إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

تحسين النطاق الترددي الهوائي عبر التغذية الغير مباشرة بواسطة المسبار

Antenna Bandwidth Improvement By Using Indirect Coaxial Probe Feeding Method

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Antenna Bandwidth Improvement by Using Indirect Coaxial Probe Feeding Method

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A Thesis Submitted in Partial Fulfillment of Requirements for the Degree of Master in Electrical Engineering-Communication Systems.

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ مهند باسم حمدان قريقع لنيل درجة الماجستير في كلية *الهندسة* قسم الهندسة الكهربائية – أنظمة الاتصالات وموضوعها:

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وبعد المناقشة التي تمت اليوم الأحد 17 شوال 1436هـ، الموافق 2015/08/02م الساعة الحادية عشرة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية *الهندسة*/ قسم الهندسة الكهربائية – أنظمة الاتصالات.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

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الملخص

تستخدم هوائيات مغير التصحيح بكثرة لما لها من مزايا عديدة، مثل أنها خفيفة الوزن. ومع ذلك فان لها بعض العيوب حيث ان لها عرض نطاق ترددي ضيق. مما جعل الباحثين لبذل كثير من الجهد للتغلب على هذه المشكلة، من خلال تقديم الكثير من التكوينات لتوسيع عرض النطاق.

في الفترات السابقة قد تم بالفعل تطوير تقنيات معينة لتعزيز عرض النطاق الترددي من هوائيات مغير التصحيح ومثال على ذلك parasitic patch, U-slot patch, L-probe coupling .

الهدف من هذا البحث هو تحسين خسارة العودة (return loss) من خلال تغذية الهوائي باساليب مختلفة. وسوف يتم اختبار مجموعة من الهوائيات المختلفة مثل هوائي مغير التصحيح و الهوائي ذو المستوى المقلوب (PIFA). سوف يتم اختبار الهوائيات في حالتين: الاولى باعتبار ان الهوائي ومصدر التغذية ككتلة واحدة، اما الاختبار الثاني سوف يتم التعامل مع كل من الهوائي ومصدر التغذية كجزئين منفصلين.

التغذية الغير المباشرة للهوائي تعمل علي تحسين النطاق الترددي و تعمل علي زيادة مكاسب مقاومه مدخلات الرنين عن طريق مزامنه المكثف و الهوائي .

Abstract

Microstrip patch antennas are widely used because of their many advantages, such as the low profile, light weight, and conformity. However, patch antennas have a main disadvantage which is the narrow bandwidth. Researchers have made many efforts to overcome this problem and many configurations have been presented to broaden the bandwidth.

Certain techniques for enhancing the bandwidth of microstrip antennas have already been developed, e.g., parasitic patch either in stacked or coplanar geometries, U-slot patch, L-probe coupling, aperture coupling and increasing the thickness of the antenna.

The goal of this research is to improve the return loss bandwidth by using different feeding techniques. This technique will be tested for various planner antenna types such as microstrip antenna and Planar Inverted F Antenna (PIFA). The research will consider the antenna and its feeder in two modes. The first one will consider them as the one part and the second will separate them in treatment.

Indirect Probe Feeding gains large band of impedance resonance obtained by adjusting the capacitance and the inductance of feeder part.

Dedication

Dedicated to my soul brothers, Dr. Monther (Abu-Basem), Moatz (Abu-Islam) and my soul nephew Islam, and to all my brother and sisters (Ezzedeen , Sultan , Mohammed , Mazin, Sheymaa, Shreen, Karem and Shams. Finally, to my parents (Abu-Monther, Om-Monther).

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I would like to start by thanking ALLAH, without his graciousness the completion of this work would not have been possible. Allah the Almighty has entrusted me with the abilities and provided me with the courage to complete a long journey.

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Finally, I must express my sincere gratitude to my wife, Madlen. She knows more than anyone else about the sacrifices that had to be made. I would like to thank her for her love, encouragement, patience and understanding throughout all of my studies. It is much appreciated.

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Abbreviation

PIFA	Planar Inverted F Antenna
MMICs	Monolithic Microwave Integrated Circuits
WLAN	Wireless Local Networks
IPF	Indirect Probe Feeding
VSWR	Voltage Standing Wave Ratio
ESA	Electrically Small Antenna
PCSA	Physically Constrained Small Antenna
FSA	Functionally Small Antenna
PSA	Physically Small Antenna
NFC	Near Field Communication systems
RFID	Radio Frequency Identification
UWB	Ultra-Wide Band
WLAN	Wireless Local Area Networks
WiMAX	Worldwide Interoperability for Microwave Access
FEM	Finite Element Method
PDE	partial differential equation
MSP	microstrip patch antenna
LHM	Left-handed meta-material

Chapter 1 Introduction

1.1 Introduction

Communication can be broadly defined as the transfer of information from one point to another [1]. Communication between human beings was first done through voice. With the desire to increase the distance of communication, devices such as Drums, signal flags and smoke were used. These optical communication devices of course utilized the light part of the electromagnetic spectrum. It has been of recent in human history that the electromagnetic spectrum, outside the visible region has been employed for communication, through the use of Radio. One of the greatest human scientific evolutions is the emergence of electromagnetic spectrum and antenna has been instrumental in harnessing the resource [2].

