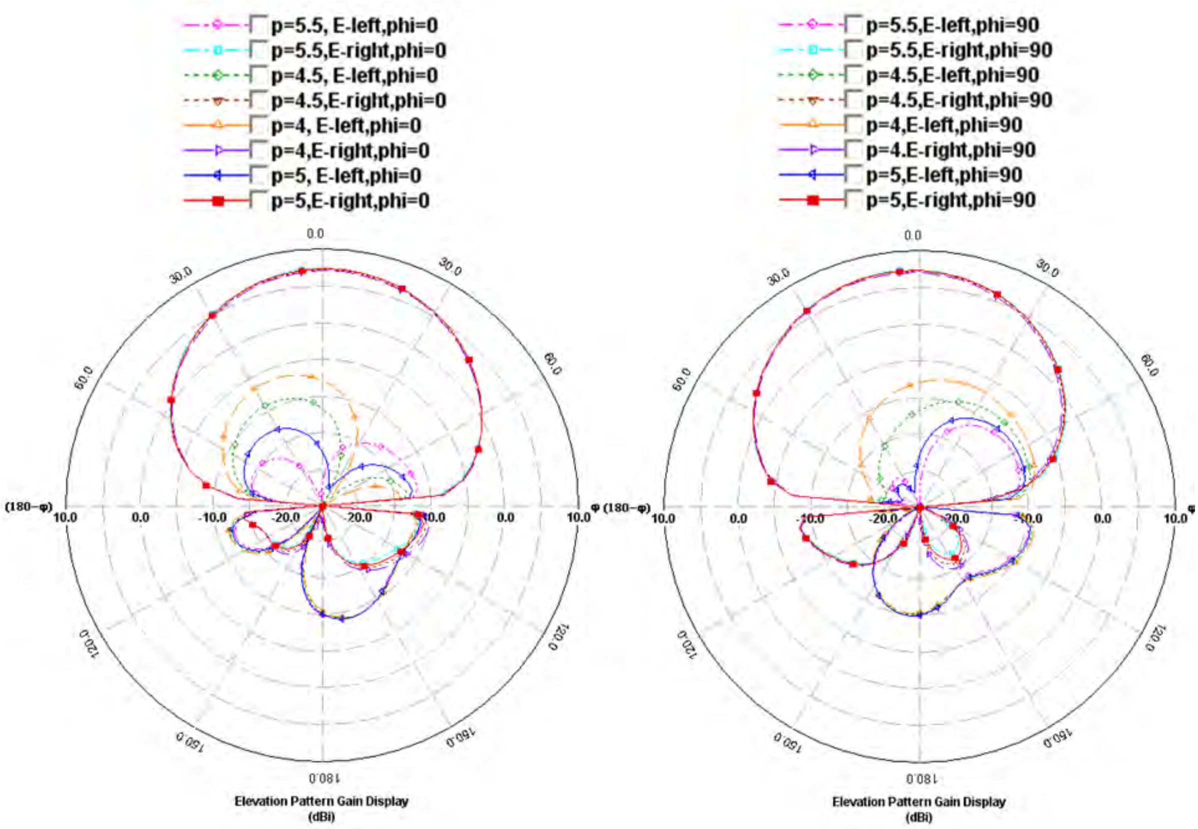


Fig.4.2.3(u) Parameter study of radiation pattern (phi=0 & 90) at 2.6GHz with different probe feeding position

4.3 References

[1] W. C. Chew, *"A broadband annular ring mimostrip antenna"* , IEEE Trans, Antennas propagate, vol. 30, no.5 pp. 918-922, Sept,1982

[2] Wong, K.-L., *"Compact and broadband microstrip antennas"*, (Wiley, New York, USA, 2002)

[3] Garg, R., Bhartia, P., Bahl, I., and Ittipiboon, A., *"Microstrip antenna design handbook"* (Artech House, Norwood, MA, USA, 2001)

[4] Prof. S.E. El-Khamy, Sen.Mem. I.E.E.E., Prof. R.M. El-Awadi, Mem.I.E.E.E., and E-B.A. El-Sharrawy , *"Simple analysis and design of annular ring microstrip antennas"*, IEE PROCEEDINGS, Vol. 133, Pt. H, No. 3, JUNE 1986

[5] J. S. Dahelle and K. F. Lee, *"Characteristics of annular ring microstrip antenna,"* ,Electron. Lett., vol. 18, pp. 1051–1052, Nov. 1982.

[6] Z. Nie, W. C. Chew, and Y. T. Lo, *"Analysis of the annular-ring-loaded circular disk microstrip antenna,"*, IEEE Trans. Antennas Propagation., vol. 38, pp. 806–813, June 1990.

Chapter 5

Size Reduction

5.1 Second proposed antenna with size reduction

The second proposed antenna is inserting tails and slots on outer ring for size reduction. The antenna keeps on using SMA connector by probe feed and the foam is added between two layers.

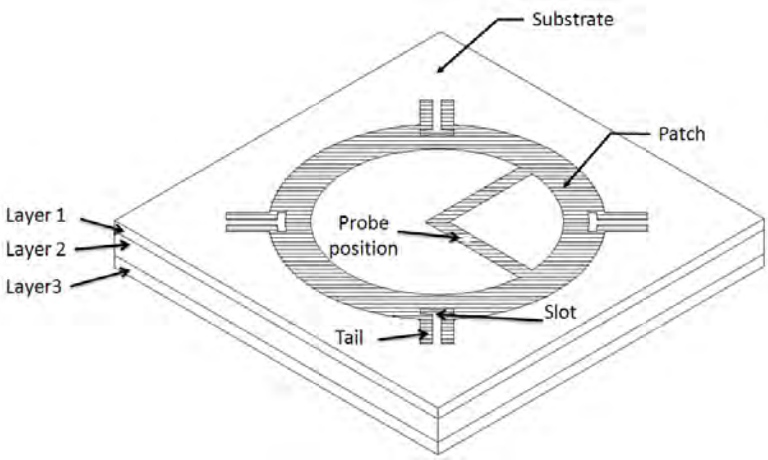


Fig. 5.1 (a) 3D view of 2nd proposed antenna

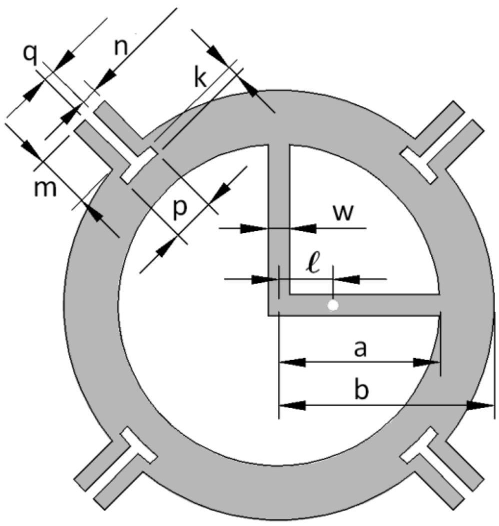


Fig. 5.1 (b) Top view and geometry of 2nd proposed antenna (unit: mm)

Compare to conventional antennas, the second proposed antenna has 37.5% size reduction. At 2.6 GHz operating frequency, outer and inner radius are 18mm (0.156 λ_o) and 13.5mm (0.116 λ_o) respectively. The ground size is 55mm x 55mm.

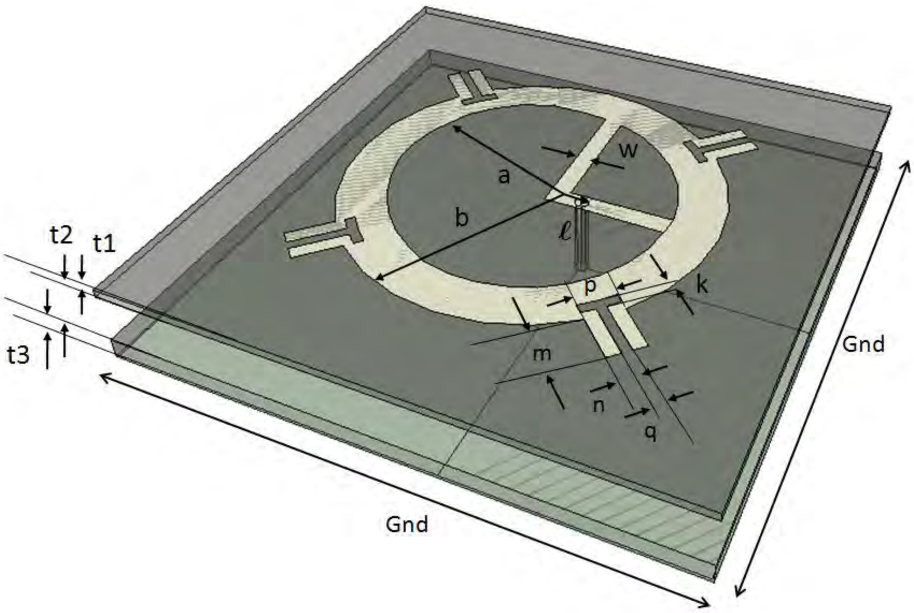


Fig. 5.1 (c) Geometry of 2^{nd} proposed antenna in IE3D

Parameters	a	b	w	ℓ	t1	t2	t3	gnd
Values(mm)	13.5	18	1.8	5	0.8	5	2	55
	0.116 λ_o	0.156 λ_o	0.0156 λ_o	0.043 λ_o	0.007 λ_o	0.043 λ_o	0.017 λ_o	0.476 λ_o

Parameters	m	n	p	q	k
Values(mm)	4.51	1.35	3.6	0.89	0.91
	0.039 λ_o	0.0117 λ_o	0.0312 λ_o	0.0077 λ_o	0.0079 λ_o

Table. 5.1 (a) Parameter values of first proposed antenna

5.1.1 Antenna description

Size reduction can be achieved at least 12-15% by cutting slot and tailing compared with the previous antenna. After modifying the structure of the antenna, the results will change obviously. Normally, by shifting the L-strip to left or right also can help matching the antenna.

The effective of parameter of tails and slots is studied. These tails and slots like a loading to increase capacitive and inductive for size reduction, meaning a wave that propagates with a phase velocity that is less than the conventional antenna. The current path is increase after adding loading. Such a wave needs less time to radiate.

$$c = f\lambda$$

$$f = \frac{c}{\lambda}$$

The resonant frequency will thus be proportional to the wave length. The longer wave length, the lower resonant frequency. Smaller size of antenna usually obtains shorter wave length. Therefore, the size of antenna is reduced.

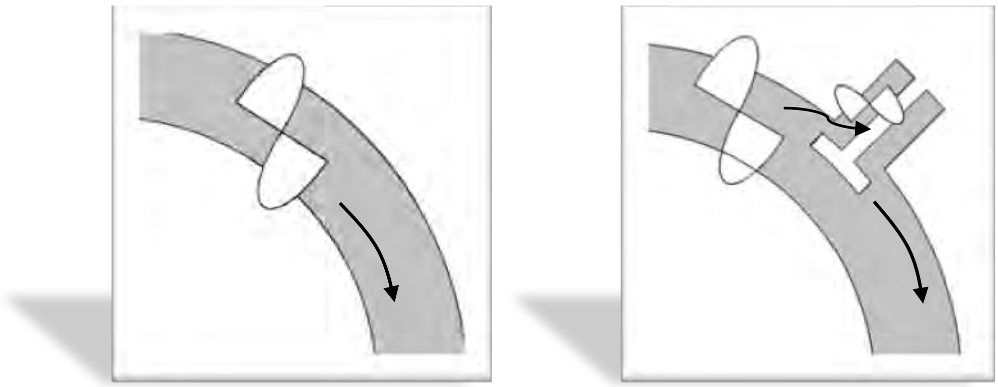


Fig. 5.1.1 (a) A loading increase capacitive and inductive "slow wave" effect

The structure of side view and bottom view of this antenna is similar to first proposed antenna. Please refer to Fig. 4.2 (d) & (e).

Fig.5.1.1 (b) Top view of second prototyped proposed antenna

Fig.5.1.1 (c) 3D view of second prototyped proposed antenna

5.1.2 Simulated and measured results

Figure 5.1.2 (b) and 5.1.2 (c) show the measured return loss and axial ratio, respectively. For S11 < -10dB, the second proposed annular ring patch antenna can operate from 2.51 GHz to 2.71 GHz.

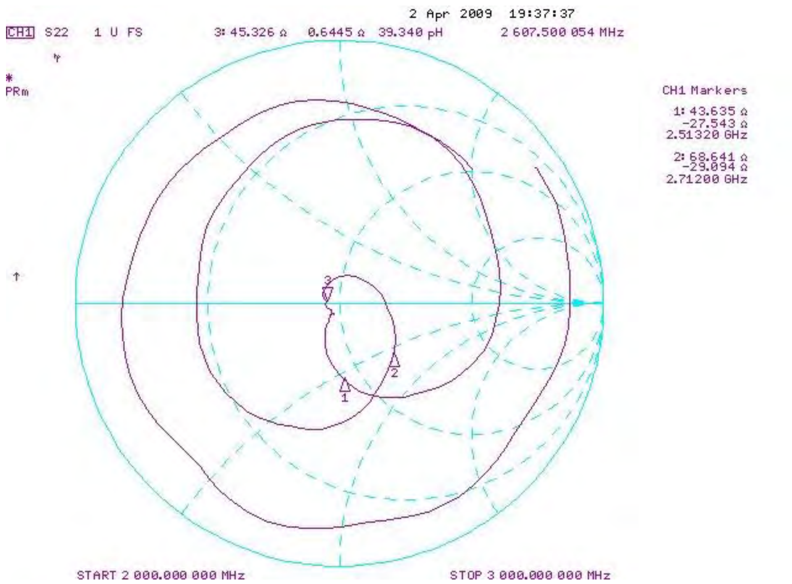


Fig. 5.1.2 (a) Measured impedance of the second proposed antenna

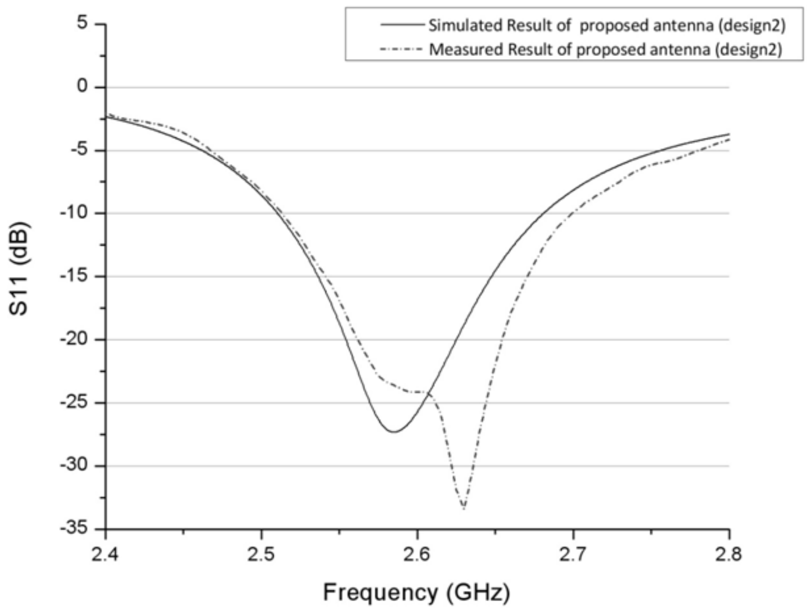


Fig. 5.1.2(b) Return loss against frequency of the 2nd proposed antenna

The impedance bandwidth is around 6%. The result shows that the antenna is little decrease than the first proposed antenna which has 6.8% impedance bandwidth.

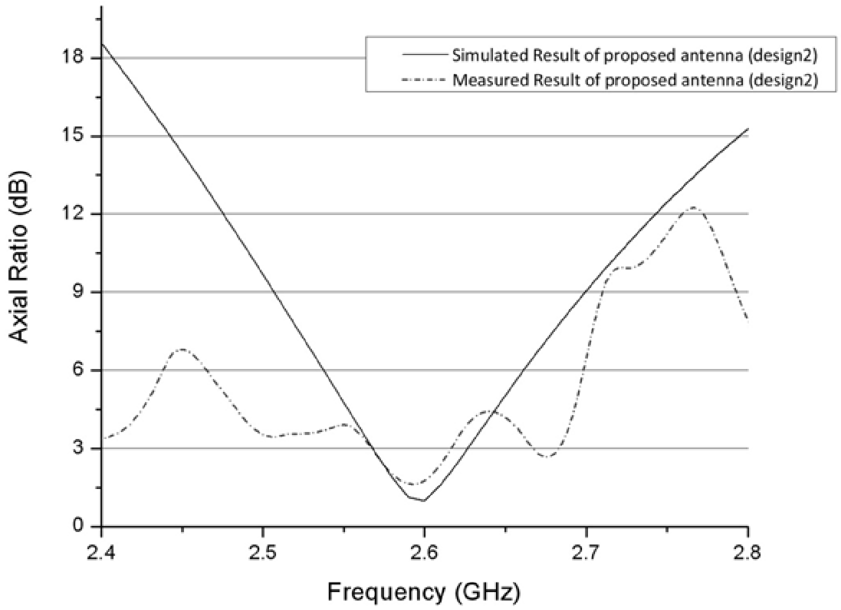


Fig. 5.1.2(b) Axial ratio against frequency of the 2nd proposed antenna

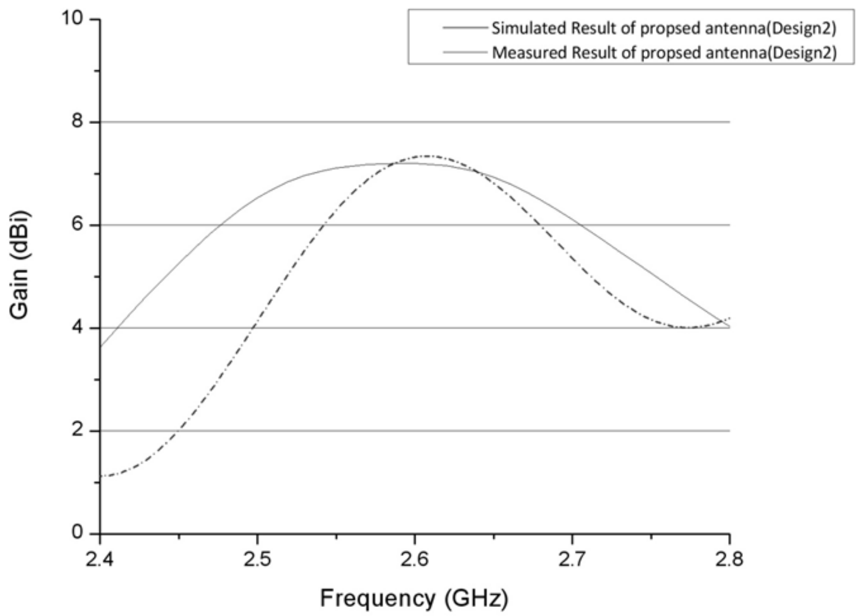


Fig. 5.1.2(c) Gain against frequency of the 2nd proposed antenna

Simulation and Measurement of operating frequency 2.6 GHz:

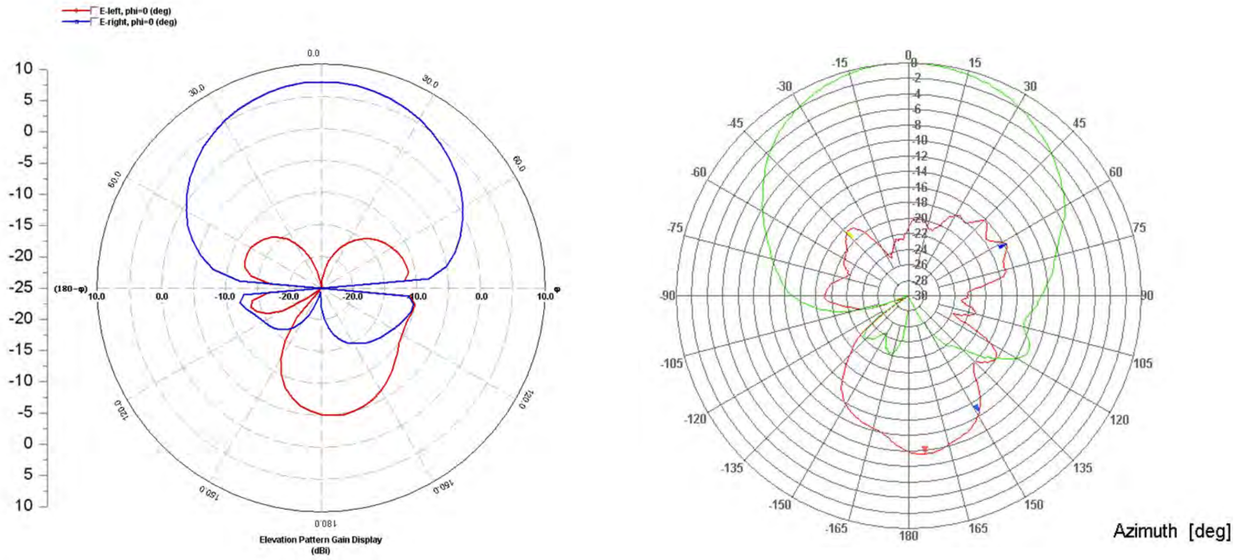


Fig.5.1.2 (d) Simulated and measured radiation pattern (phi=0) of 2nd proposed antenna