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space [3]. Another explanation says that an antenna can be defined usually metallic device, which radiates and receives electromagnetic waves more specifically, radio waves. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band [4].

There are several types of antennas were developed since the past times due nowadays. Such as wire antennas; aperture antennas; microstrip antennas; Array Antennas; reflector antennas; and lens antennas [4].

1.2 Theoretical background

A Microstrip Antenna in its simplest form consists of a radiating patch on one side of dielectric substrate and ground plane on other side. Microstrip Patch Antennas are popular for their well-known attractive feature, such as a low profile, lightweight, and compatibility with Monolithic Microwave Integrated Circuits (MMICs). Modern Communication System, Such as those for satellite links (GPS, Vehicular, etc.), as well as emerging applications, such as Wireless Local Networks (WLAN), offer require antennas with compactness and low-cost, thus rendering planar technology useful, and sometimes unavoidable. Conventional microstrip patch antennas has some drawbacks of low efficiency, narrow bandwidth (3-6) % [5, 6]. Different feed configurations, including aperture coupled, microstrip line feed and coaxial feed can be used as shown in Figure1.1.

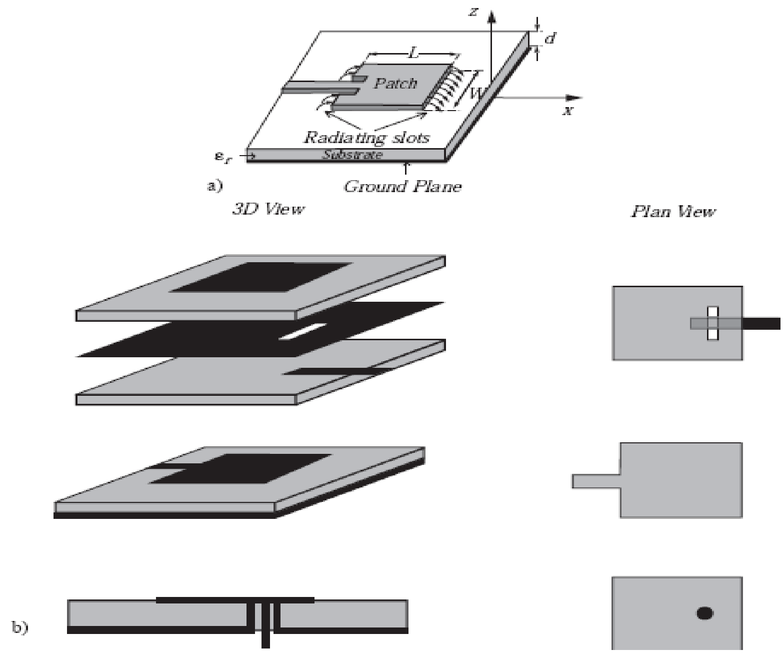


Figure 1. 1: Microstrip antennas and their feeds (a) a microstrip antenna with its coordinates, (b) three feeding configuration: coupling feed, microstrip feed and coaxial feed [7]

Planar inverted-F antennas (PIFAs):

PIFAs have received much attention because their size makes them suitable for integration into portable communication devices. For instance, Ogawa et al. designed a PIFA suitable for shoulder mounting, [8] Virga and Rahmat-Samii [9] included a PIFA on a handset, and Ng et al. developed a PIFA for inclusion on a laptop computer chassis [10].

A PIFA consists of a top plate element, a ground plane, a feed wire attached to the top element through a hole in the ground plane, and a shorting wire or strip that is directly connected between the top element and the ground plane. Related to the linear inverted-F antenna and the short-circuited microstrip antenna, [11] a typical design is shown in figure 1.2. The design of the antenna involves selection of the top plate width, length, and height above the ground plane as well as the location and width of the feed wire and the shorting strip. For PIFA antennas on an infinite ground plane, the resonant frequency varies with the width of the shorting strip and the dimensional ratio of the top element [3].

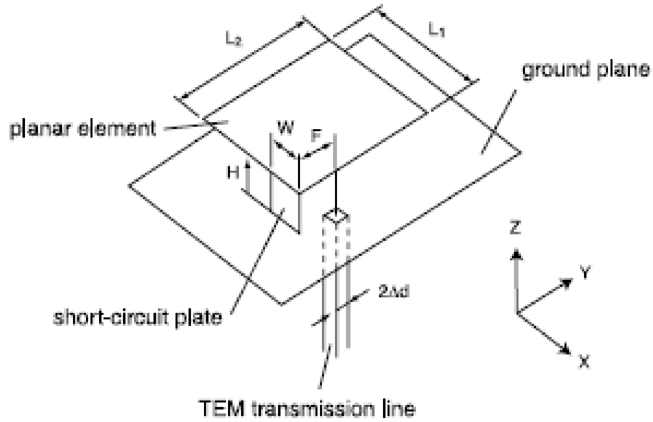


Figure 1. 2: Structure of the planar inverted-F antenna.

Rectangular and circular patches are most common, but any shape that possesses a reasonably well-defined resonant mode can be used [1]. These include, for example, annular rings, ellipses and triangles. The patch is a resonant element and therefore one of its dimensions must be approximately one half of the guided wavelength in the presence of the dielectric substrate. There are four fundamental techniques to feed or excite the patch. These are presented in chapter 3 and include the microstrip-line feed, the probe feed, the aperture-coupled feed and the proximity-coupled feed. The main drawback associated with microstrip patch antennas in general is that they inherently have a very narrow impedance bandwidth (due to their multilayered configuration, aperture-coupled feeds and proximity-coupled feeds tend to have a slightly wider bandwidth than probe feeds and microstrip-line feeds). In most cases, the impedance bandwidth is not wide enough to handle the requirements of modern wireless communications systems [2]. The narrow impedance bandwidth of microstrip patch antennas can be referred to the thin substrates that are normally used to separate the patch and the ground plane. The general performance trends of a microstrip patch antenna are illustrated in Figure 1.3. Here, Figure 1.3(a) shows the typical trend for impedance bandwidth versus substrate thickness, as a function of the substrate's dielectric constant, while Figure 1.3(b) shows the typical trend for surface-wave efficiency versus substrate thickness, also as a function of the substrate's dielectric constant. From these it can be seen that, in order to increase the bandwidth, the substrate thickness has to be increased, while the dielectric constant has to be kept as low as possible. A low dielectric constant is also required to keep surface-wave losses as low as possible. Therefore, in order to obtain a wideband microstrip patch antenna with good surface-wave efficiency, the performance trends of Figure 1.3 point to a thick substrate with a very low dielectric constant.

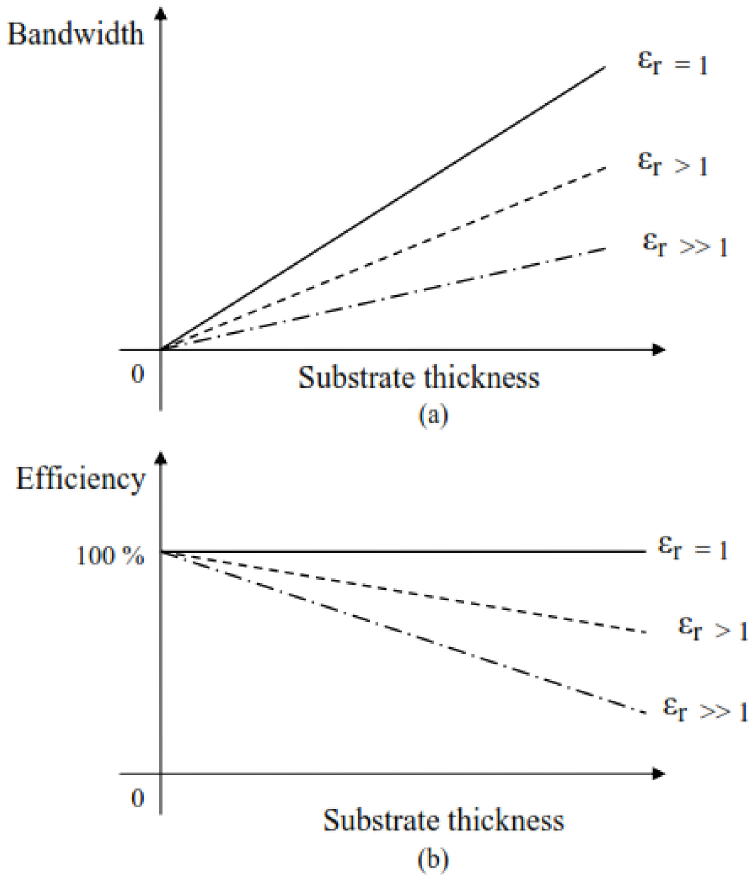


Figure 1. 3: Illustrative performance trends of a microstrip patch antenna. (a) Impedance bandwidth. (b) surface-wave efficiency.

1.3 Problem Statement

Practically bandwidth of Microstrip Patch Antenna is narrow but today wireless communication systems require higher operating bandwidth. Such as about 7.6% for a global system for mobile communication (GSM; 890-960 MHz), 9.5% for a digital communication system (DCS; 1710-1880 MHz), 5% for a personal communication system (PCS; 1850–1990MHz) and 12.2% for a universal mobile telecommunication system (UMTS;1920-2170 MHz) [12].

Narrow bandwidth available from printed microstrip patches has been recognized as one of the most significant factors limiting the widespread applications of this class of antennas.

Various techniques used to increase the bandwidth of microstrip patch antenna maybe classified as follows:

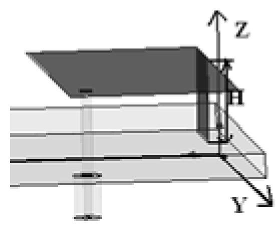
1- Decreasing the Q-factor of the patch by increasing the substrate height and lowering the dielectric constant.

2- Use the multiple resonators located in one plane.
3- Use the multilayer configurations with multiple resonators stacked vertically.
4- Use impedance matching networks.

One of these techniques is the indirect probe feeding. Indirect Probe Feeding gains large band of impedance resonant obtained by adjusting the capacitance and the inductance of feeder part.

The feeder part can be considered as small loaded dipole antenna.