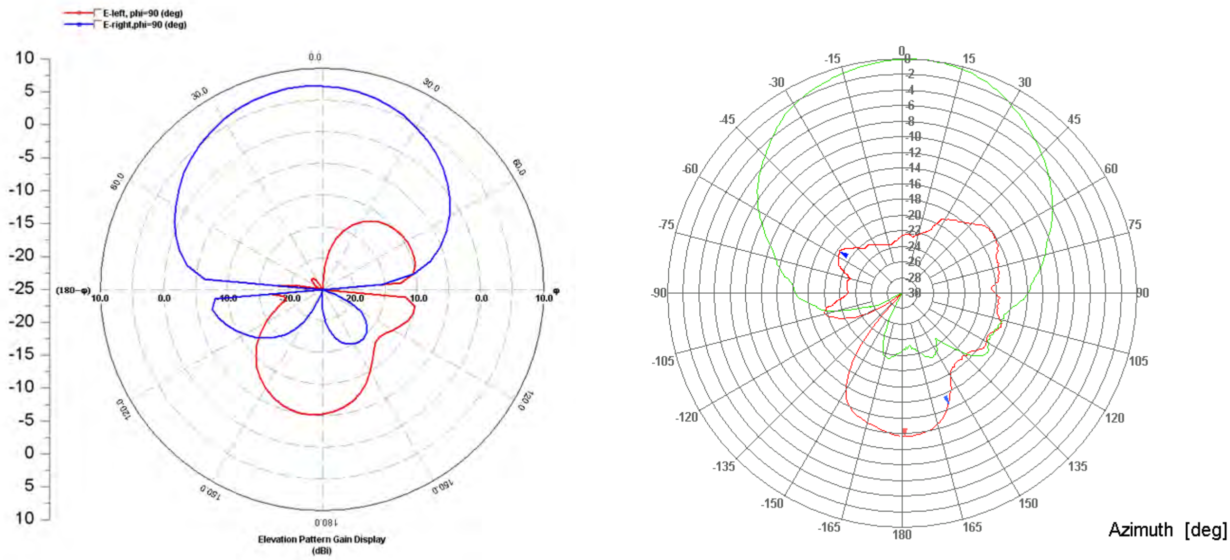


Fig. 5.1.2(e) Simulated and measured radiation pattern (phi=90) of 2nd proposed antenna

Fig. 5.1.2 (a) and Fig. 5.1.2 (b) show simulated and measured result of impedance and axial bandwidth. It seems that axial bandwidth is fully under cover the impedance bandwidth. Due to tail and slot is added, we need more careful the procedures of fabrication. Both bandwidth looks like little narrow than previous design. And we would summary in section 5.4"Comparison of proposed antenna with size reduction". Fig. 5.1.2 (d) and Fig. 5.1.2 (e) show measured radiation pattern (phi=0) and (phi=90), respectively. It is easy to observe the radiation pattern which also perform right hand circularly-polarization (refer to section 4.2.2). For phi=0, the 3db beamwidth of the polarization is around 90 degree. (phi=90)

5.1.3 Analysis and investigation

Different parameter will affect the results. By shifting the L-strip to left or right can help matching the operating frequency, return loss and axial ratio. Fig. 5.1.3 (b) and Fig. 5.1.3 (c) show the relationship of S11 and axial ratio with different width of slot.

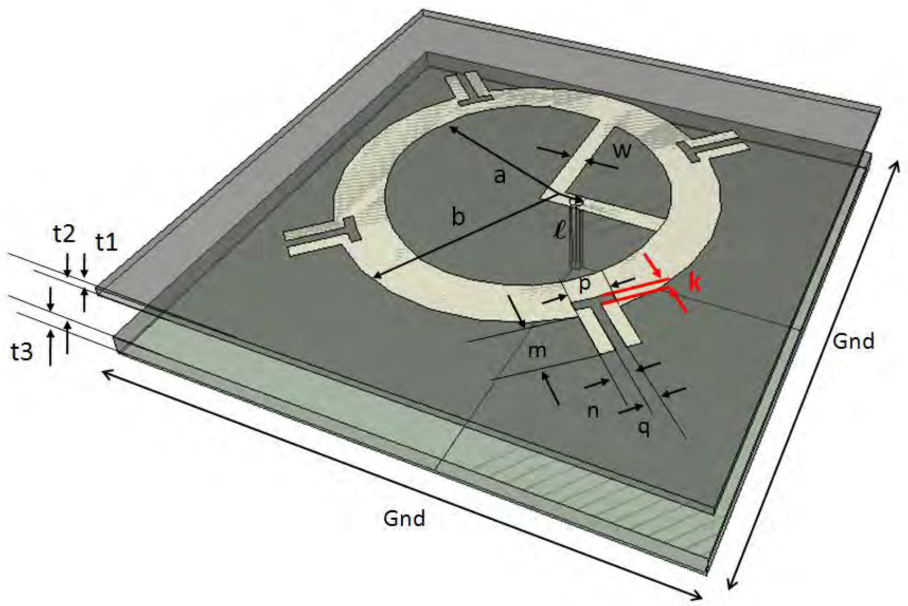


Fig. 5.1.3(a) Parameter study of different width of slot

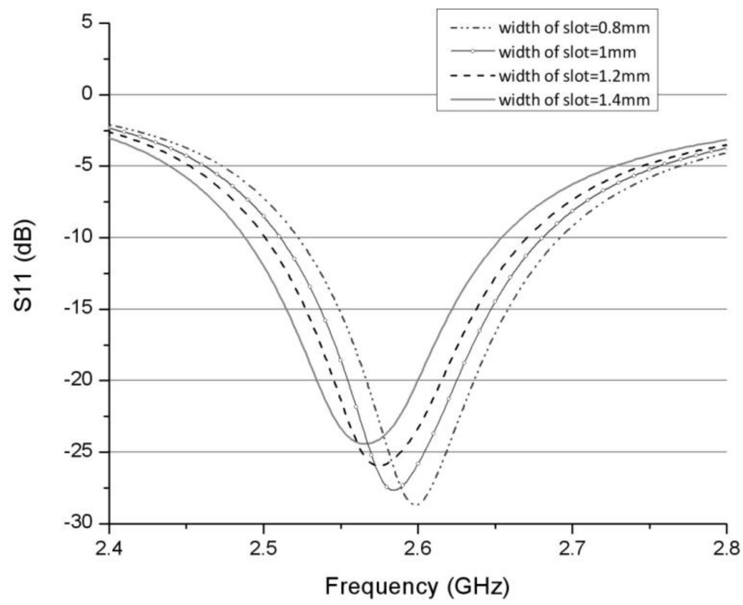


Fig. 5.1.3(b) Parameter study of S11 with different width of slot

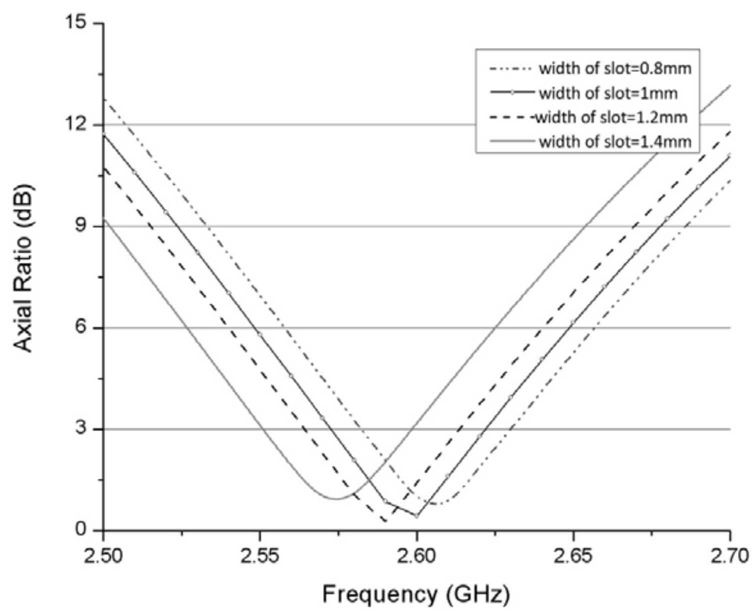


Fig. 5.1.3(c) Parameter study of AR with different width of slot

The optimized width of slot is 1mm which found in simulation. And following figure will show that how non-sensitivity to width of tail performs in this antenna.

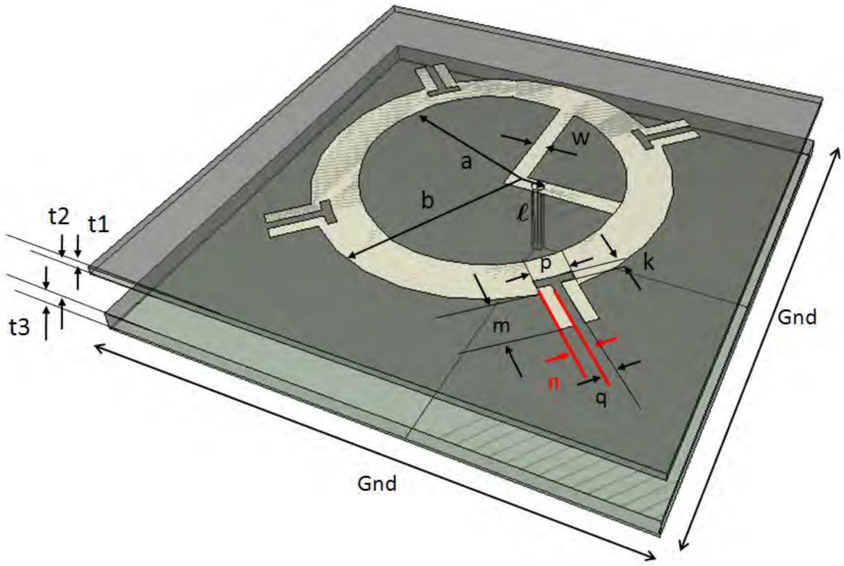


Fig. 5.1.3(d) Parameter study of different width of tail

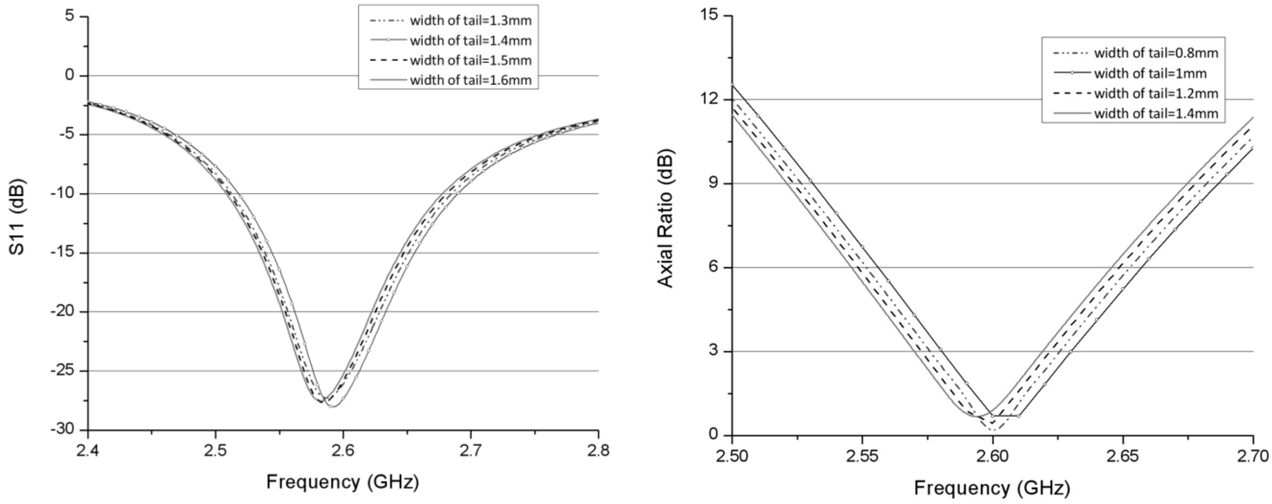


Fig. 5.1.3(e) Parameter study of return loss and AR with different width of tail

All parameter studies of return loss and AR performance which do not show in this section are also studied. The results of return loss and AR are not sensitivity to modify the length of slot and tail. On the other hand, we also can make a tiny adjustment of the inner ring boundary. The better results can be achieved. But the results are not regularly linear for adjusting the inner ring boundary.

5.2 Third proposed antenna with size reduction

The 3rd proposed antenna is integrated the inner CMRC technique for size reduction.

The 3D and top view of 3rd proposed antenna are shown as below.

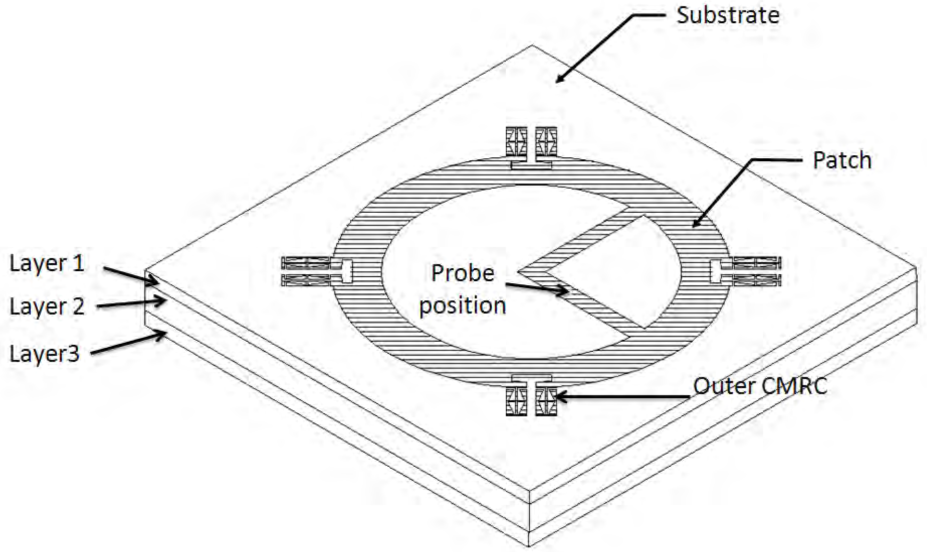


Fig. 5.2 (a) 3D view of 3rd proposed antenna

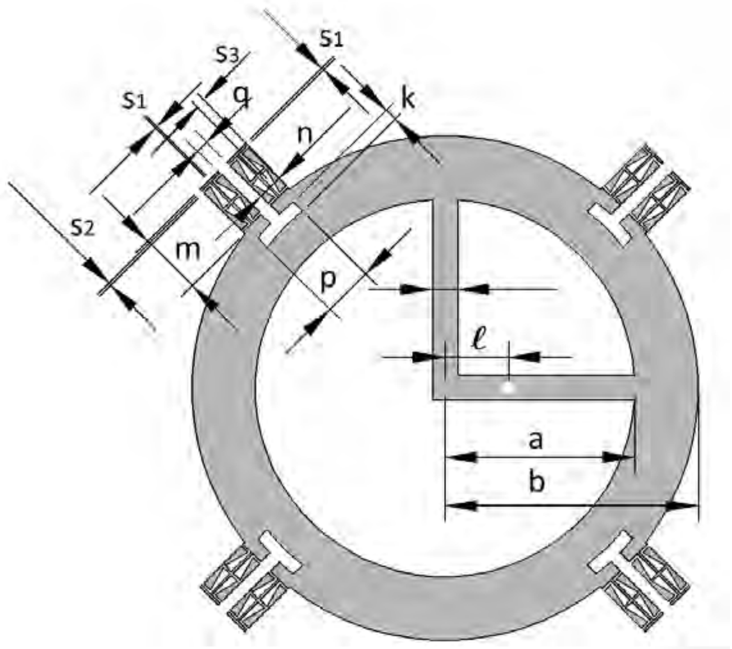


Fig. 5.2 (b) Top view and geometry of 3rd proposed antenna (unit: mm)

Parameters	a	b	w	ℓ	t1	t2	t3	gnd
Values(mm)	13	17	1.8	5	0.8	5	2	51
	0.11 λ_o	0.147 λ_o	0.0156 λ_o	0.043 λ_o	0.007 λ_o	0.043 λ_o	0.017 λ_o	0.442 λ_o

Parameters	m	n	p	q	k	s1	s2	s3
Values(mm)	4.3	1.87	3.4	0.93	0.86	0.187	0.187	0.65
λ_o	0.037	0.0162	0.0294	0.008	0.0074	0.00162	0.00162	0.00563

Table. 5.2 (a) Parameter values of thrid proposed antenna

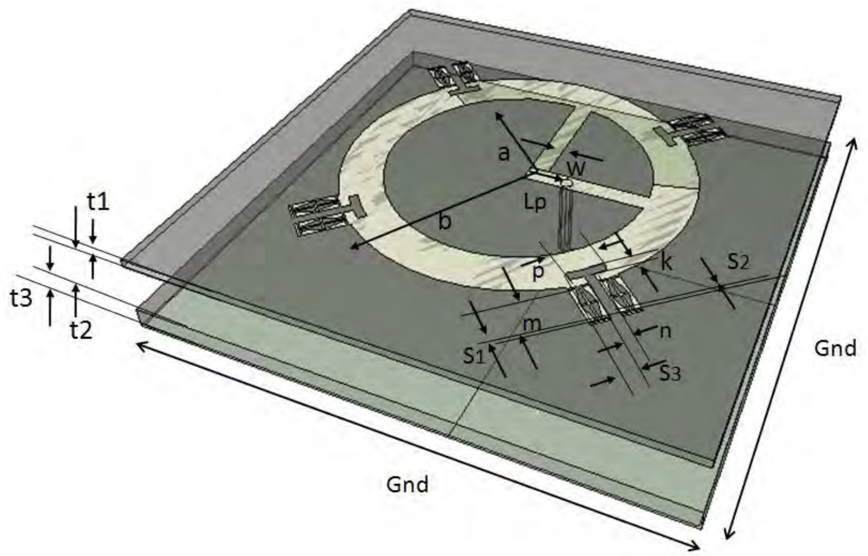


Fig. 5.2 (c) 3D view and geometry of 3^{rd} proposed antenna (unit: mm)

The percentage of size reduction is calculated as follow:

Outer radius of 1^{nd} and 3^{rd} proposed antenna=20mm and 17mm

Further patch size reduction compared with 1^{st} antenna= $\left(1-\dfrac{17}{20}\right)\times 100\% = 15\%$

Further projection size reduction compared with 1^{st}antenna= $\left(1-\dfrac{51}{65}\right)\times 100\% = 21.5\%$

5.2.1 Antenna description

With new method of inserting CMRC filters, size reduction can be achieved at least 20-23% compared with first proposed antenna and 41% compared with conventional half wavelength antenna, also 7.3~8% compared with the second proposed antenna. This antenna operates at 2.6GHz with 6.4% bandwidth (VSWR<2). It has a reasonable gain of 6.71dBi. It is enough for wireless communication.

Actually, in some case, size reduction is very important. It can reserve the place for other uses and improve the beamwidth of the antenn. Therefore, the research of size reduction is required and needed. CMRC is mainly element for size reduction in this proposed antenna. Large scale of CMRC is significant. I mentioned that we can adjust narrow connecting lines and gap of CMRC to attain slow eave effects for size reduction at specified frequency.

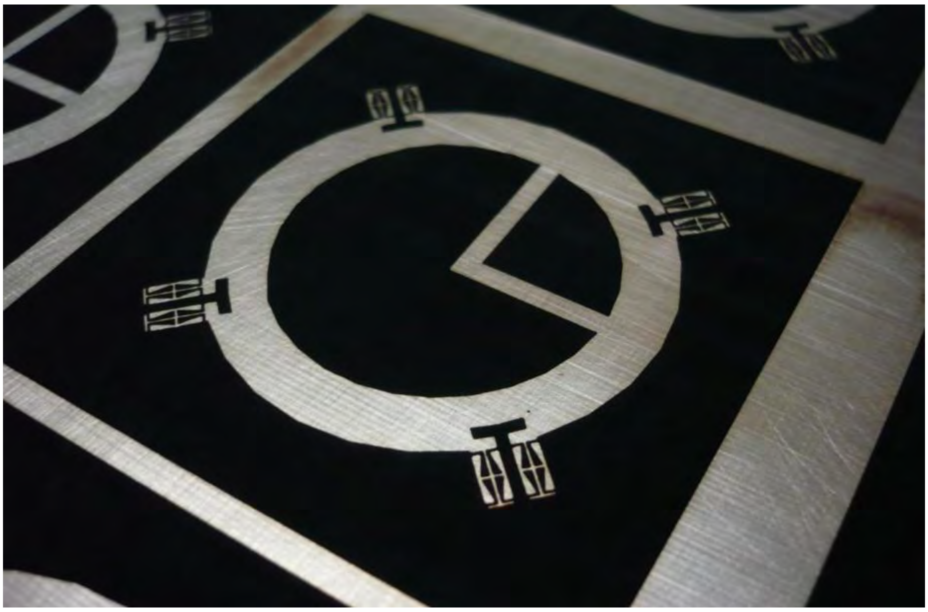


Fig. 5.2.1 (a) Prototype of third proposed antenna

The printer in City University of Hong Kong always lack of ink. It will affect the quality of the patch due to the mistake in fabrication process. So I try to use "film printer" to print out the design. And the high accurate is required in this design.

Fig.5.2.1 (b) Top and 3D view of third prototyped proposed antenna

I recommend that complicated structure of antenna should use "film printer" and "dry-film photoresist" technique in prototype fabrication. New fabrication room is available around Feb, 2009 at City University of Hong Kong.

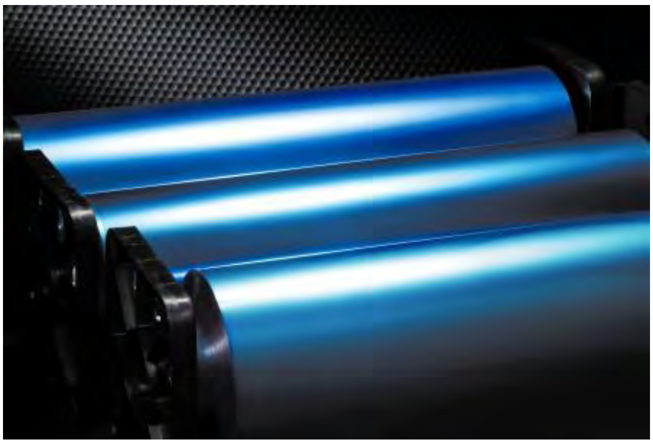


Fig. 5.2.1 (c) Example of dry-film photoresist

Dry film is available in a range of film thickness from 1.0 to 1.5 mil. For very fine line resolution, thin film is desirable. Thick film is more suitable if hole tenting is needed. However, the four pair of CMRC are intergrated to this antenna. Resonable results are obtained in this design through many times of frabracation.

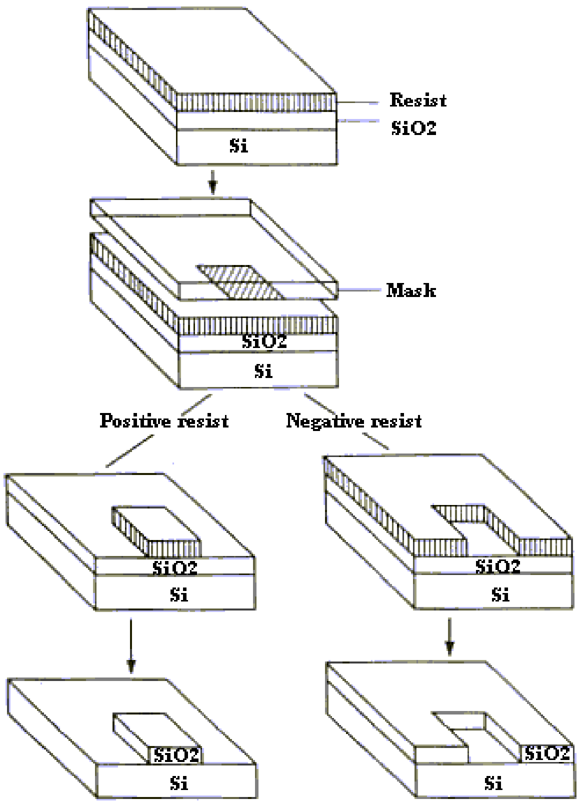


Fig. 5.2.1 (d) Example of positive and negative photoresist

5.2.2 Simulated and measured results

Figure 5.2.2 (b) and (c) shows the return loss and AR, respectively. It found that measured result has less performance then simulated results because the fabrication tolerance. Measured impedance BW which S11 <-10dB is about 6~7%. And it operated at 2.54-2.73 GHz.

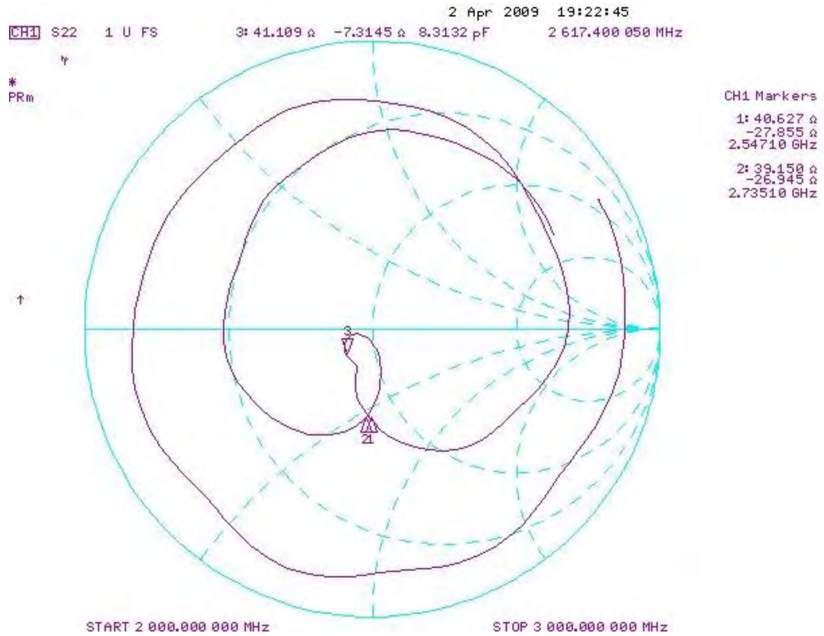


Fig. 5.2.2 (a) Measured impedance of the third proposed antenna

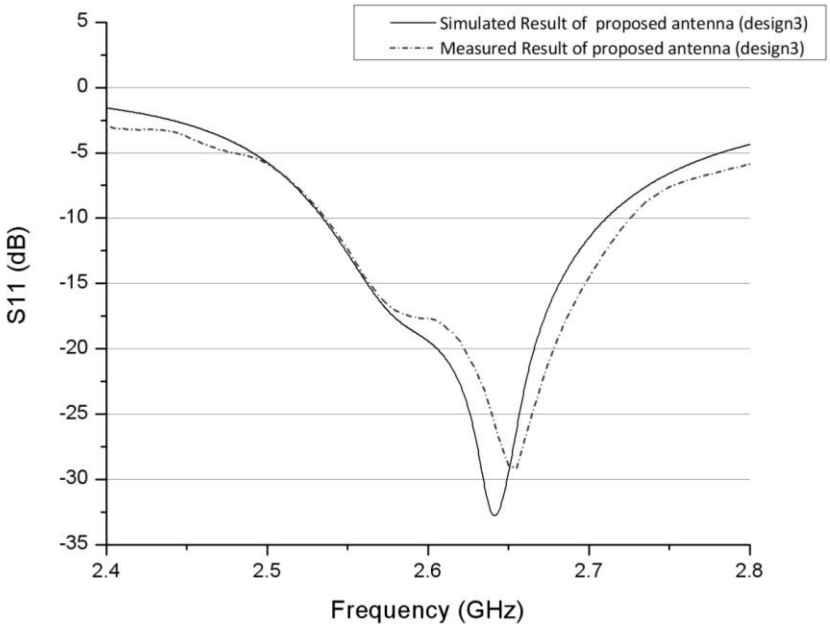


Fig. 5.2.2(b) Return loss against frequency of the 3rd proposed antenna

At operating frequency 2.6 GHz, the axial ratio just only excesses 3dB. The result is not pretty good.

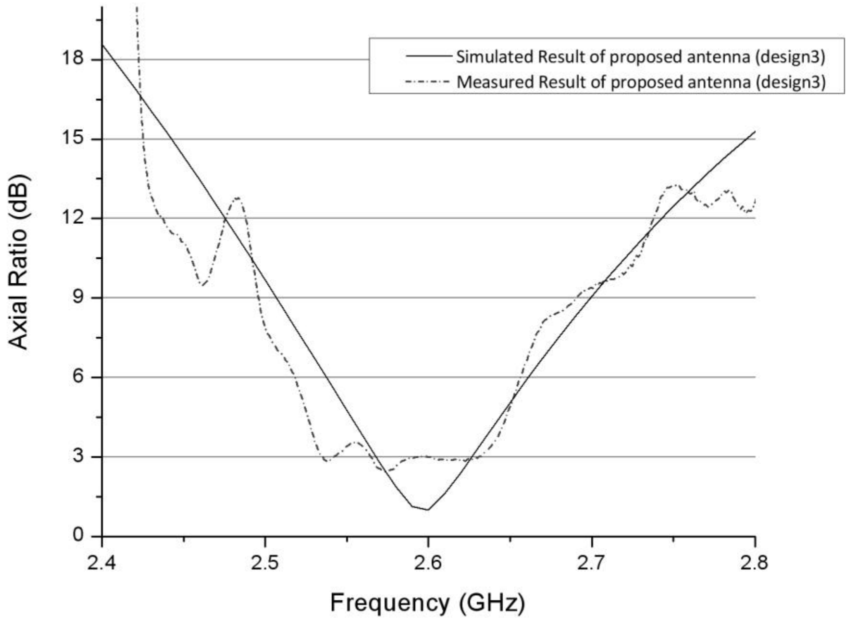


Fig. 5.2.2(c) AR against frequency of the 3rd proposed antenna

At 2.6 GHz, the measured gain is smaller than simulation. It has a gain of 6.1 dBi. It is enough for typical usage.

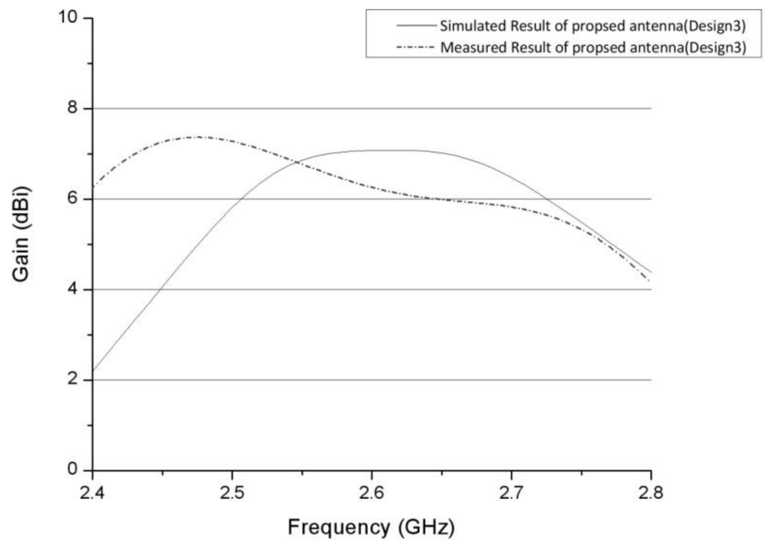


Fig. 5.2.2(d) AR against frequency of the 3rd proposed antenna

Simulation and Measurement of operating frequency 2.6 GHz:

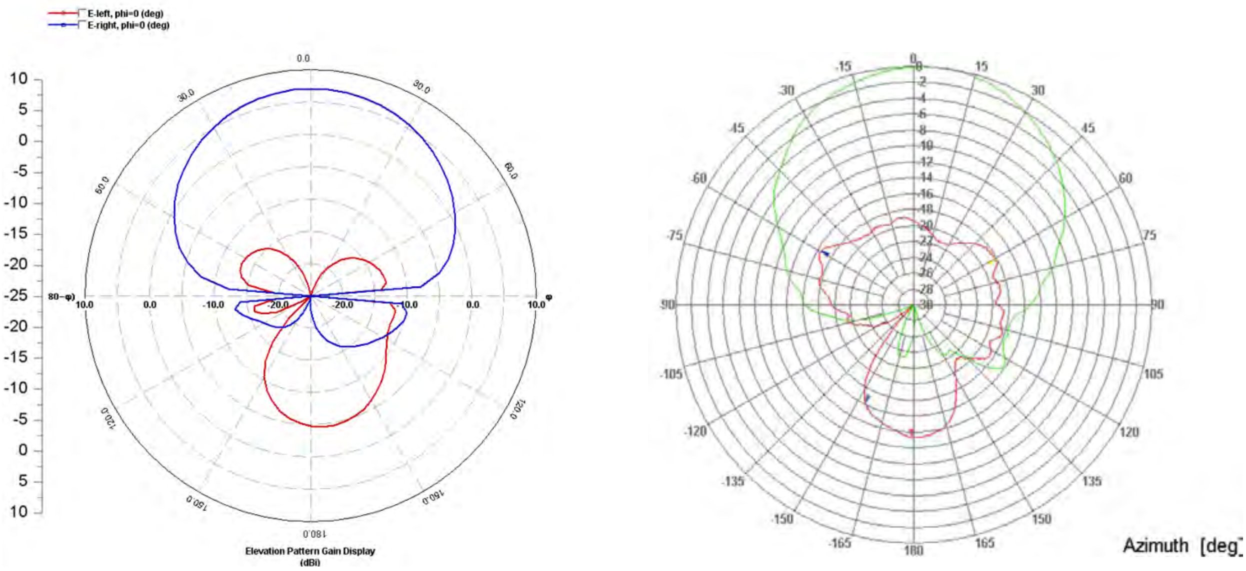


Fig.5.2.2 (e) Simulated and measured radiation pattern (phi=0) of 3rd proposed antenna

5.2.3 Analysis and investigation

In this design, by shifting the L-strip to left or right can also help matching the CP performance. The relationship between them is similar to second proposed antenna. Fig. 5.2.3(a) and Fig. 5.2.3(b) show the relationship of S11 and axial ratio with just placing different scale of CMRC. "CMRC size s=1" on the figure means that the reference dimension of CMRC. With similar patch size compared with the first proposed antenna, smaller frequency can be obtained. Now, I would like to show the relationship of S11 return loss and axial ratio with size of CMRC and the performance of size reduction. Obviously, changing the size of CMRC can achieve further size reduction. In this project, we choose the size of CMRC as the optimized dimension (refer to Fig. 5.1 (b)), the S11 return loss and axial ratio results are the best.

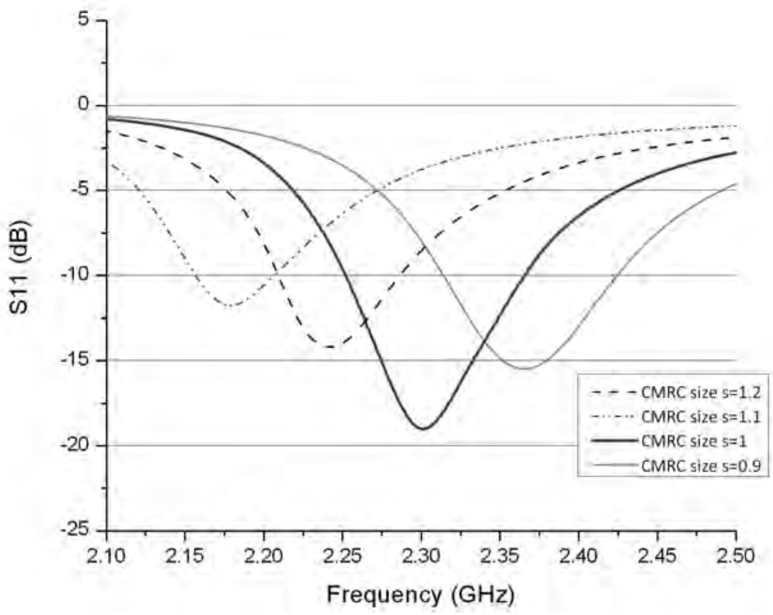


Fig. 5.2.3(a) Parameter study of S11 with different CMRC size (unit: scale)

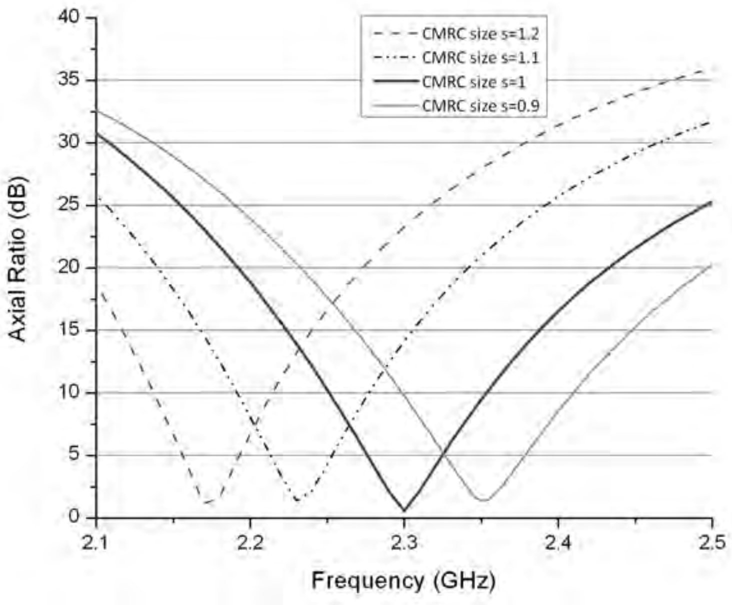


Fig. 5.2.3(b) Parameter study of axial ratio with different CMRC Size (unit: scale)

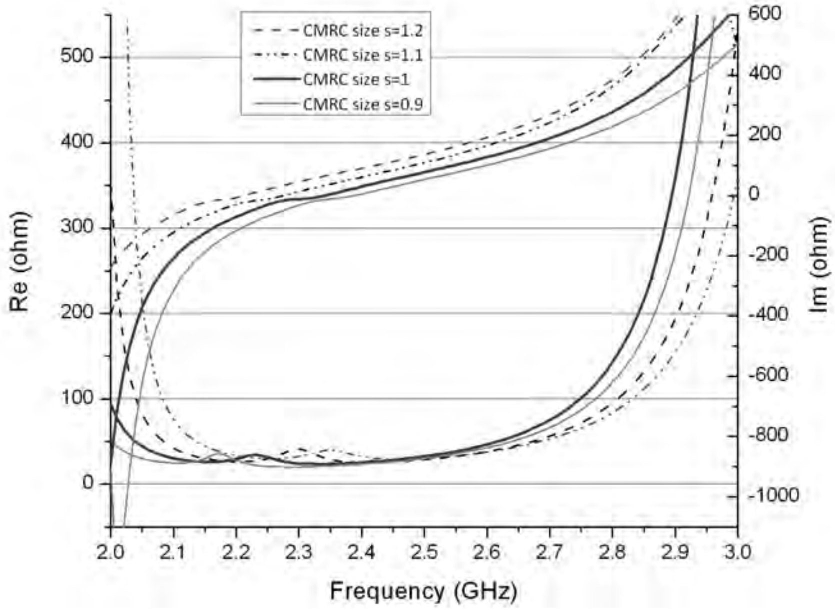


Fig. 5.2.3(c) Parameter study of impedance with different CMRC size (unit: scale)

After comparing the different results, we found that the decision of choosing CMRC size is quite important. From the simulation study, a range of the CMRC size is attained from 0.9 to 1.3 scales, which can achieve reasonable matching. By also tuning the L-strip on the inner ring, the circularly polarization can be excited. Figures 5.2.3(a) to Figure 5.2.3(c) illustrate the parameter study results with different CMRC size.

Apart from this, we found that all results are in good agreement from observing the results of parameter study. For example, if the CMRC size changes to 1.1 scale, the S11 resonant frequency will change to 2.23GHz, the CP resonant frequency also will change to 2.23GHz. In the following part, in order to achieve further size reduction, fourth antenna with a new technique is proposed.