- The ordinary feeder



- The proposed feeder

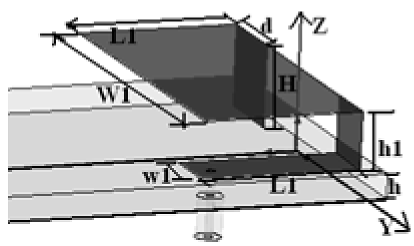


Figure 1. 4: probe feed (a) direct (b) indirect.

1.4 Literature Review

The inherently narrow impedance bandwidth is the major weakness of a microstrip antenna. Techniques for bandwidth enhancement have been intensively studied in past decades. Several methods including the utilization of parasitic patches [14] and thick substrates [15] have been suggested in the literature.

Certain techniques for enhancing the bandwidth of planar antennas have already been developed, e.g., parasitic patch either in stacked or coplanar geometries, U-slot patch [16], L-probe coupling [17], aperture coupling and increasing the thickness of the antenna. In this research, a novel simple alternative for enhancing the impedance bandwidth of a conventional quarter-wave patch antenna is proposed.

Methodology

Different method and technique related to enhance the bandwidth of microstrip antenna. This research was divided into different phases which:

1. Design basic microstrip antenna.
2. Redesign the microstrip antenna using IPF to enhance the bandwidth.
3. Design new shape of microstrip antenna with IPF technique to get new result.
4. Examine different attempt to find the mathematical and physical explanations techniques of IPF.
5. Simulation and Testing of the results.

Researches on this type of science should be performed using electromagnetic modeling and simulation programs, so I will apply my work using HFSS simulation program.

1.5 References

[1] K.T Ahmed, M. B Hossain and M.J Hossain, "Designing a high bandwidth patch Antenna comparison with the former patch Antenna," Canadian journal on multimedia and wireless network, Vol.2, No. 2 April,2011.

[2] S.K Behera, "Novel Tuned Rectangular Patch Antenna as a load for phase power combining," Ph.D Thesis, Jadavpur University, Kolkata, India.

[3] J. D. Kraus, "Basic Antenna Concepts," in Antennas, pp. 17 – 82, 2nd ed., NewYork: McGraw-Hill, 1988.

[4] C. A. Balanis, "Antennas," in Antenna theory : analysis and design, pp. 1 – 10, 3rded., New York: Wiley, 2005.

[5] R.G.Voughan."Two-port higher mode circular microstrip antennas. IEEE,Trrans.Antenna Propagation,".36(3):309-321, 1988.

[6] A.K.Bhattacharjee, S.R.Bhadra, D.R.Pooddar,"Equivalence of Impedance and radiation properties of square and circular microstrip patches antennas". IEEProc.1365(Pt,H,no.4):338-342.

[7] Y. Huang and K. Boyle, Antennas: From Theory to Practice,1st ed., John Wiley & Sons, 2008.

[8] Ogawa, K., Uwano, T., and Takahashi, M. "A shoulder-mounted planar antenna for mobile radio applications," IEEE Trans. Veh. Technol., vol. 49, No. 3, May 2000, pp. 1041–1044.

[9] Virga, K. L. and Rahmat-Samii, Y. "Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging," IEEE Trans. Microwave Theory Tech., vol. 45, No. 10, Oct. 1997, pp. 1879–1888

[10] Ng, A. K. P. Lau, J., and Murch, R. D. "2.4 GHz ISM band antenna for PC cards," IEEE Antennas and Propagation Society International Symposium. 1999 Digest. vol.3, 1999, pp. 2066–2069

[11] Sanford, G. and Klein, L. "Increasing the beamwidth of a microstrip radiating element," IEEE AP-S Int. Symp. Digest, June 1979, pp. 126–129.

[12] Kin-Lu Wong; Yi-Fang Lin, "Microstrip-line-fed compact microstrip antenna with broadband operation," Antennas and Propagation Society International Symposium, 1998. IEEE , vol.2, no., pp.1120,1123 vol.2, 21-26 June 1998.

[13] Pozar, D. M., Schaubert, D, H., “Microstrip Antennas: The Design and Analysis of Microstrip Antennas”, IEEE Press, New York, 1995.

[14] R. Q. Lee, K. F. Lee, and J. Bobinchak, “Characteristics of a two-layer electromagnetically coupled rectangular patch antenna,” Electron. Lett., vol. 23, pp. 1070–1072, 1987.

[15] E. Chang, S. A. Long, and W. F. Richards, “Experimental investigation of electrically thick rectangular microstrip antennas,” IEEE Trans. Antennas Propagat., vol. AP-43, pp. 767–772, 1986.

[16] T. Huynh and K. F. Lee, “Single-layer single-patch wideband microstrip antenna,” Electron. Lett., vol. 31, pp. 1310–1312, Aug. 1995.

[17] Y. X. Guo, K. M. Luk, and K. F. Lee, “U-slot circular patch antennas with L-probe feeding,” Electron. Lett., vol. 35, pp. 1694–1695, Sept. 1999.

[18] Ansoft Corporation, “user’s guide – High Frequency Structure Simulator,” 225 West Station Square Dr. Suite 200, Pittsburgh, PA 15219-1119, 2005.