5.3 Fourth proposed antenna with size reduction

The 4th proposed antenna is integrating the inner and outer CMRC technique for size reduction. The antenna keeps on using SMA connector by probe feed. The 3D and top view of 4th proposed antenna are shown as below.

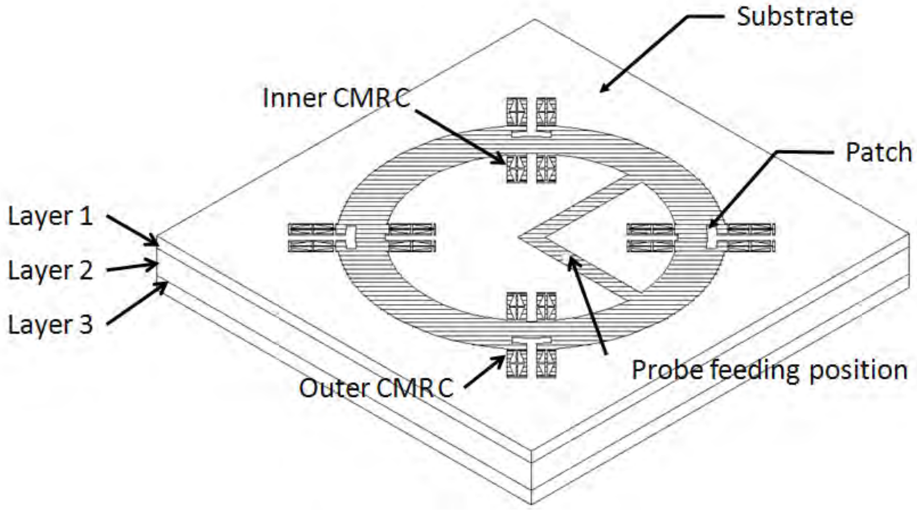


Fig. 5.3 (a) 3D view of fourth proposed antenna

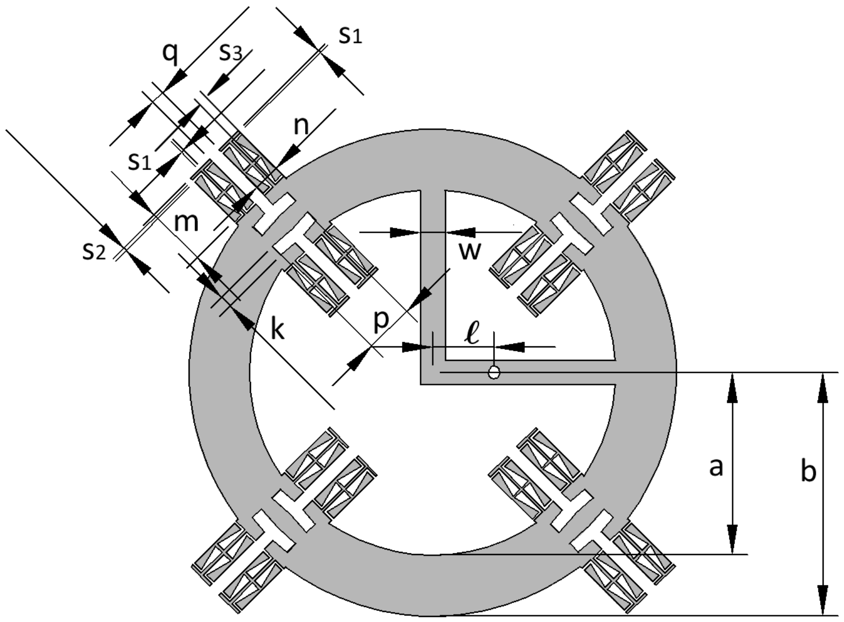


Fig. 5.3 (b) Top view and geometry of fourth proposed antenna (unit: mm)

Parameters	a	b	w	ℓ	t1	t2	t3	gnd
Values(mm)	11.68	15.53	1.72	5	0.8	5	2	46
	0.101 λ_o	0.269 λ_o	0.0149 λ_o	0.43 λ_o	0.007 λ_o	0.043 λ_o	0.017 λ_o	0.398 λ_o

Parameters	m	n	p	q	k	s1	s2	s3
Values(mm)	3.88	1.52	3.07	0.84	0.772	0.168	0.169	0.59
λ_o	0.0336	0.0132	0.026	0.00728	0.0067	0.00145	0.00146	0.0051

Table. 5.3 (a) Parameter values of fourth proposed antenna

5.3.1 Antenna description

Inner CMRC is inserted in order to obtain further size reduction. It is one of advantages of ring shape antennas. You just imagined that how can you inset anything inside the center of rectangular or other patches.

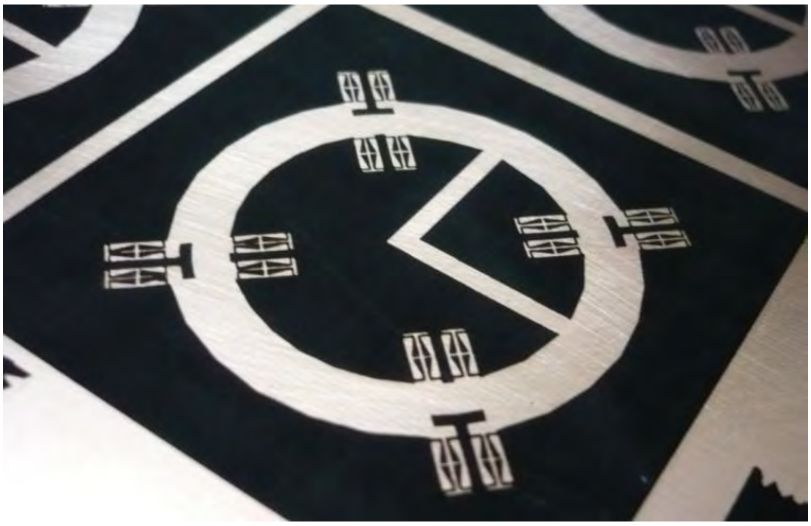


Fig. 5.2.1 (a) Prototype of fourth proposed antenna

This proposed antenna offers greatly improved characteristics, including size reduction, and increased beamwidth, similar structure to the third proposed design and so on. However, the impedance and AR bandwidth become sightly narrow. So there is still much capability for continued study. Further enhancement is needed because smaller size antenna has narrower impedance and AR BW, performance can be improved by alternative methods.

In section 6, detailed further enhancement is shown.

5.3.2 Simulated and measured results

The fourth proposed annular ring patch antenna can operate from 2.56 GHz to 2.71 GHz by observing smith chart.

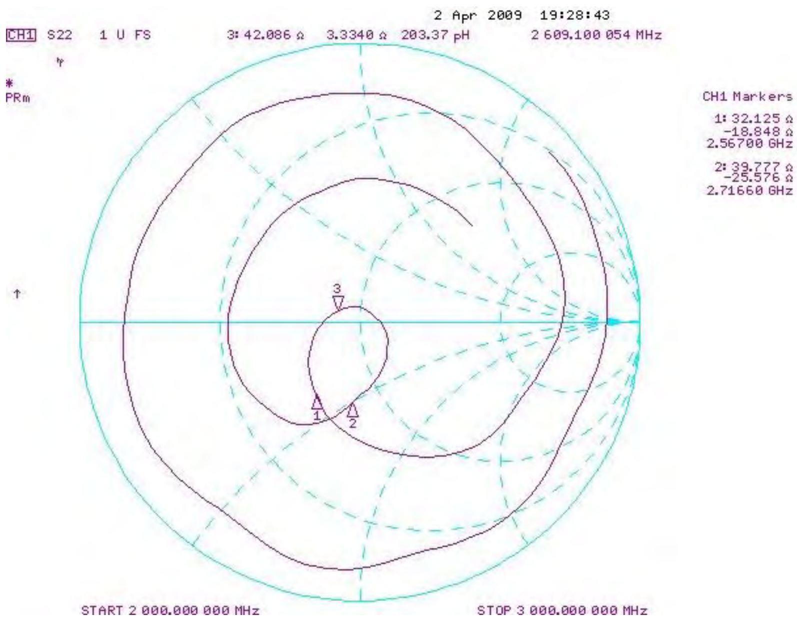


Fig. 5.3.2 (a) Measured impedance of 4th proposed antenna

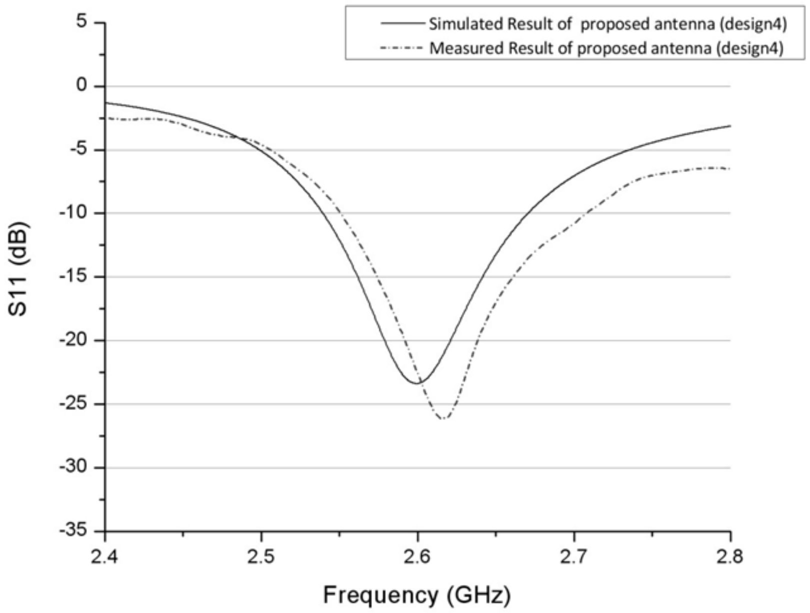


Fig. 5.3.2(b) Return loss against frequency of 4th proposed antenna

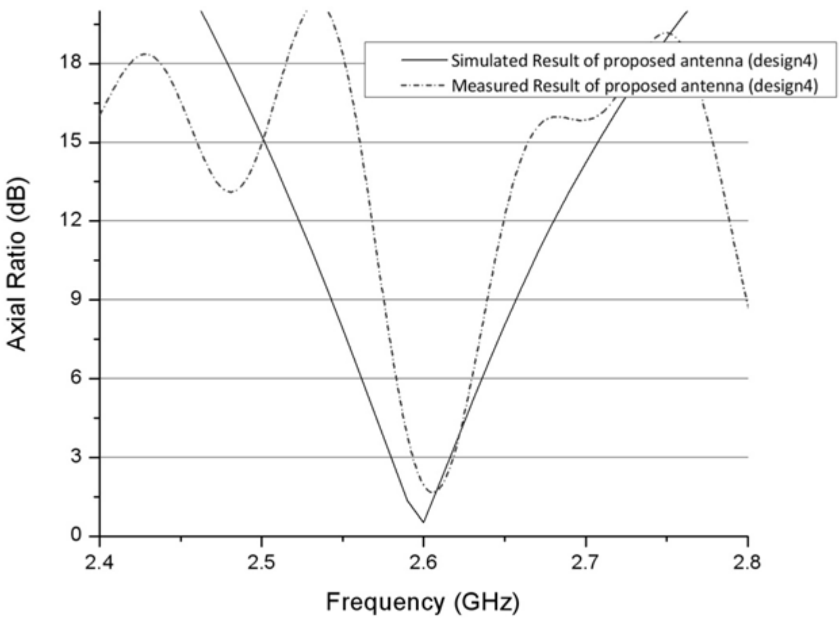


Fig. 5.3.2(c) AR against frequency of 4th proposed antenna

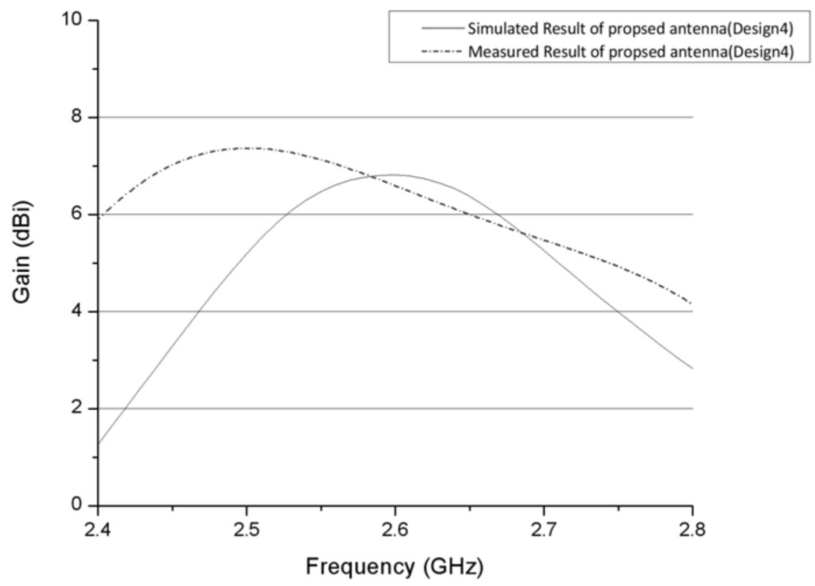


Fig. 5.3.2(d) Gain against frequency of 4th proposed antenna

Simulation and Measurement of operating frequency 2.6 GHz:

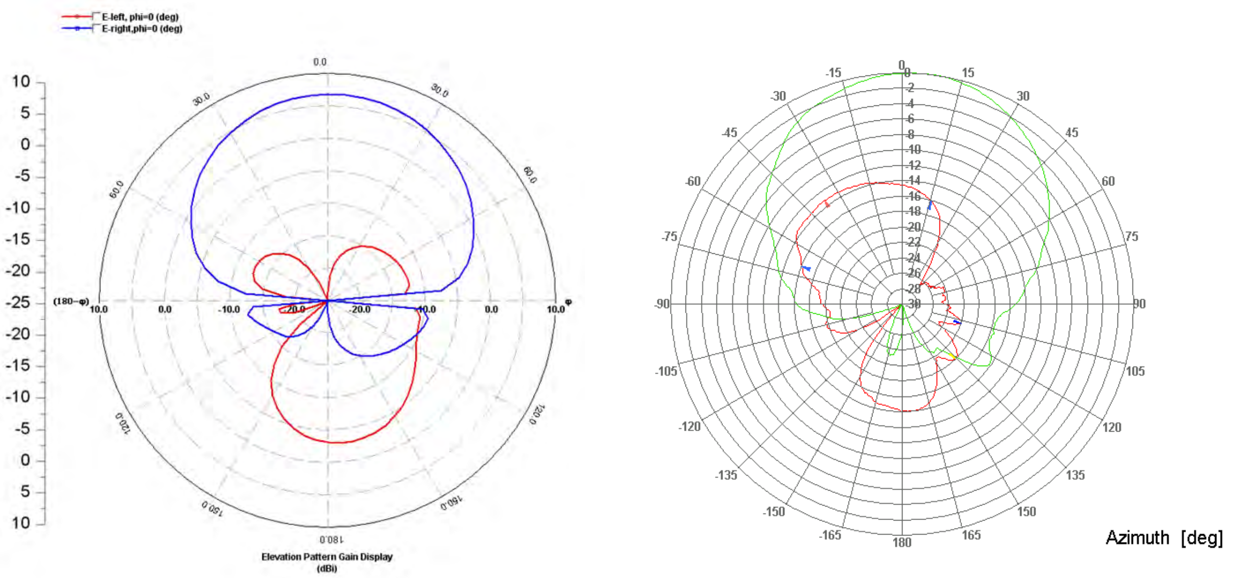


Fig.5.3.2 (e) Simulated and measured radiation pattern (phi=0) of 4th proposed antenna

5.4 Comparison of proposed antenna with size reduction

Four proposed antennas with size reduction are done. The size reduction is from 30.6% to 46.9%. Detail summary table will be displayed as follow. Now, let see the trend of return loss and axial ratio. The results of four proposed antennas are shown in one figure.

Fig.5.4 (a) Prototype of 1st to 4th proposed antenna

All of these antennas operate at the same frequency 2.6 GHz, and size reduction is achieved. For above proposed designs, impedance and AR BW are little small but it is satisfied. And other performances remain unchanged

When the size is reduced, the impedance BW keeps 5~6%. Obviously, the shape of return loss more and more matches the CP resonant frequency. Figure 5.4 (c) indicates that the axial ratio becomes little narrow, from 1.9% to 1.58%. It is a drawback of size reduction. By using enchantment technique, overcome the CP performance.

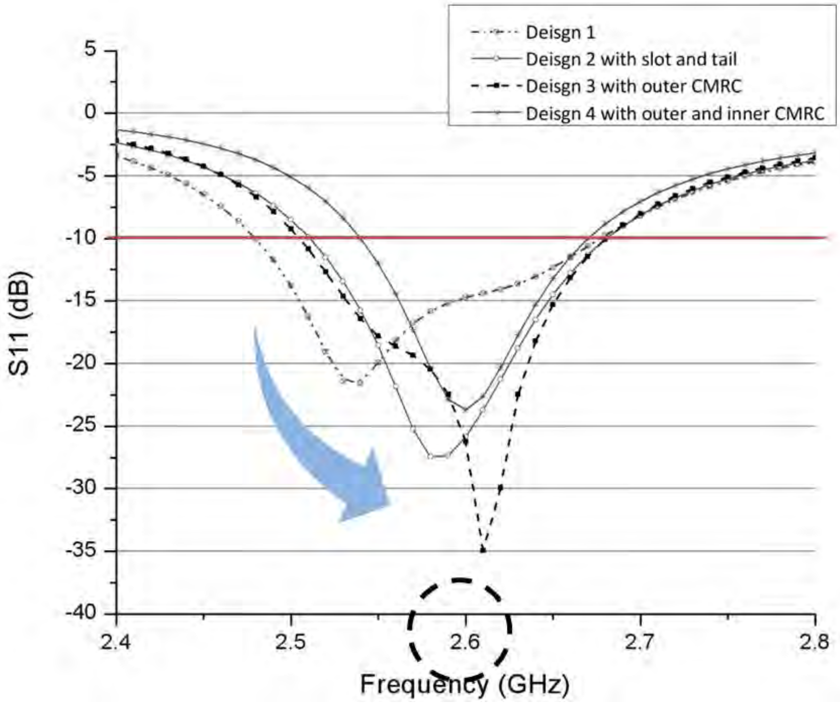


Fig.5.4 (b) Comparison of return loss of 1st to 4th proposed antenna

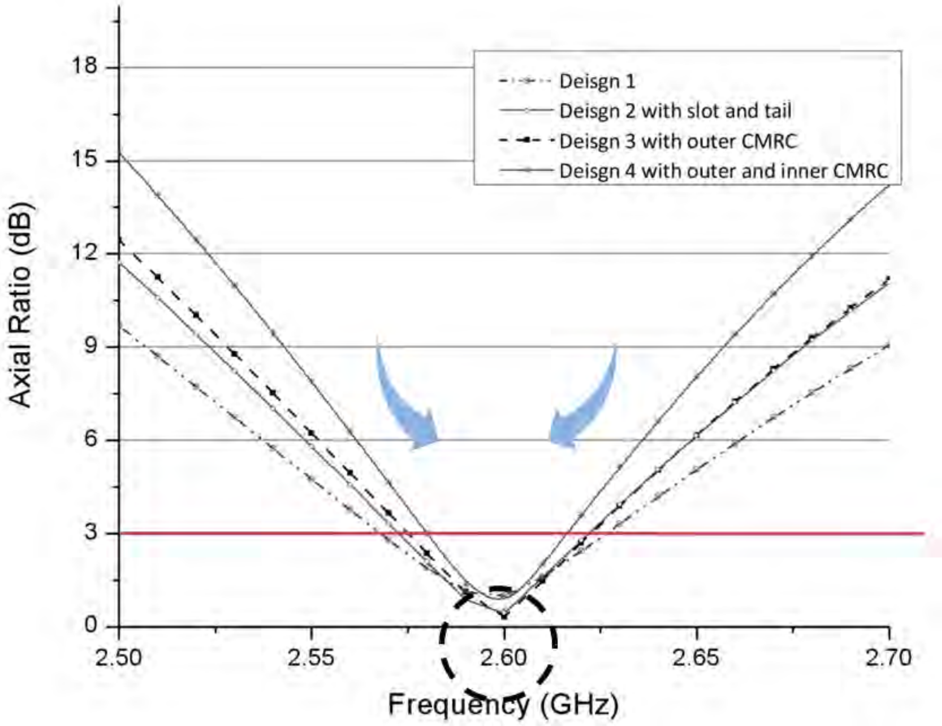


Fig.5.4 (c) Comparison of AR of 1st to 4th proposed antenna

	1st Design	2nd Design	3rd Design	4th Design
Impedance BW	2.48-2.675GHz	2.524-2.68GHz	2.52-2.687GHz	2.53-2.68
% of Imped. BW	6.8%	6%	6.4%	5.8%
AR BW	2.57-2.62GHz	2.571-2.618GHz	2.574-2.619GHz	2.576-2.617GHz
% of AR BW	1.9%	1.8%	1.73%	1.58%
Gain	7.06dBi	7.12dBi	6.71dBi	6.81dBi
3dB Beamwidth	88.41 at phi=0 89.64 at phi=90	90.74 at phi=0 92.55 at phi=90	91.73 at phi=0 93.078 at phi=90	92.71 at phi=0 95.05 at phi=90
Radius	20mm	18mm	17mm	15.3mm
Size Reduction	30.6%	37.5%	41%	46.9%

Fig.5.4 (d) Summary of 1st to 4th proposed antenna

5.5 References

[1] G.J.K. Moernaut and G.A.E. Vandenbosch , *"Size reduced meander line annular ring microstrip antenna"*, Electronic Letters 11th November 2004 Vol. 40 No. 23

[2] Iwasaki, H.; *"A circularly polarized small-size microstrip antenna with a crossslot"*Antennas and Propagation, IEEE Transactions on Volume 44, Issue 10, Oct 1996 Page(s):1399 - 1401

[3] K. L. Wong and Y. E. Lin, *"Compact circularly polarized circular microstrip antenna with cross slot and peripheral cuts"*, Electronic Letters, 34, 1040-1041, May 28, 1998

[4] K. L. Wong and Y. E. Lin, *"Circularly polarized microstrip antenna with tuning stub"*, Electronic Letters 34, 831-832, April 30, 1998

[5] W. S. Chen, C. K. Wu, and K. L. Wong, *"Compact circularly polarized microstrip antenna with bent slots"*, Electronic Letters 34, 1278-1279, June 25, 1998

[6] Y.J. Sung and Y.S. Kim, *"An improved design of microstrip patch antennas using compact microstrip resonant cell"*, Antennas and Propagation Society International Symposium, 2004. IEEE Volume 1, 20-25 June 2004 Page(s):966 - 969 Vol.1

Chapter 6

Enhancement

6.1 Fifth proposed antenna with using novel L-probe

The fifth proposed antenna is applying L-probe feeding technique for enhancement and further size reduction. The topology of antenna is kept as the fourth proposed antenna. It also keeps on using SMA connector but by L-probe fed and air between two layers. Other parameters also remain unchanged.