Chapter 2 Antenna Theory & Concepts

Antennas exist in different forms; here is a list of the different types of antennas classified so that each group possesses a number of features that are specific to it:

1- Wire antennas: include monopoles, dipoles, Yagi-Uda arrays,
2- Aperture antennas: include Horn antennas…
3- Reflector antennas: parabolic reflector antenna, dish antennas …
4- Microstrip antennas: include patch antennas …
5- Array antennas; linear, planar and circular.

2.1 Antenna Types

Antennas come in different shapes and sizes to suit different types of wireless applications. The characteristics of an antenna are very much determined by its shape, size and the type of material that it is made of. Some of the commonly used antennas are briefly described below.

2.1.1 Wire antennas

Wire antennas are the oldest and still the most prevalent of all antenna forms. They can be made from either solid or tubular conductors. A wire is defined as a conductor (e.g., a piece of metal) whose length is much greater than its diameter. Thus, an antenna is a wire antenna if it is composed primarily of one or more wires.

The wires do not have to be connected. Unconnected elements are called parasitic, and act as passive antennas that receive radiation from the surrounding connected elements and re-radiate them in different directions [1]. Such parasitic can produce excellent results, as the Yagi-Uda antennas.

To compute the electromagnetic properties of wire antennas accurately, it is necessary to solve Maxwell's equations subject to boundary conditions imposed by the wires and their surrounding environment. This approach gives rise to an integral equation (integral equations) that is are complicated and for which approximate solutions have been reported for many years. However, modern numerical methods implemented on powerful digital computers led to sophisticated results and are applicable to many wire antenna configurations.

Array wire antennas are composed of many wires arranged in a way to produce a directional radiation pattern. These may have all the elements or parts of them driven (fed). An array of parallel wires where not all the elements are driven is called a YagiUda antenna [2]. This is going to be dealt with in what follows.

1. Yagi-Uda antenna

Yagi-Uda (or simply Yagi) antennas are very popular because of their simplicity and relatively high gain. They are widely used in the HF, VHF and UHF frequency ranges. The first research on the Yagi-Uda antennas was performed by Shintaro Uda at Tohoku University in Sendai, Japan, in 1926 and was published in Japanese in 1926 and 1927. The work of Uda was reviewed in an article written in English by Uda's professor, H.Yagi, in 1928. [7]

The basic unit of a Yagi antenna consists of three elements: a driven element or driver, a reflector and one or more directors. The driver is the element fed by the input signal. The reflector acts as a mirror to reflect radiation from the driver. The directors are those parasitic elements which receive the signal and direct it back in the same direction of reception [7]. Figure 2.1 illustrates a configuration of a general Yagi antenna.

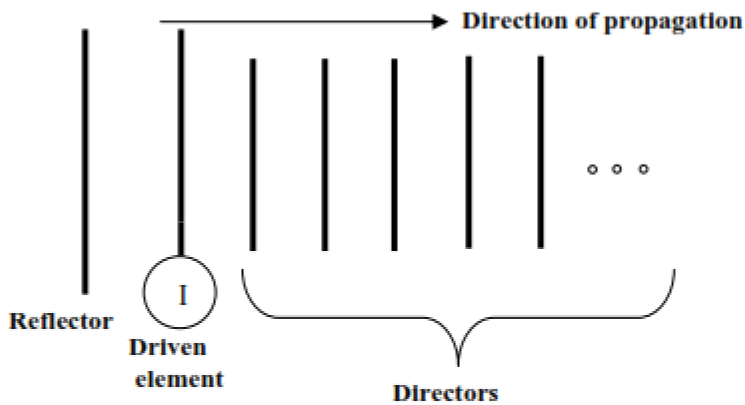


Figure 2. 1: A configuration for a general Yagi antenna

Yagi antennas are termed to be endfire traveling-wave antennas. The currents on the director elements farther out from the driver have decreasing current amplitudes. This causes a smaller gain increase for each director added to the end of the Yagi array. In fact, adding up to five directors provides a significant increase in gain. But further addition gives relatively little gain improvement [7].

The characteristics of the Yagi are affected by the geometric parameters of the array: the lengths of the elements, the spacing and the element diameter. The radiation pattern of a Yagi antenna is shown in figure 2.2.

To sum up, the Yagi antenna has the following general features [9]

- High gain
- Low weight
- Low cost
- Relatively narrow bandwidth.

Although the last property is a drawback for the Yagi, this property is not of great significance, it is the gain that is more important in any Yagi antenna design. On the other hand, if a folded dipole is used as a driver, the electrical performance of the antenna will remain stable over a wider bandwidth. This is besides increasing the input impedance of the driver [7].