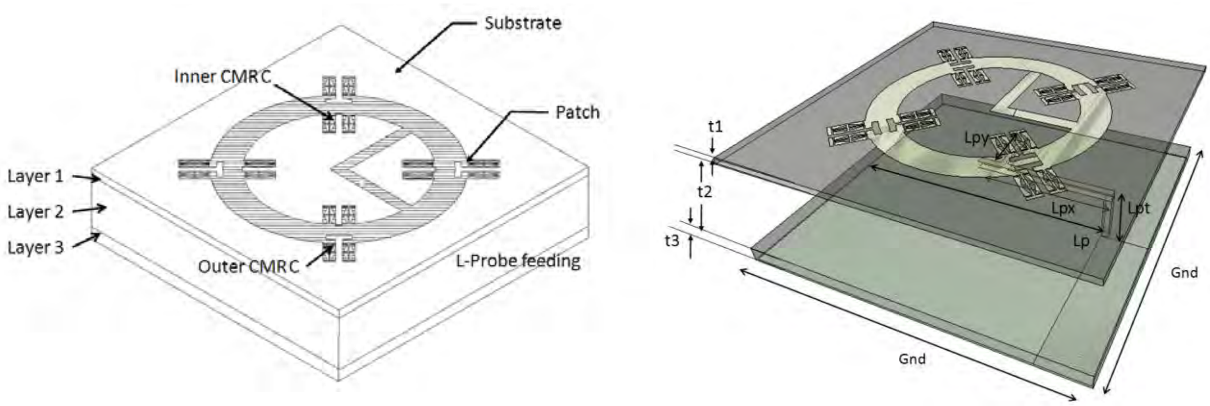


Fig. 6.1 (a) 3D view and geometry of fifth proposed antenna

Actually, the thickness is increased for applying L-probe. The projection area is reduced to 46mm.

Parameters	Lpx	Lpy	Lpt	Lp	t1	t2	t3	gnd
Values(mm)	19	6.5	6.5	16.5	0.8	14.7	2	46
	0.165 λ_o	0.056 λ_o	0.056 λ_o	0.143 λ_o	0.007 λ_o	0.127 λ_o	0.017 λ_o	0.398 λ_o

Table. 6.1 (a) Parameter values of fifth proposed antenna

6.1.1 Antenna description

Different with tradition L-probe, y-horizontal portion is added. The function of this y-horizontal portion also introduces capacitance to cancel out the inductance from vertical probe. Improvement of the impedance and AR bandwidth is obviously. Let see the geometry of novel L-probe as figure 6.1 (b), it consist of three part of portion. (1) Lpx, (2) Lpy and (3) Lpt represent the length of x- horizontal portion, y-horizontal portion and height of vertical portion, respectively.

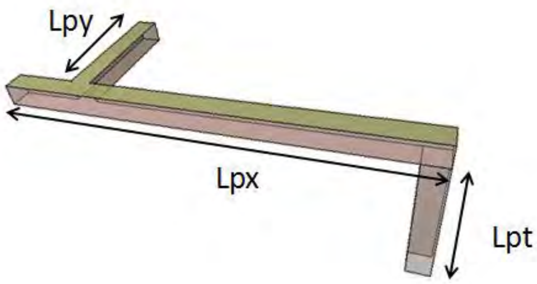


Fig. 6.1 (b) Geometry of novel L-probe (unit: mm)

The parameter of L-probe is sensitivity to the results. So we need to care in L-probe fabrication. Many times of regulation is required.

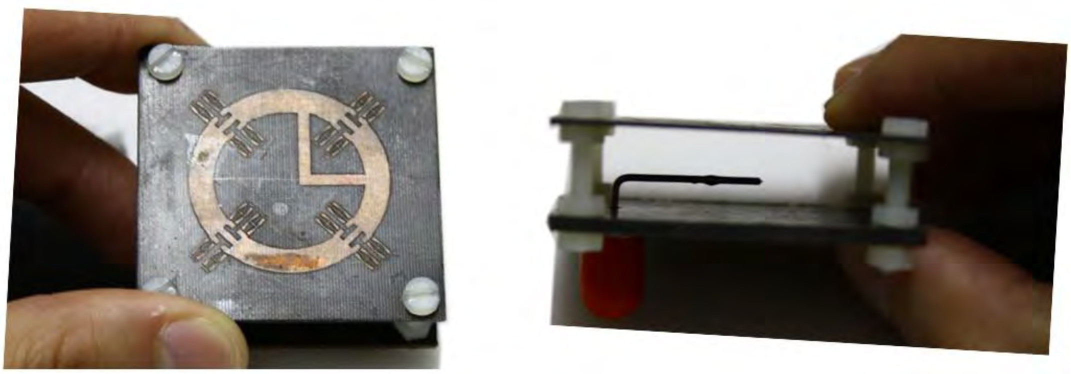


Fig. 6.1 (c) prototype of fifth proposed antenna with novel L-probe

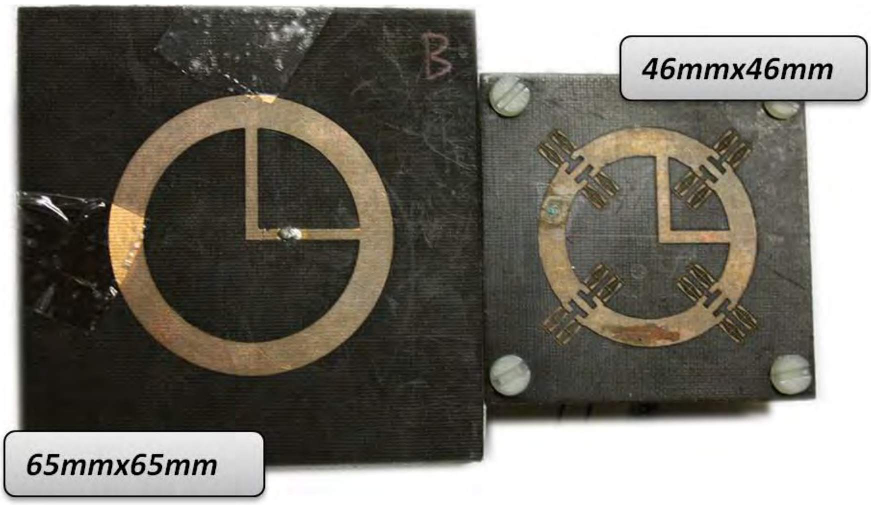


Fig. 6.1 (c) Comparison of first and fifth proposed antenna

Area of 1st and 4th design is 42.25cm2 and 21.1cm2 respectively. So compared to the first proposed antenna, it has further 51% projection area reduction.

6.1.2 Simulated and measured results

Figure 6.1.2 (a) illustrates the measured input impedance. A small circle is placed around 50 ohms on smith chart. So the optimized matching is obtained. And all simulated and measured are shown as follow.

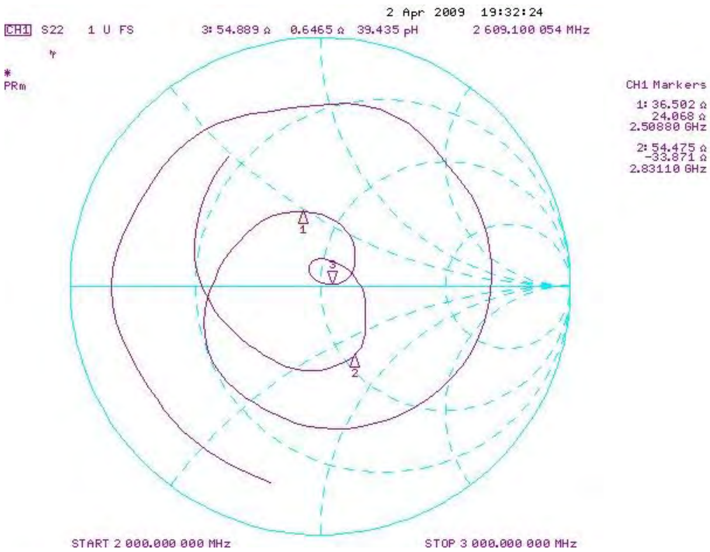


Fig. 6.1.2 (a) Measured impedance of the fifth proposed antenna

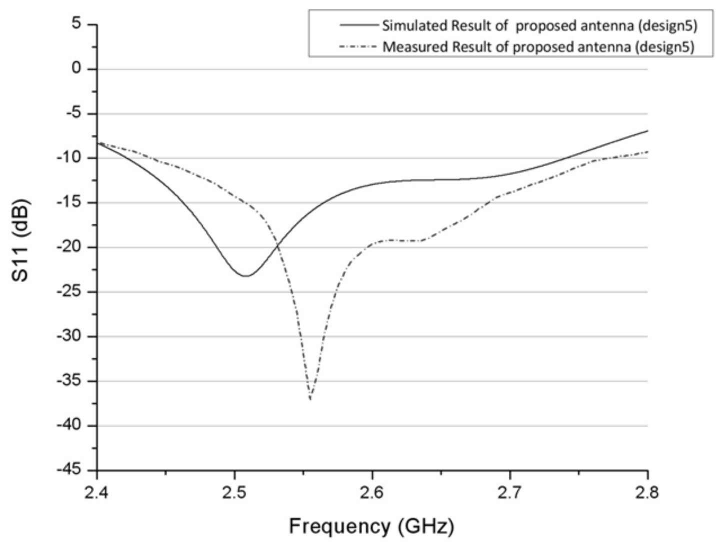


Fig. 6.1.2 (b) Simulated and measured return loss of the fifth proposed antenna

It is a little different in measured result because drilling and fabrication problem. For more accurate results, high precise fabrication is need. Figure 6.1.2 (c) presents the measured axial ratio of the antenna. The 3dB axial ratio BW is from 2.59-2.64 GHz, which has about 1.91% 3dB axial ratio bandwidth. And measured gain is 6.1dBi.

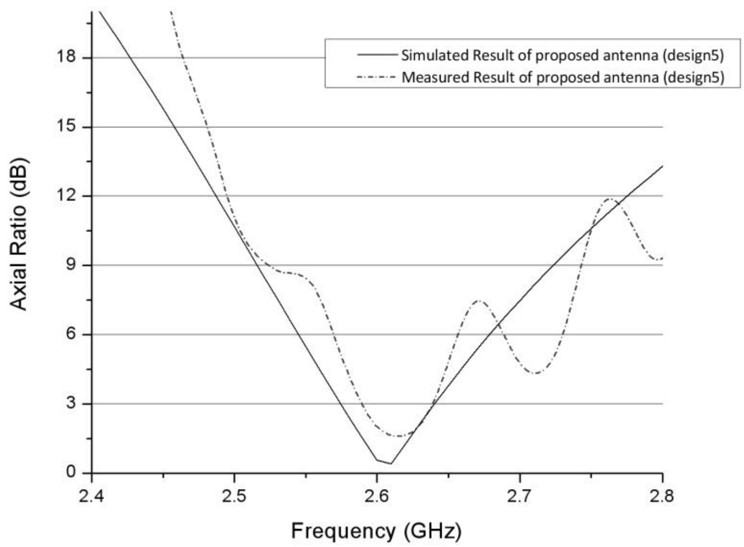


Fig. 6.1.2 (c) Simulated and measured AR of the fifth proposed antenna

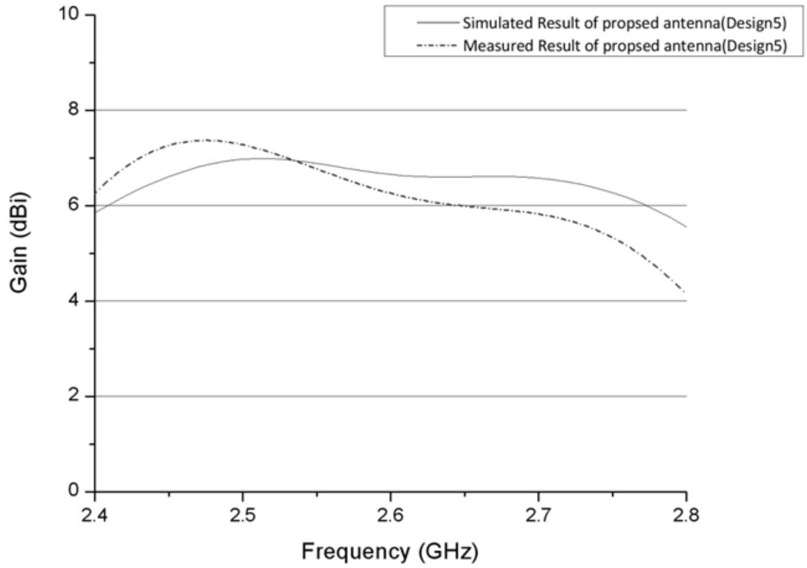


Fig. 6.1.2 (d) Simulated and measured gain of the fifth proposed antenna

Simulation and Measurement of operating frequency 2.6 GHz:

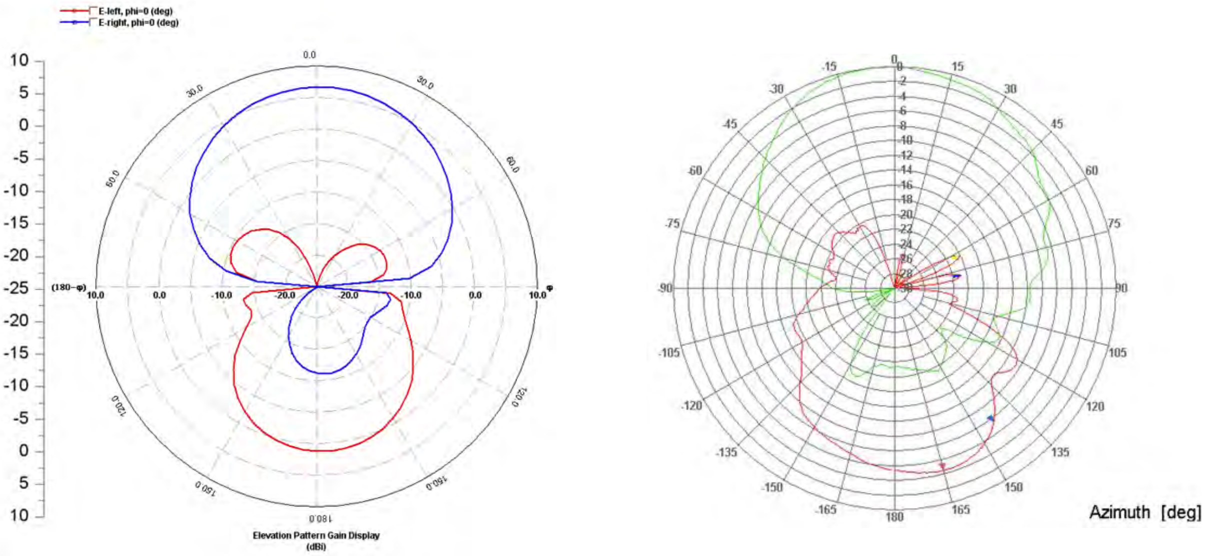


Fig.6.1.2 (e) Simulated and measured radiation pattern (phi=0) of first proposed antenna

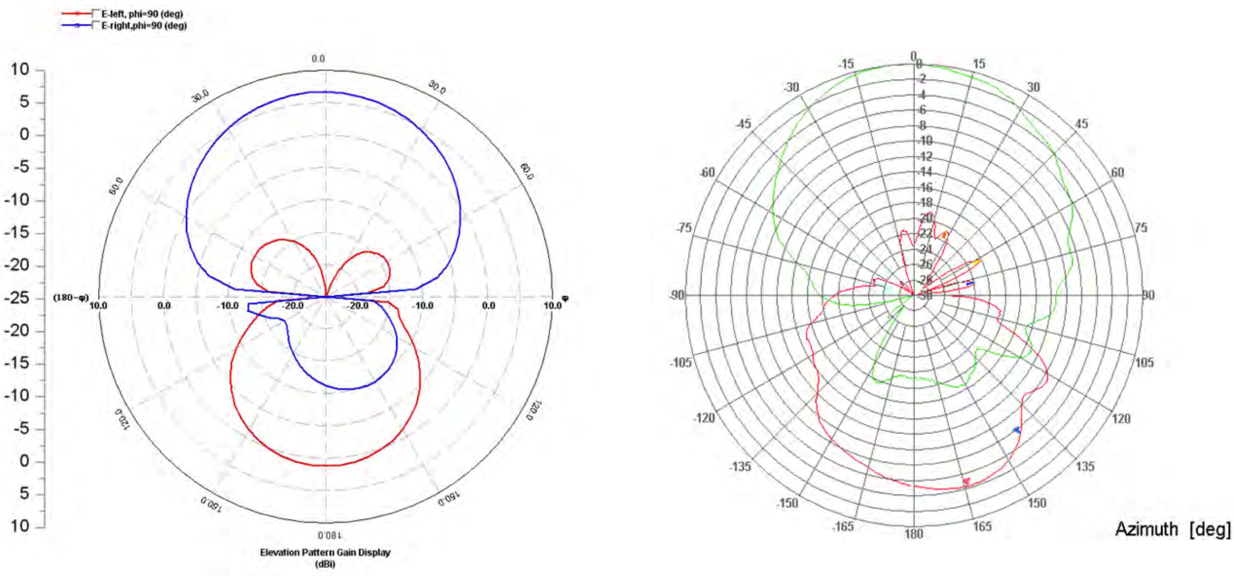


Fig.6.1.2(f) Simulated and measured radiation pattern (phi=90) of first proposed antenna

6.1.3 Analysis and investigation

Some significant parametric studies are displayed with different dimension of novel L-probe (Lpx, Lpy and Lpt) and L-probe position from the original values varying different values. For adjusting novel L-probe, smith chart is used to observe the input impedance characteristics. I would like to show the chart to all of you for information.

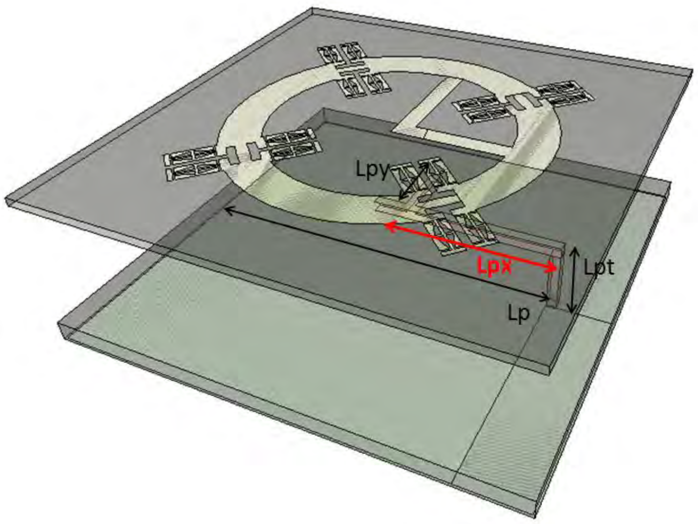


Fig. 6.1.3 (a) Parameter study of different length of x-horizontal portion of novel L-probe

After having the characteristics of input impedance, it is easily to know that the trend of tuning the parameter of novel L-probe. Orientation of the trend towards left, right or up, down is clearly in this chart. Now, all studies are shown as follow.

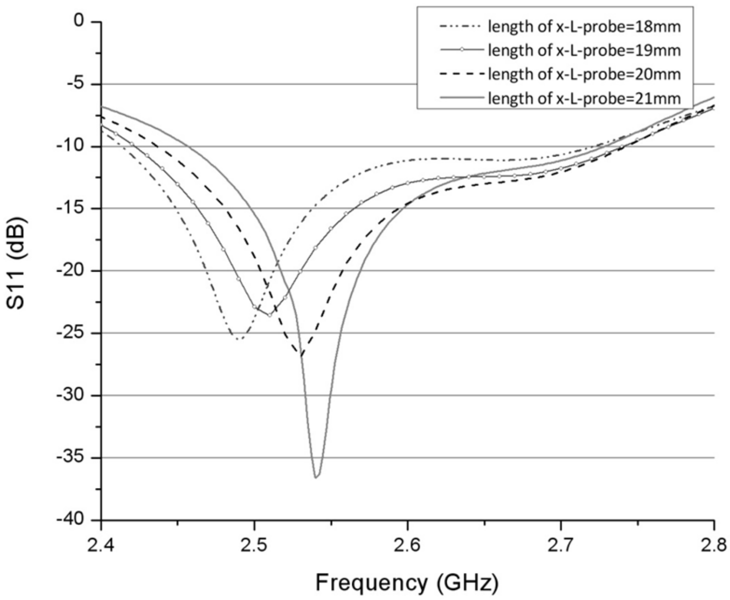


Fig.6.1.3 (b) Parameter study of S11 against frequency with different Lpx

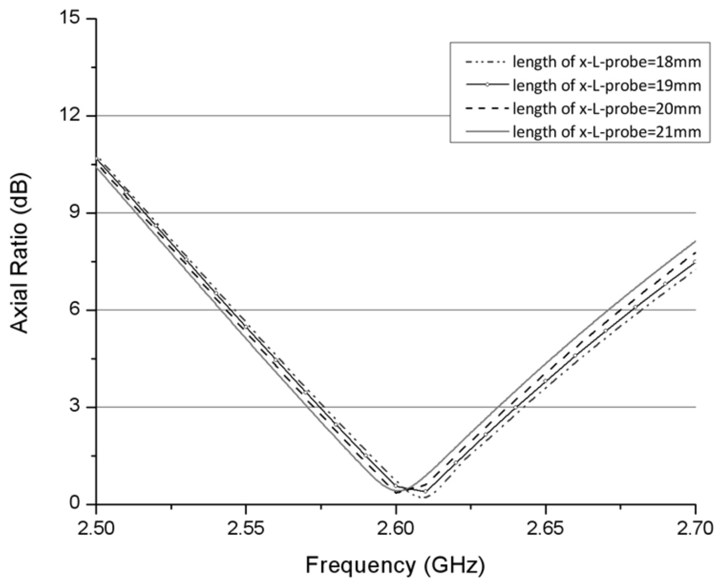


Fig.6.1.3 (c) Parameter study of AR against frequency with different Lpx

Figure 6.1.3(b) and (c) show the variations of changing Lpx from 18mm to 21mm. It shows that the AR is not much sensitive to Lpx, whereas this parameter affects the matching performance. It seems to move smaller frequencies when reduce the length of x-horizontal portion.

Let me summary a table.

Length of x-horizontal	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
18mm	2.414-2.719	11.92%	2.575-2.643	2.59%
19mm	2.422-2.741	12.4%	2.754-2.641	2.57%
20mm	2.437-2.742	11.78%	2.572-2.638	2.53%
21mm	2.456-2.728	10.46%	2.57-2.634	2.46%

Table.6.1.3 (a) Impedance and AR BW with different Lpx

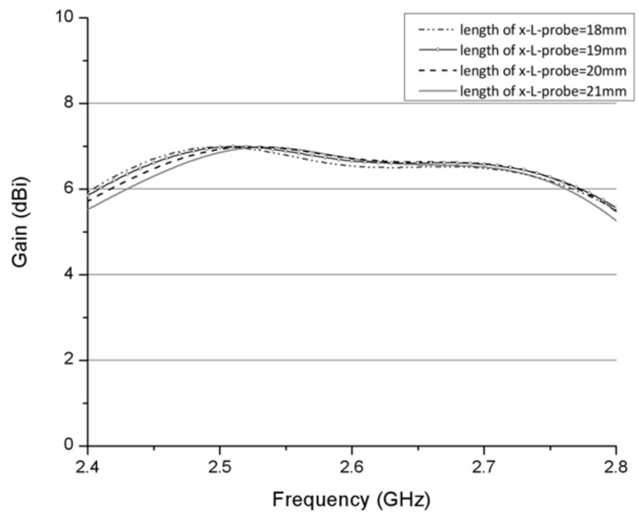


Fig.6.1.3 (d) Parameter study of gain against frequency with different Lpx

As the result of gain and radiation pattern is not much changed when we adjust the Lpx, Lpy, Lpt and Lp. All these results will just be shown in this example.

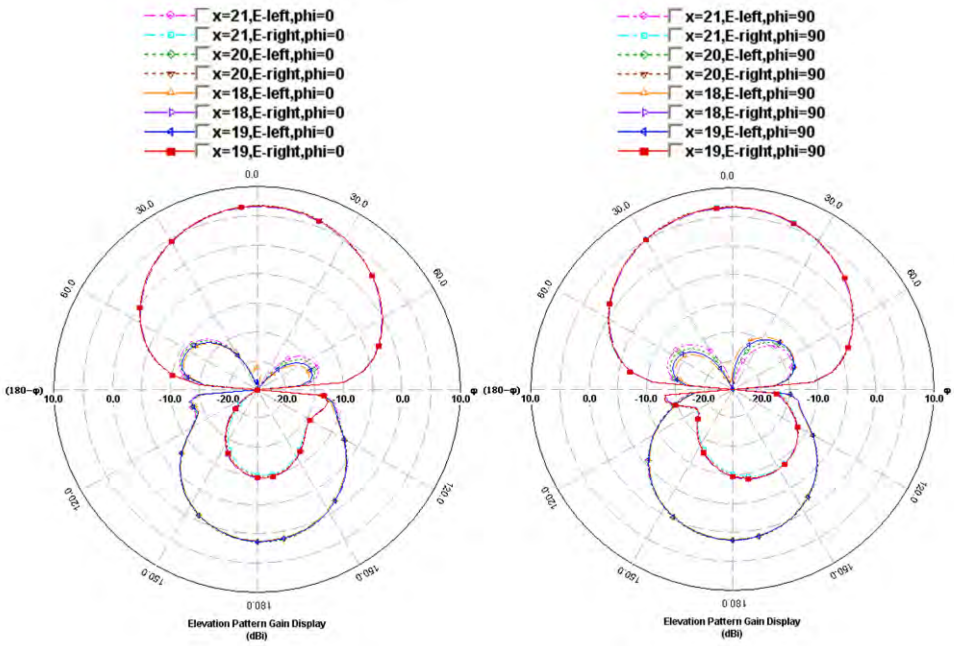


Fig.6.1.3(e) Parameter study of radiation pattern (phi=0 & 90) at 2.6GHz with different Lpx

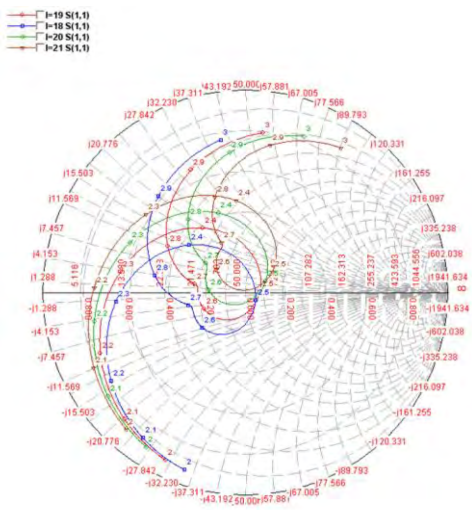


Fig.6.1.3(f) Parameter study of input impedance with different Lpx

Figure 6.1.3(h) and (i) show the variations of changing Lpy from 5.5mm to 8.5mm. The characteristics of all performance are like preceding section, varying Lpx. In this antenna design, the height of L-probe slightly determines the performance of AR.

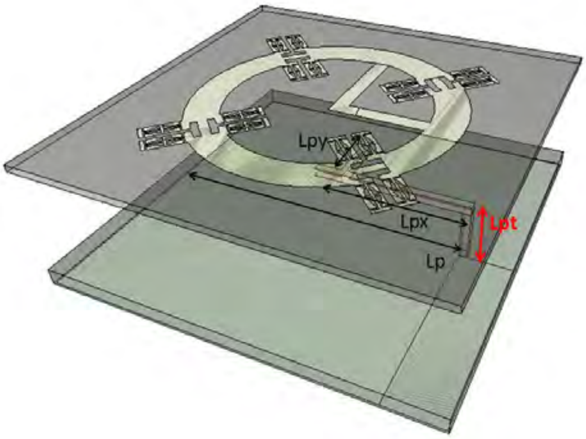


Fig. 6.1.3 (g) Parameter study of different height of vertical portion of novel L-probe

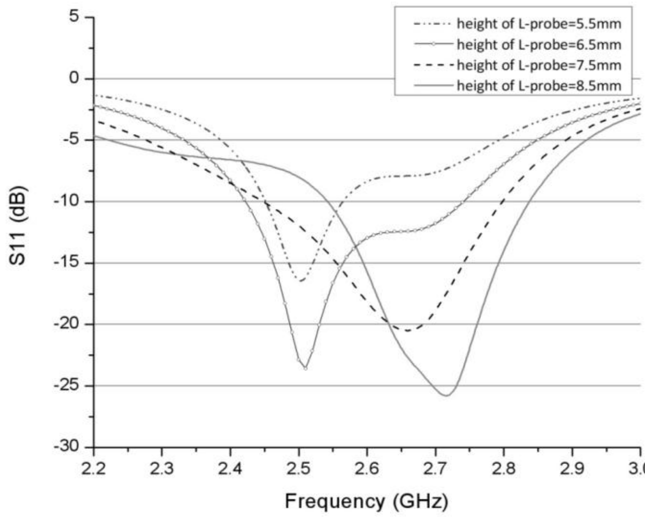
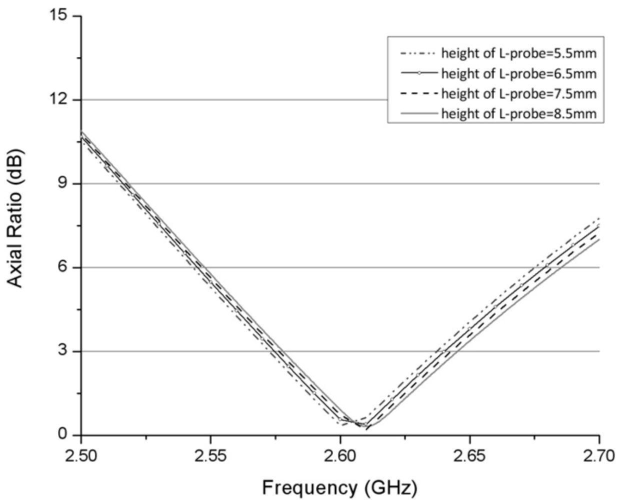


Fig.6.1.3 (h) Parameter study of S11 against frequency with different Lpt



<u>Fig.6.1.3 (i) Parameter study of AR against frequency with different Lpt</u>

Height of L-probe	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
5.5mm	2.452-2.564	4.45%	2.571-2.638	2.53%
6.5mm	2.422-2.741	12.4%	2.754-2.641	2.57%
7.5mm	2.451-2.797	13.21%	2.574-2.643	2.62%
8.5mm	2.542-2.836	10.95%	2.577-2.66	2.62%

Table.6.1.3 (b) Impedance and AR BW with different Lpx

From the simulation study, a range of L-probe height is attained from 6.5mm to 8.5mm, which can achieve good input impedance and axial ratio bandwidth. From above table, good impedance and axial bandwidth is 13.21% and 2.62% respectively,

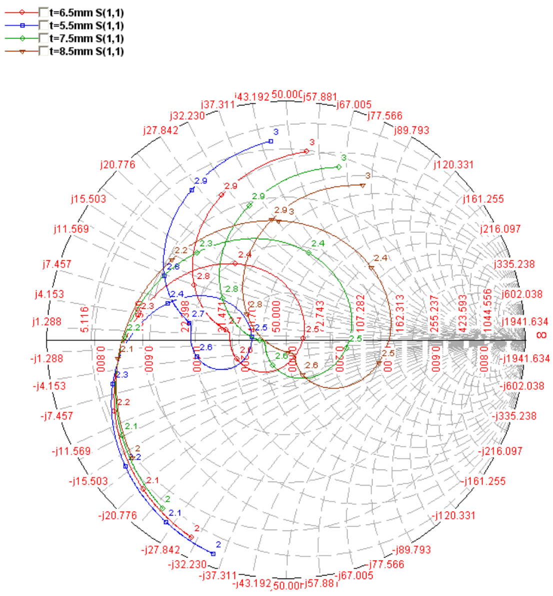


Fig.6.1.3(l) Parameter study of input impedance with different Lpx

As mentioned in last example, the probe position of L-probe is also slightly determines the performance of axial ratio.

6.2 Sixth (Last) proposed antenna with using novel L-probe

The sixth proposed antenna is adding metallic wall and mounting on the ground plane. In my previous design, the backlobe side is increased due to small ground plane. Increasing the size of ground plane is meaningless for the topic which is size reduction. Therefore, a metallic wall is added on the edge of the ground plane and forms a T-shaped (refer to 6.2 (a)). The topology of antenna is kept as the fifth proposed antenna. All parameter remains unchanged. Geometry parameters, 3D view and Top view of sixth proposed antenna is similar to previous design as the figure 6.1 (a) and (b).

For simplifying fabrication, simple metal ground is used instead of ground with dielectric constant. So less performance is presented.

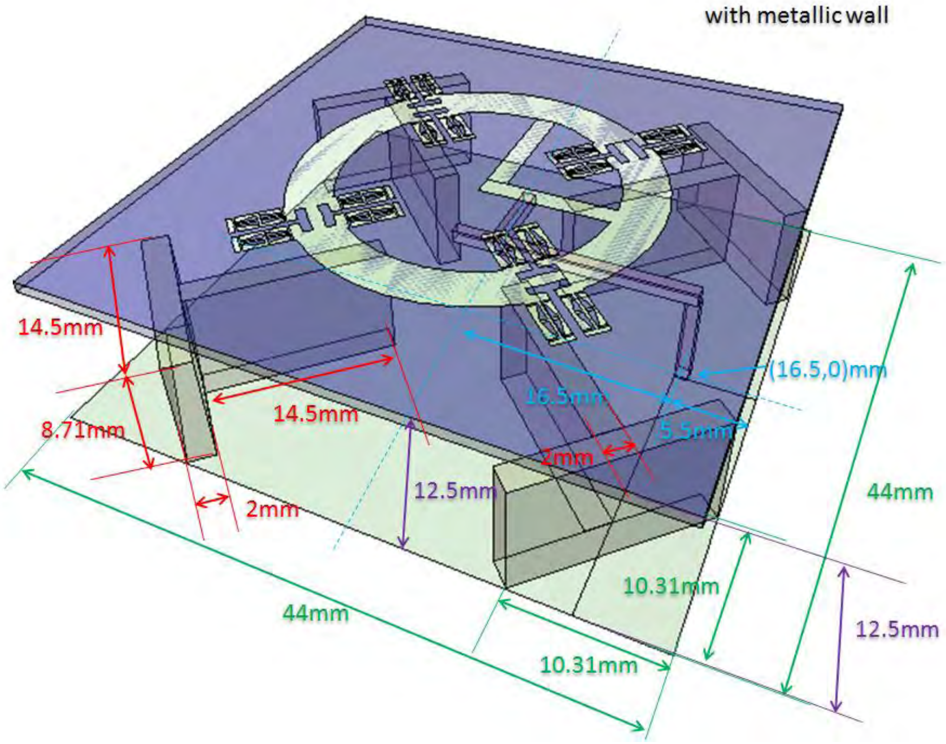


Fig. 6.2 (a) Geometry of design 6 withT-shaped metallic wall

6.2.1 Antenna description

In my point of view, the function of this T-shaped ground plane is to reflect and concentrate the flow of radiation from the ground plane. In other words, it is used for increasing the current path of ground. When the metallic wall is added, backlobe side can be reduced helpfully. And the thickness of the antenna can be also reduced. Due to the existence of metallic wall, antenna performance can be improved effectively.

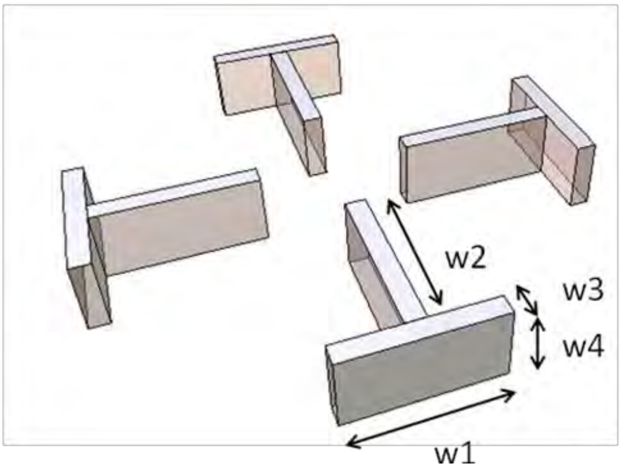


Fig. 6.2 (b) Geometry of T-shaped metallic wall (unit: mm)

6.2.3 Simulated results

In the sixth proposed design, only simulated results are obtained because of delay of fabrication. However, by referring all previous designs, most of measured results are not much different than simulated results. So I suppose that the different of this design is not so large due to the reliable results of simulation. It is too difficult fabrication for mounting a wall on substrate. In the following, all simulation results with substrate and metallic ground are shown.