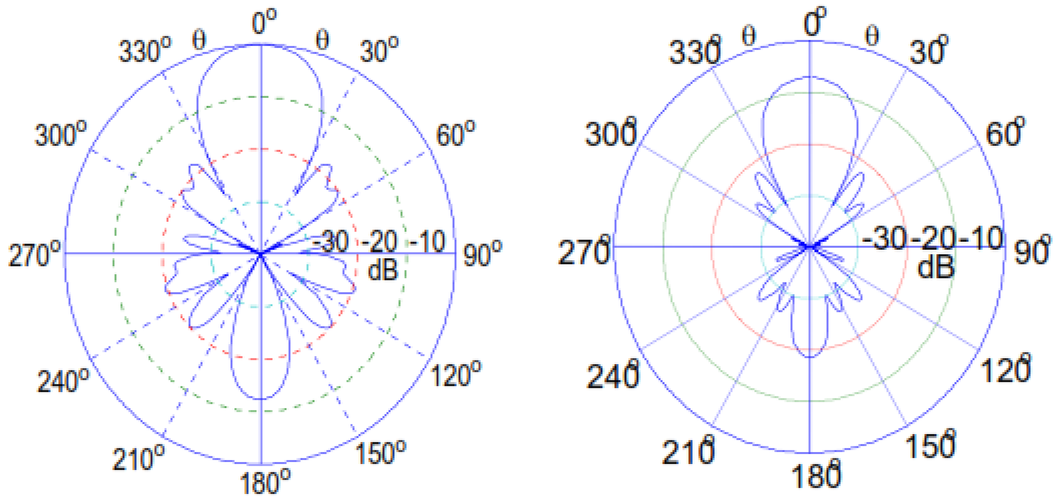


Figure 2. 2: A typical radiation pattern of a Yagi antenna (13 elements. Right: E-Plane. Left: H-plane).

The second type of antennas that is of great importance is the group of linear and planar array antennas. These are widely used in modern wireless communications and radar systems.

2. Half Wave Dipole

The length of this antenna is equal to half of its wavelength as the name itself suggests. Dipoles can be shorter or longer than half the wavelength [6], but a tradeoff exists in the performance and hence the half wavelength dipole is widely used.

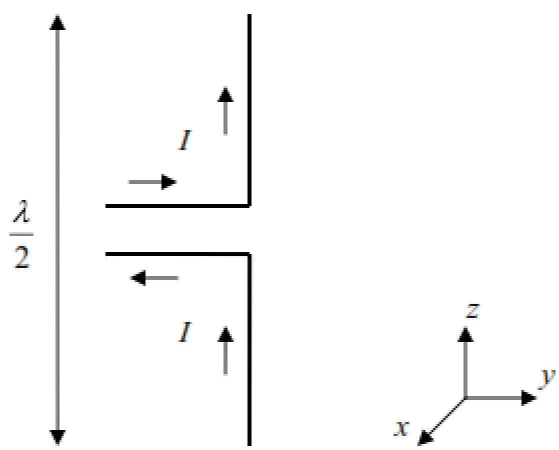


Figure 2. 3: Half Wave Dipole.

The dipole antenna is fed by a two wire transmission line, where the two currents in the conductors are of sinusoidal distribution and equal in amplitude, but opposite in direction. Hence, due to canceling effects, no radiation occurs from the transmission line. As shown in figure 2.3, the currents in the arms of the dipole are in the same direction and they produce radiation in the horizontal direction. Thus, for a vertical orientation, the dipole radiates in the horizontal direction. The typical gain of the dipole is 2dB and it has a bandwidth of about 10%. The half power beamwidth is about 78 degrees in the E plane and its directivity is 1.64 (2.15dB) with a radiation resistance of 73Ω [4]. Figure 2.4 shows the radiation pattern for the half wave dipole.

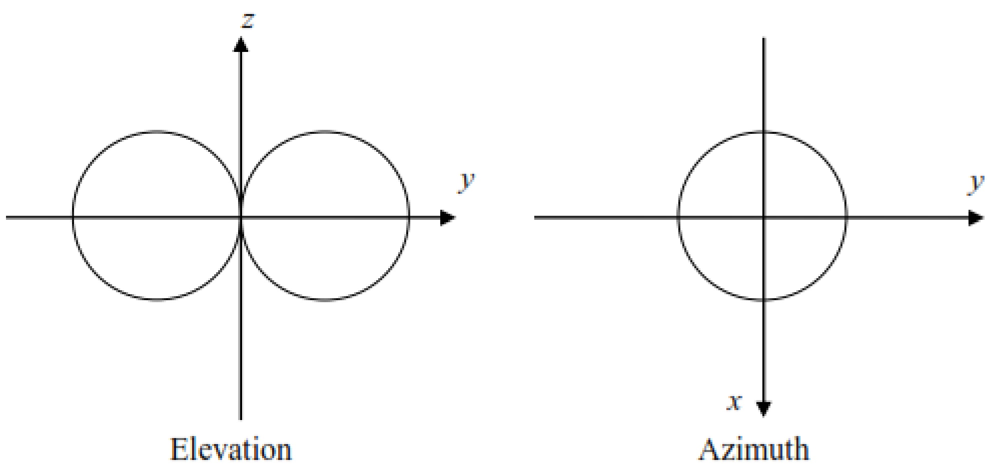


Figure 2. 4: Radiation pattern for Half wave dipole.

3. Monopole Antenna

The monopole antenna, shown in figure 2.5, results from applying the image theory to the dipole. According to this theory, if a conducting plane is placed below a single element of length 2/L carrying a current, then the combination of the element and its image acts identically to a dipole of length L except that the radiation occurs only in the space above the plane.

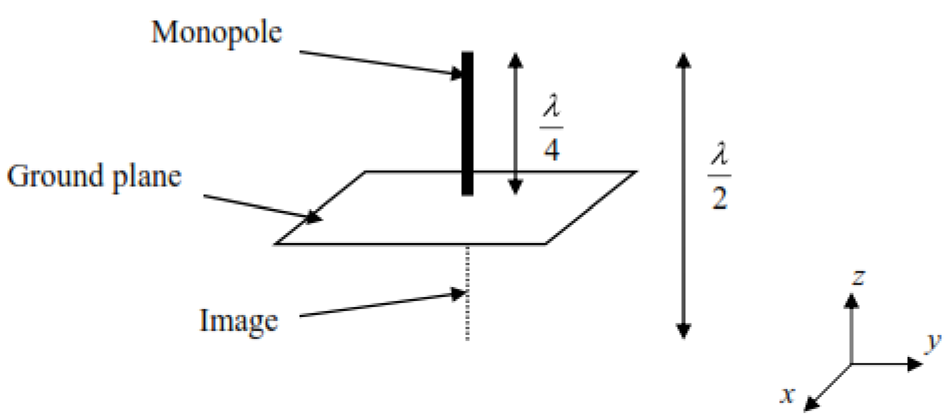


Figure 2. 5: Monopole Antenna

For this type of antenna, the directivity is doubled and the radiation resistance is halved when compared to the dipole. Thus, a half wave dipole can be approximated by a quarter wave monopole (L/2= λ/4).The monopole is very useful in mobile antennas where the conducting plane can be the car body or the handset case. The typical gain for the quarter wavelength monopole is 2-6dB and it has a bandwidth of about 10%. Its radiation resistance is 36.5 Ω and its directivity is 3.28 (5.16dB) [5]. The radiation pattern for the monopole is shown below in figure 2.6.

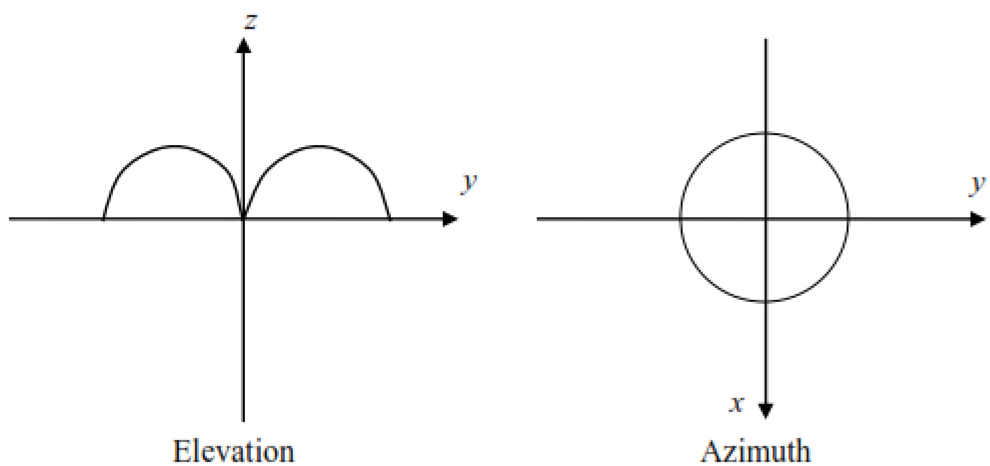


Figure 2. 6: Radiation pattern for the Monopole Antenna.

4. **Loop Antennas**

The loop antenna is a conductor bent into the shape of a closed curve such as a circle or a square with a gap in the conductor to form the terminals as shown in figure 2.7. There are two types of loop antennas-electrically small loop antennas and electrically large loop antennas. If the total loop circumference is very small as compared to the wavelength (*L*<<<< λ), then the loop antenna is said to be electrically small. An electrically large loop antenna typically has its circumference close to a wavelength. The far-field radiation patterns of the small loop antenna are insensitive to shape [5].

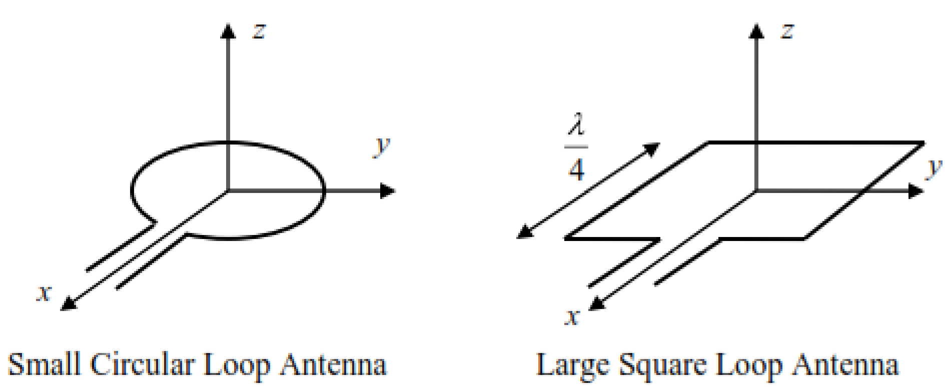


Figure 2. 7: Loop Antenna.