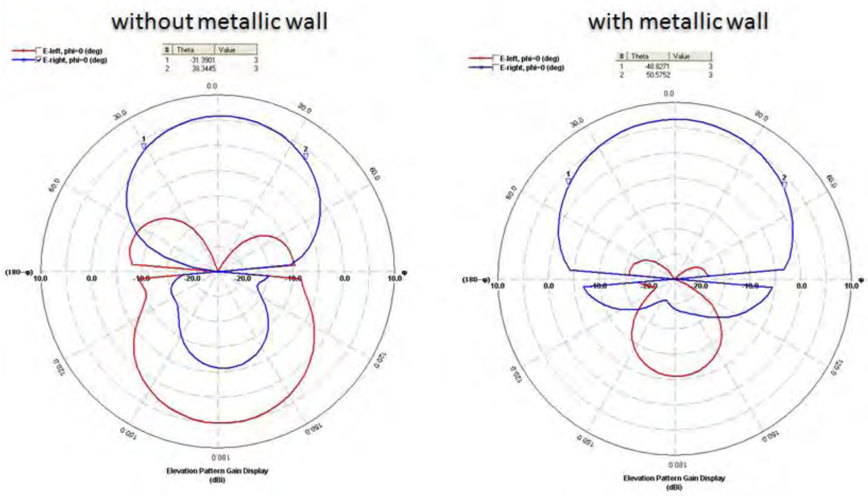
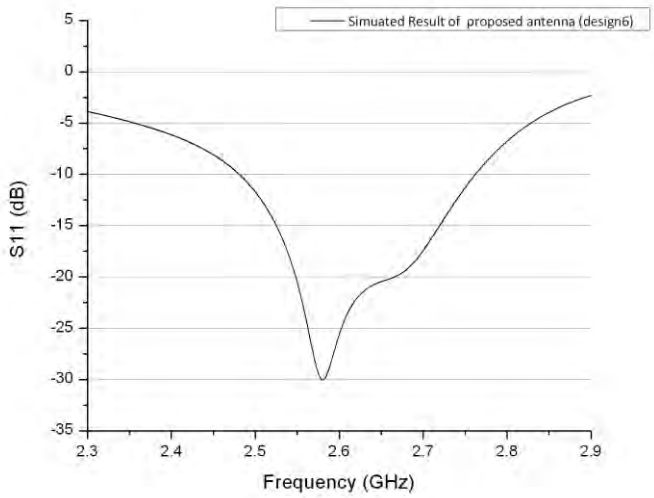
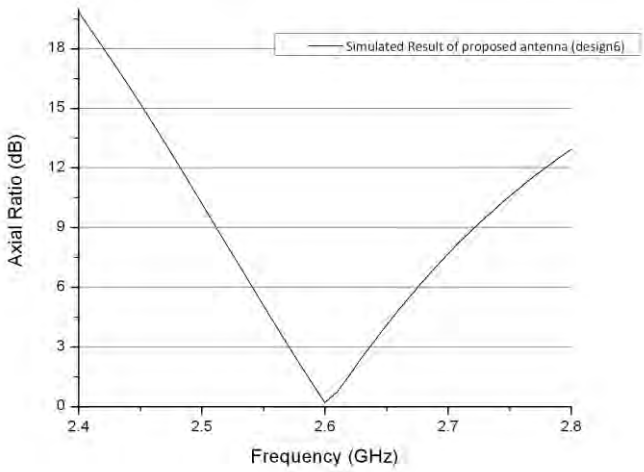


Fig.6.2.3 (a) Simulated pattern of the sixth proposed antenna



(b)



(c)

Fig. 6.2.3(b) & (c) Simulated return loss and AR of the sixth proposed antenna

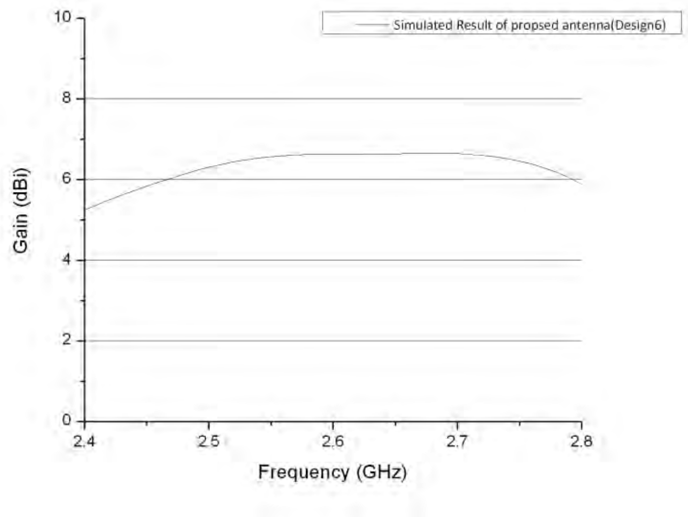


Fig. 6.2.3(d) Simulated gain of the sixth proposed antenna

6.2.3 Analysis and investigation

As the fabrication of this design is sightly difficult because metallic wall are placed on corner, so one more fabrication tolerance needs to concern. In this proposed antennas design, the difficulty is the parameter decision. As you can see the figure, geometry parameters are more than previous designs. It needs to undergo a parameter study to estimate the characteristics. Therefore, by that is meant time which consumes is long.

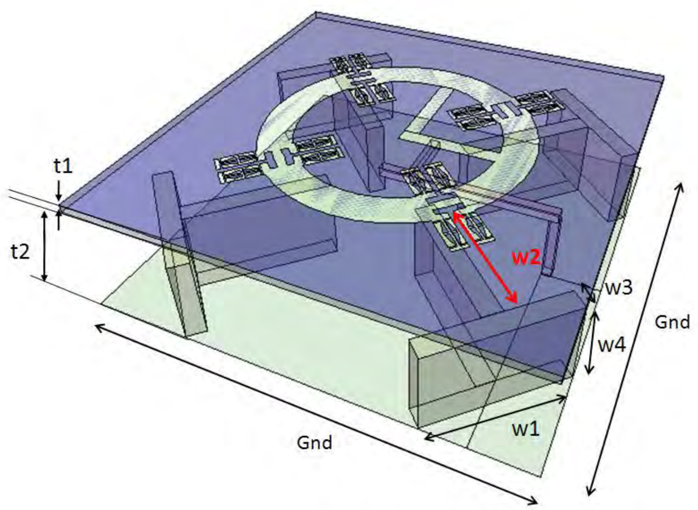


Fig. 6.2.3 (a) Parameter study of different length of metal wall w2

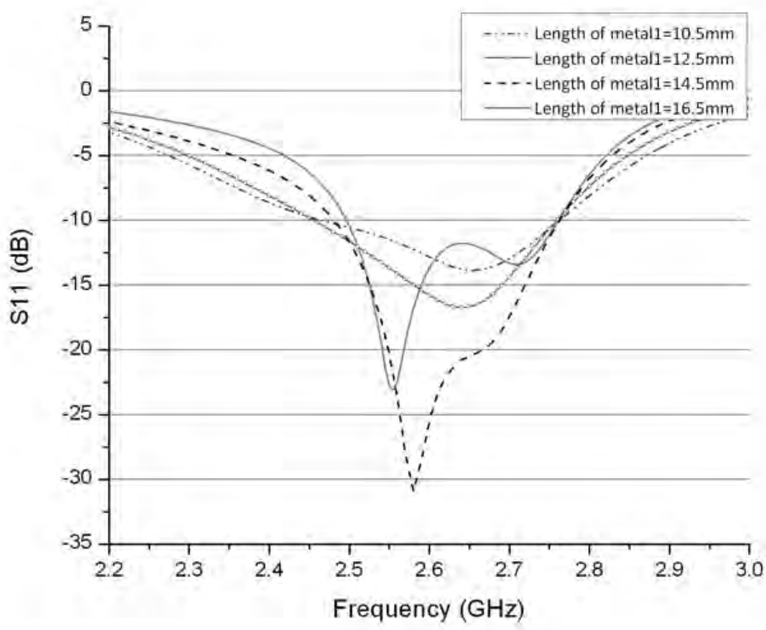


Fig.6.2.3 (b) Parameter study of S11 against frequency with different w2

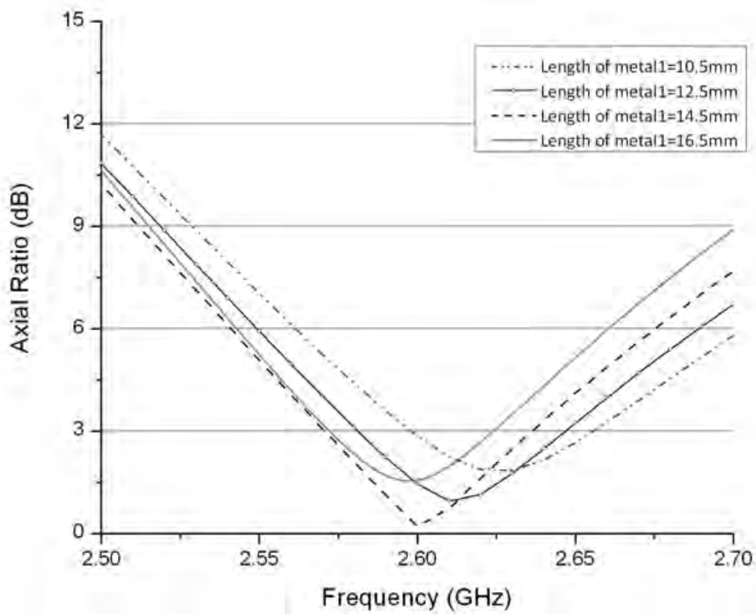


Fig.6.2.3 (c) Parameter study of AR against frequency with different w2

Length of metallic wall	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
11.44mm	2.462-2.764	11.56%	2.598-2.655	2.20%
13.44mm	2.456-2.76	11.66%	2.581-2.647	2.53%
14.5mm	2.482-2.762	10.68%	2.570-2.637	2.54%
16.44mm	2.496-2.762	10.12%	2.571-2.624	2.04%

Table.6.2.3 (a) Impedance and AR BW with different w2

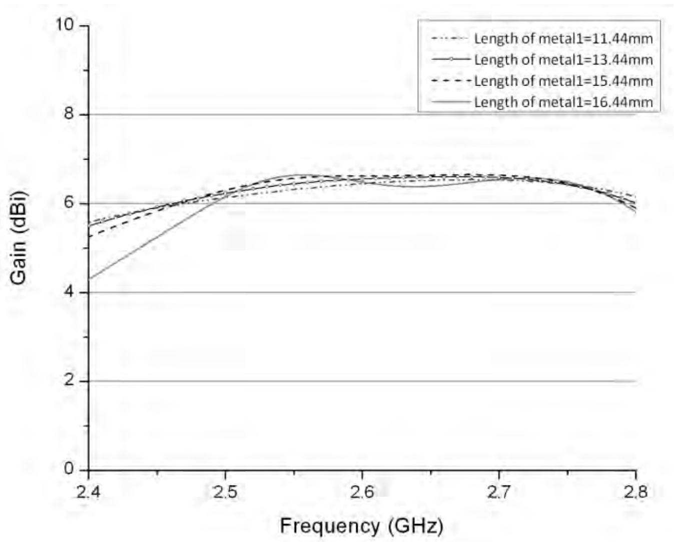


Fig.6.2.3 (d) Parameter study of gain against frequency with different w2

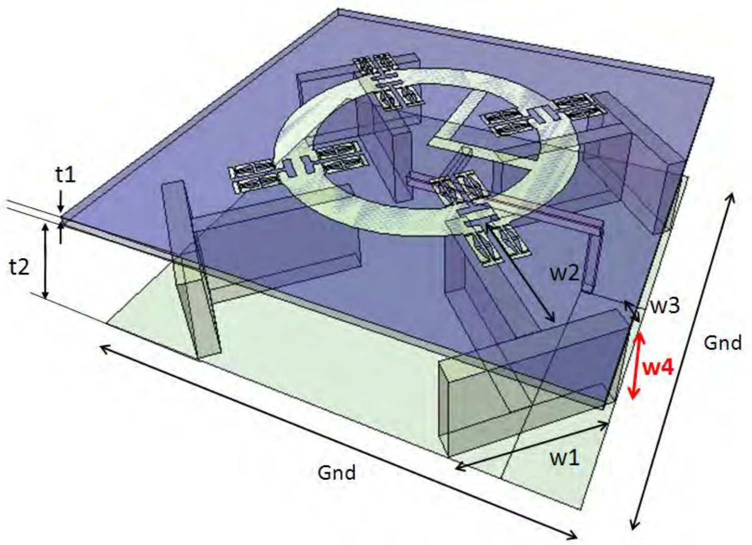


Fig. 6.2.3 (e) Parameter study of different height of metal wall w4

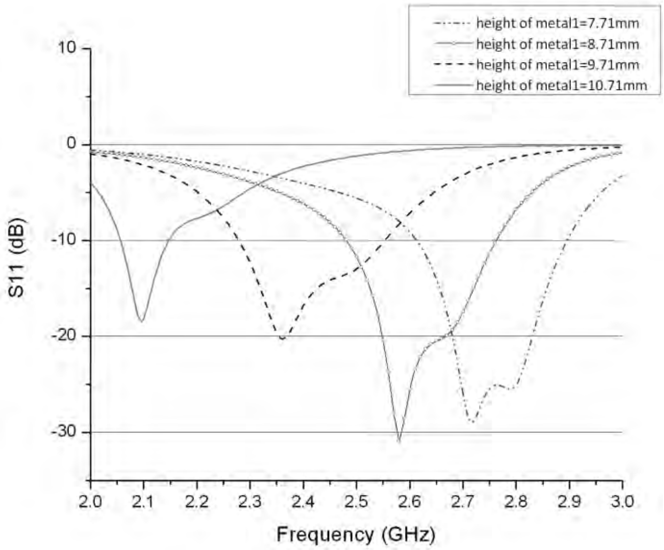


Fig.6.2.3 (f) Parameter study of S11 against frequency with different w4

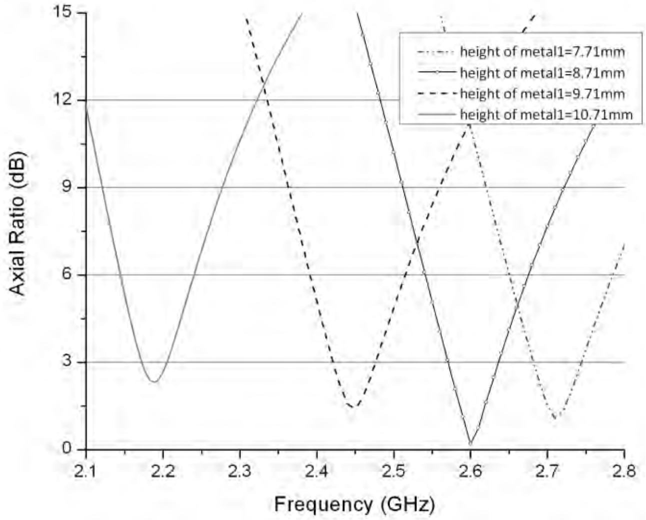


Fig.6.2.3 (g) Parameter study of AR against frequency with different w4

Height of metallic wall	Imped. BW (S11<-10dB) (GHz)	% Imped. Bandwidth	AR BW (AR<3dB)(GHz)	% AR Bandwidth
7.71mm	2.612-2.894	10.24%	2.681-2.743	2.31%
8.71mm	2.482-2.762	10.68%	2.570-2.637	2.54%
9.71mm	2.28-2.552	11.26%	2.421-2.476	2.26%
10.71mm	2.054-2.148	4.47%	2.171-2.206	1.61%

Table.6.2.3 (b) Impedance and AR BW with different w3

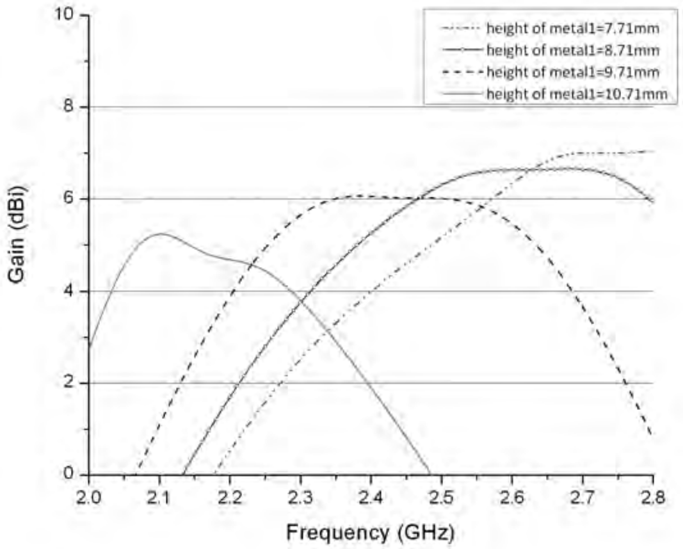


Fig.6.2.3 (h) Parameter study of gain against frequency with different w4

The antenna with the largest size reduction has radius ~53% of the dimensions of the conventional half wavelength antenna when both resonate at the same frequency. Although design 6 were used simple metal ground that results are less performance then using dielectric ground, it also has size reduction and good suppressed backlobe.

As we can see all studies from figure 6.2.3(a)-(h). It is too sensitivity to height of metallic wall. We need to prepare some little different dimensions for measurement testing. And also, for validating the metallic wall, the dielectric ground of pervious design also change to simple metal ground. Just like as below.

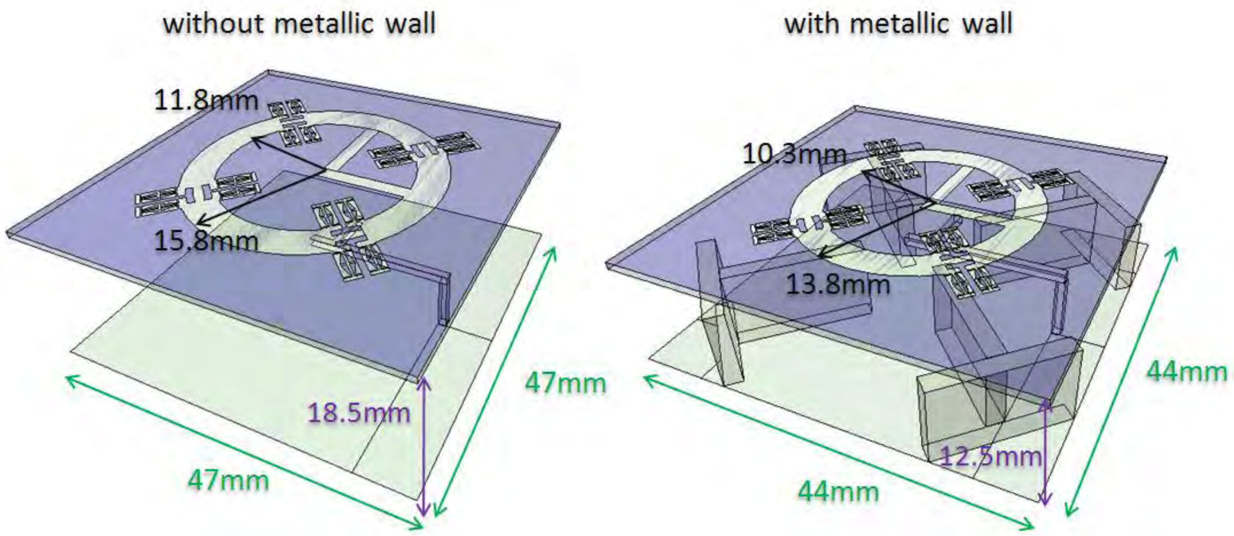


Fig.6.2.3 (i) Comparison of with and without metallic wall

Let me make a short summary of these two proposed antenna:

Outer radius (without metallic wall) =15.8mm
Outer radius (with metallic wall) =13.8mm

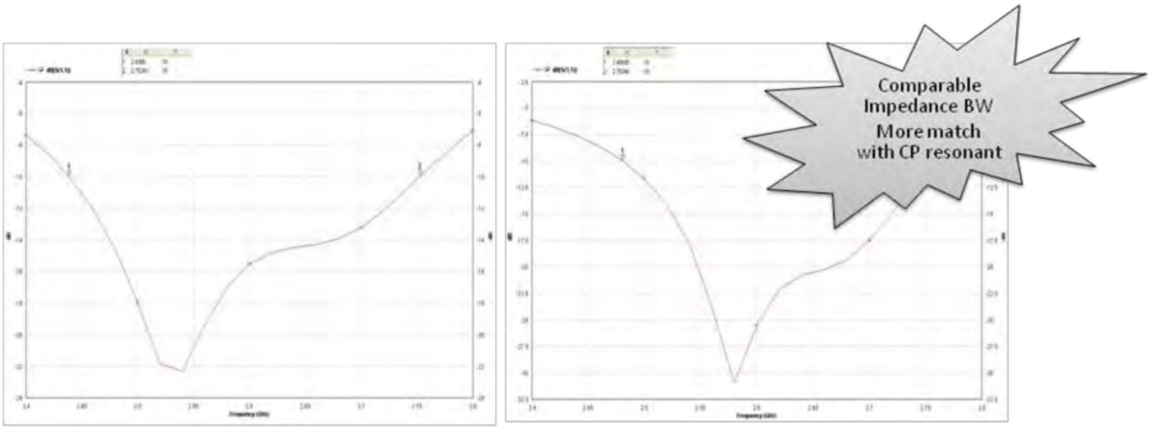
Further size reduction $=\left(1-\dfrac{13.8}{15.8}\right)\times 100\% = 12.66\%$

Further (projection area) size reduction $=\left(1-\dfrac{19.36cm^2}{22.09cm^2}\right)\times 100\% = 12.35\%$

Further (volume) size reduction $=\left(1-\dfrac{24.2cm^3}{40.87cm^3}\right)\times 100\% = 40.79\%$

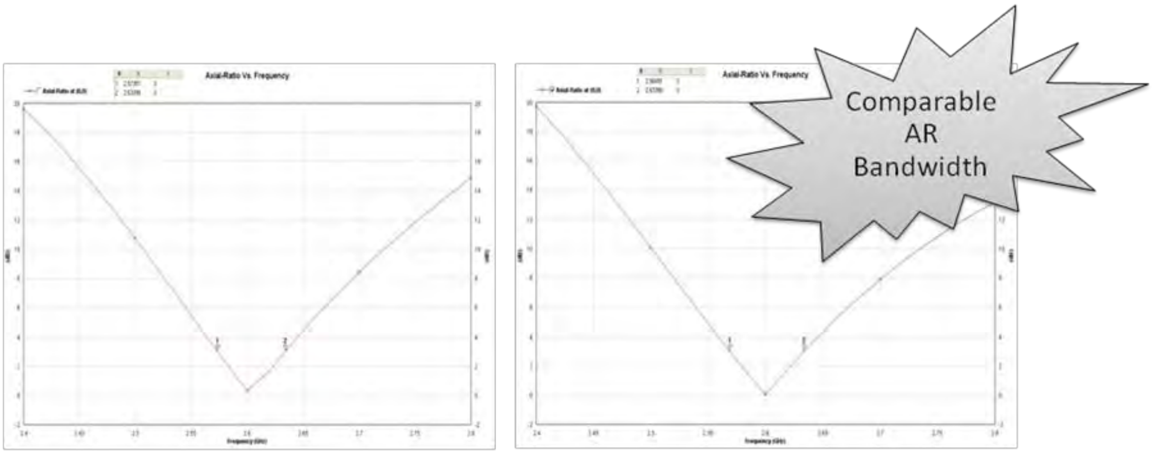
Size reduction compare with conventional antenna$=\left(1-\dfrac{27.6}{57.69}\right)\times 100\% = 52.1\%$

After adding metallic wall, it has some advantages such as 1) further size reduction, 2) suppressed backlobe side, 3) increased beadwidth, 4) comparable impedance bandwidth & AR BW and 5) stable gain



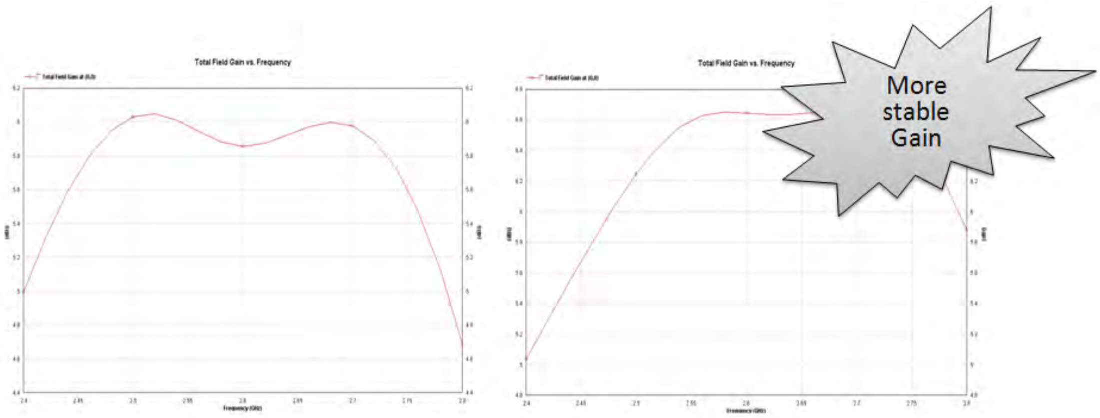
without metallic wall　　　　with metallic wall

Fig.6.2.3 (j) Comparison of return loss of with and without metallic wall



without metallic wall　　　　with metallic wall

Fig.6.2.3 (k) Comparison of AR of with and without metallic wall



without metallic wall　　　　with metallic wall

Fig.6.2.3 (k) Comparison of gain of with and without metallic wall

6.3 Comparison of all antennas with size reduction and enhancement

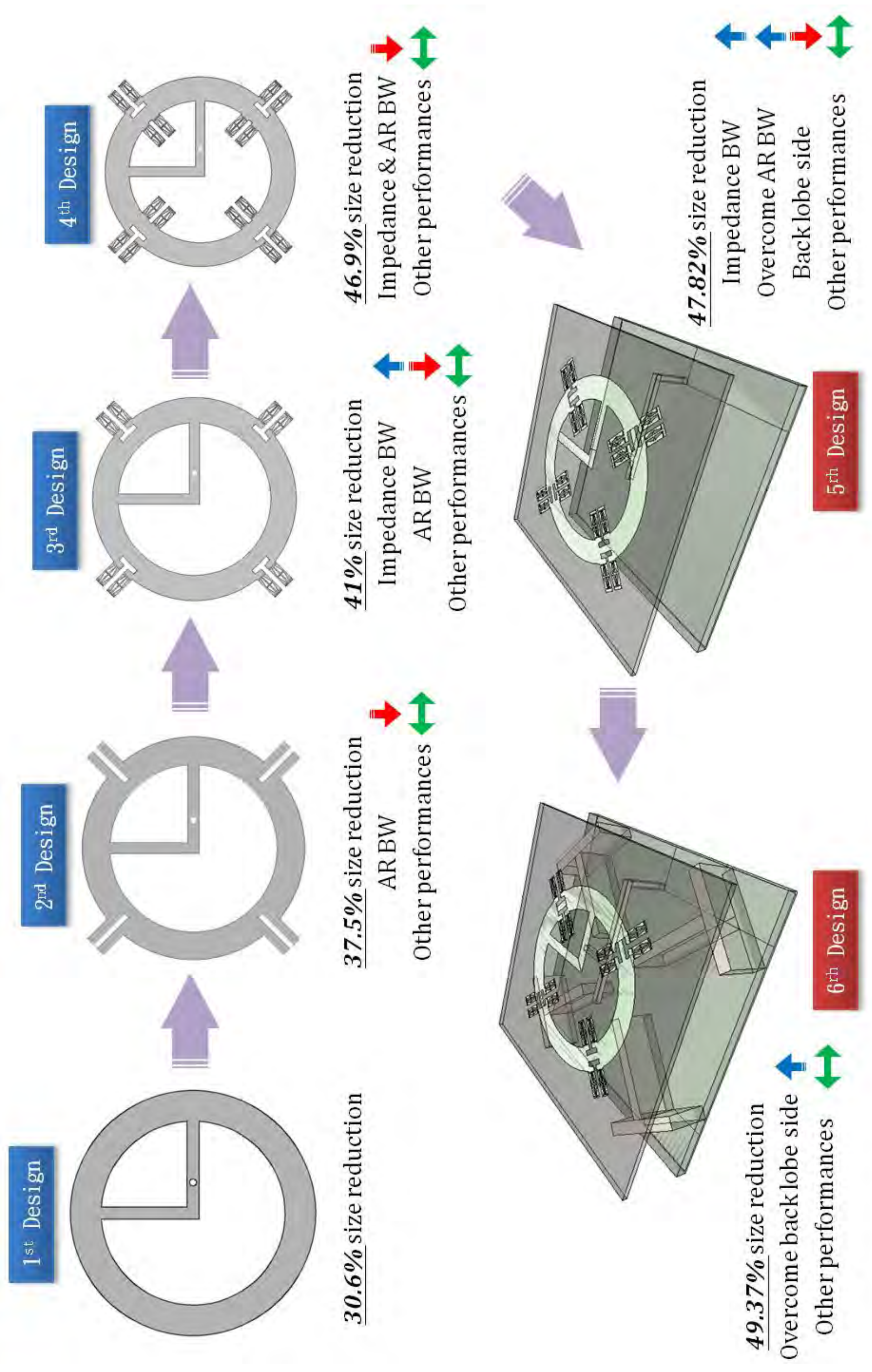
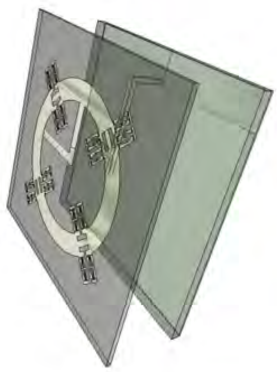
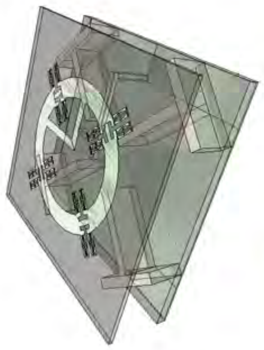
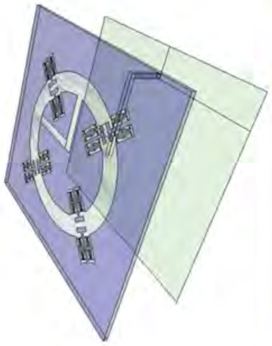
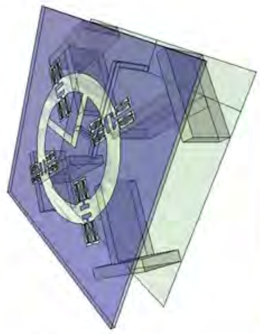


Fig.6.3 (a) Summary of all antennas with size reduction and enhancement









	5th Design	6th Design	5th Design (simple metal GND)	6th Design (simple metal GND)
Impedance BW	2.422-2.741 GHz	2.398-2.818 GHz	2.438-2.751 GHz	2.482-2.762 GHz
% of Imped. BW	12.4%	16.11%	12.06%	10.68%
AR BW	2.565-2.631GHz	2.558-2.642 GHz	2.574-2.634GHz	2.570-2.637 GHz
% of AR BW	2.53%	3.21%	2.32%	2.54%
Gain	6.65dBi	6.61dBi	6.04dBi	6.64dBi
3dB Beamwidth	83.65 at phi=0 86.05 at phi=90	94.7 at phi=0 96.4 at phi=90	79.1 at phi=0 72.86 at phi=90	99.6 at phi=0 100.71 at phi=90
Radius	15.3mm	14.4mm	15.8mm	13.8mm
Size Reduction	46.9%	50%	45.22%	52.16%

Studied by Simulation

Table.6.3 (a) All antennas 5th and 6th with using dielectric GND and simple metal GND

Chapter 6
Enhancement

Where design 5 and 6 are changed to use simple metal ground for validating a metallic wall, and less performance is presented.

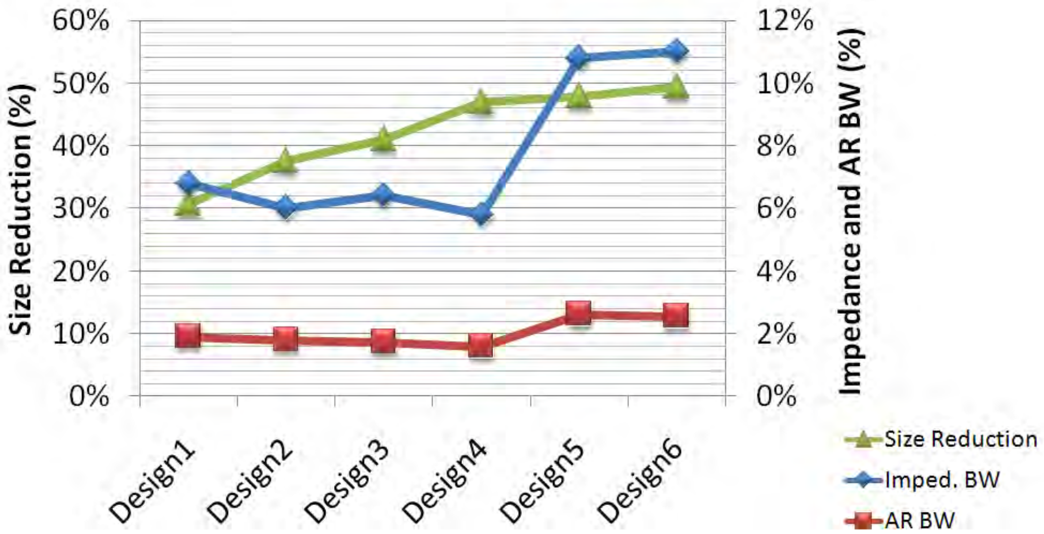


Fig.6.3 (b) Chart of all antennas with size reduction and enhancement

6.4 Capability of development

Next, this antenna has a large capacity for development, For example, use double patch to have extreme BW improvement and use vertical patch to have extreme size reduction. There are good examples for further development.

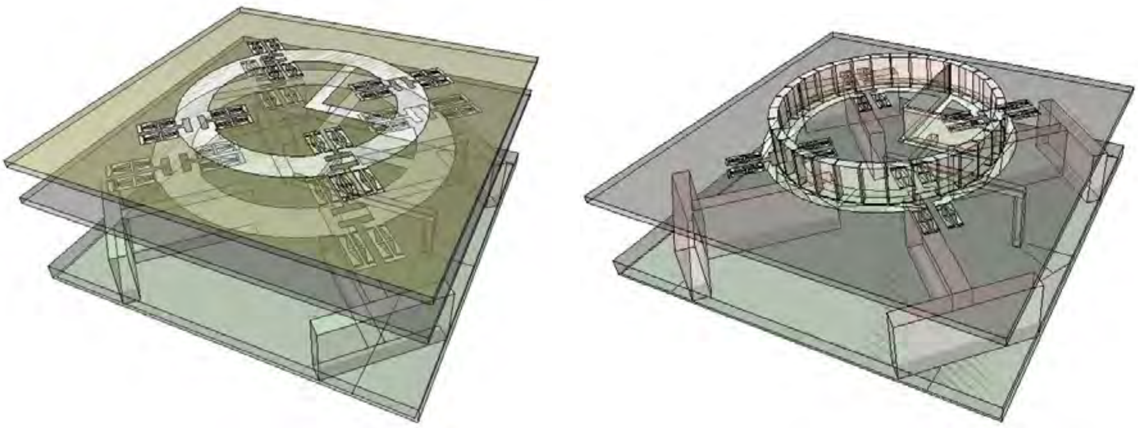


Fig.6.4 (a) Example of development capability

6.5 References

[1] Yong-Xin Guo, Chi-Lun Mak, Kwai-Man Luk, *"Analysis and Design of L-Probe Proximity Fed-Patch Antennas",* IEEE Trans. Antennas Propagation, vol. 49, no. 2, February 2001

[2] K. M. Luk, Y. X. Guo, K. F. Lee and Y. L. Chow, *"L-probe Proximity Fed U-slot Patch Antenna"*, Electronic Letters, vol. 34, no. 19, pp. 1806-1807, September 1998.

[3] Y.-X. Guo, K.-M. Luk, and K.-F. Lee, *"L-probe proximity-fed annular ring microstrip antennas",* IEEE Trans. Antennas and Propagat., vol. 49, no. 1, pp. 19–21, Jan. 2001.

[4] Lam Siu and Kwai-Man Luk," Unidirectional Antenna With Loaded Dielectric Substrate", IEEE Antennas and wireless propagation letters, no. 7, 2008

Chapter 7

Conclusion

7.1 Achievement Summary

In this project, I start from the fundamental design to advanced design. It is a good practical training for me to be a professional engineer. Not only learnt a technical skill, but also learnt some project management skill such as project planning and flow. Actually, I improve my antenna knowledge which I got from EE4036- wireless communication-antenna part. Implementing antenna products consists of many problems, which I need to tide over. In addition, it also trains up my problem solving skill and data analysis skill.

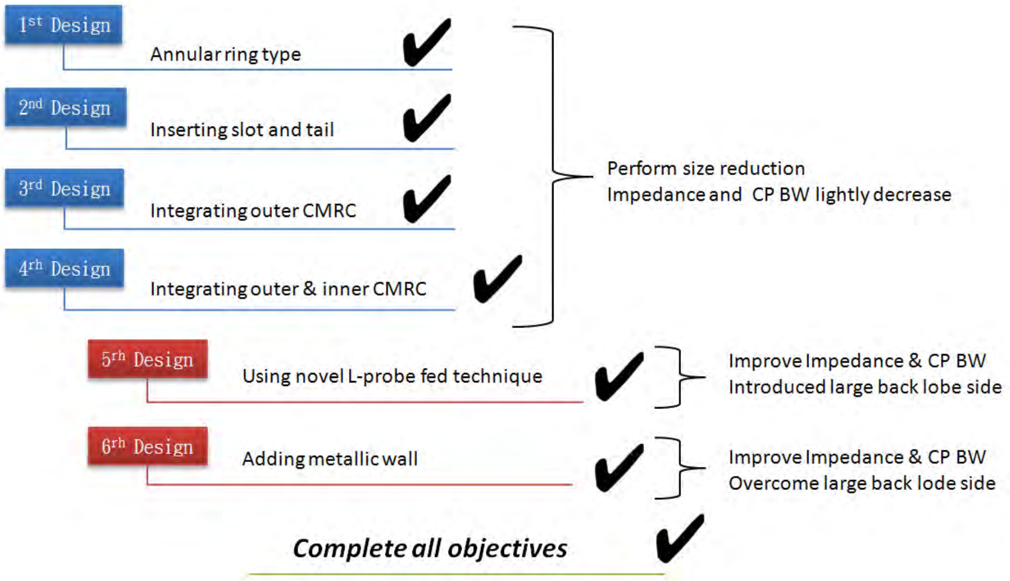


Fig.7.1 (a) Summary of all achievements

From above figure, summary of all achievements is shown. The first to fourth design perform size reduction and fifth to sixth design perform enhancement. And I have completed all objectives of this project.

7.2 Conclusion and discussion of all proposed antennas

This project report is dedicated to the design of circularly-polarized annular ring patched antennas with size reduction. In the modern times, size reduction is a major consideration in wireless communication. Annular-ring patch antennas have many advantages including light-weight, low profiles and smaller size compared to other patch antennas. However, they have narrow impedance bandwidth, typically 1~3%. Further size reduction in annular ring patch antennas is challenged and superior difficulty. Mostly used method for size reduction is to use expensive and high dielectric constant material. In order to maintain the production cost, the new technique for size reduction is proposed instead of changing the topology of antennas.

Firstly, the first annular ring type with circularly-polarized is proposed. The diameter of this ring is 40mm and ground size is 65x65mm. Measured impedance (S11< -10dB) and AR (AR<3dB) bandwidth are 6.8% and 1.9% respectively. Size reduction compared to conventional half wave length antenna is 30.6%. All results and studies are presented in chapter 4. Then, the second design with inserting slot and tail is proposed. The diameter of this ring is 36mm with 54x54mm size of ground. Measured impedance and AR bandwidth are 6% and 1.8% respectively. 37.5% size reduction is achieved. Then, with integrating outer CMRC, the third proposed antenna is constructed and depicted. The diameter of the ring is slightly reduced to 34mm and the ground is 51mm. Although it achieves 41% size reduction, impedance and AR bandwidth are slightly decreased. The fourth proposed antenna with integrating outer and inner CMRC is carrier out. Measured impedance and AR bandwidth are 5.8% and

1.58% respectively. It has almost 47% size reduction but both impedance and AR bandwidth are substantially decreased. All performance of second to fourth proposed antenna are performed and described in chapter 5.

Although both bandwidth of above design is functional and good enough for satellite application, the enhancement is need for good precision and stability. Fifth proposed and sixth (last) proposed antenna are shown in chapter 6. The fifth proposed antenna with novel L-probe-fed has been presented and experimentally studied. The diameter of the ring is reduced to 15.3mm and the ground is 45mm. Although it can increase the bandwidth of the antenna, it induces little large undesired back lode side because the thickness is increased for L-probe and the ground size ought to increase also but it remains unchanged. So the sixth (last) proposed antenna is carried out. The underside back lode side is overcome and confirmed by IE3D. But the fabrication is difficult. Most of both measured and simulated results of all proposed antennas meet requirement and in good agreement. By adjusting the parameters of all proposed antennas, the proper performance can be obtained.

All in all, six proposed antennas presented in this report. Most design can be used as small antennas for satellite application. And they are easy to fit in satellite hand-held devices. Moreover, the manufacturing cost of six proposed antennas is relatively low. For a large capability development, further size reduction and bandwidth enhancement is challenged.

Glossary

AR	**Axial Ratio**
ARPA	**Annular ring patch antenna**
AUT	**Antenna under Test**
BW	**Bandwidth**
CMRC	**Compact microstrip resonant cell**
CP	**Circularly-polarization**
GPS	**Global positioning system**
LHCP	**Left hand circularly-polarization**
LP	**Linear-polarization**
RHCP	**Right hand circularly-polarization**
RL	**Return loss**
VSWR	**Voltage standing wave ratio**