As shown in figure 2.8, the radiation patterns are identical to that of a dipole despite the fact that the dipole is vertically polarized whereas the small circular loop is horizontally polarized.

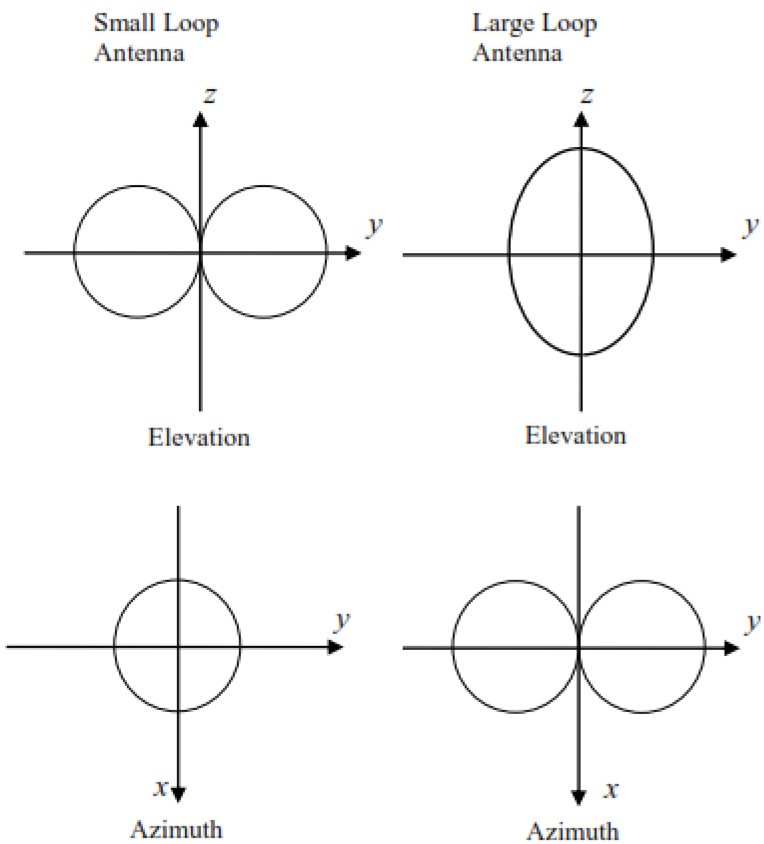


Figure 2. 8: Radiation Pattern of Small and Large Loop Antenna.

The performance of the loop antenna can be increased by filling the core with ferrite. This helps in increasing the radiation resistance. When the perimeter or circumference of the loop antenna is close to a wavelength, then the antenna is said to be a large loop antenna.

The radiation pattern of the large loop antenna is different than that of the small loop antenna. For a one wavelength square loop antenna, radiation is maximum normal to the plane of the loop (along the z axis). In the plane of the loop, there is a null in the direction parallel to the side containing the feed (along the x axis), and there is a lobe in a direction perpendicular to the side containing the feed (along the y axis). Loop antennas generally have a gain from -2dB to 3dB and a bandwidth of around 10%. The small loop antenna is very popular as a receiving antenna [2]. Single turn loop antennas are used in pagers and multiturn loop antennas are used in AM broadcast receivers.

5. **Helical Antennas**

A helical antenna or helix is one in which a conductor connected to a ground plane, is wound into a helical shape. Figure 2.9 illustrates a helix antenna. The antenna can operate in a number of modes, however the two principal modes are the normal mode (broadside radiation) and the axial mode (endfire radiation). When the helix diameter is very small as compared to the wavelength, then the antenna operates in the normal mode [8]. However, when the circumference of the helix is of the order of a wavelength, then the helical antenna is said to be operating in the axial mode.

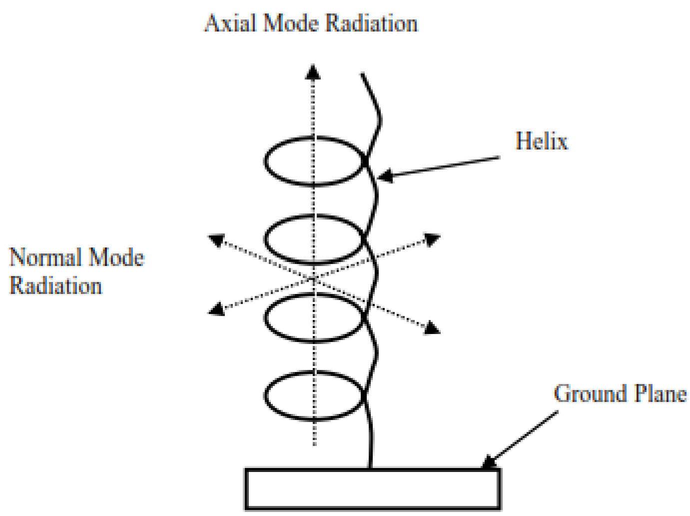


Figure 2. 9: Helix Antenna.

In the normal mode of operation, the antenna field is maximum in a plane normal to the helix axis and minimum along its axis. This mode provides low bandwidth and is generally used for hand-portable mobile applications [8].

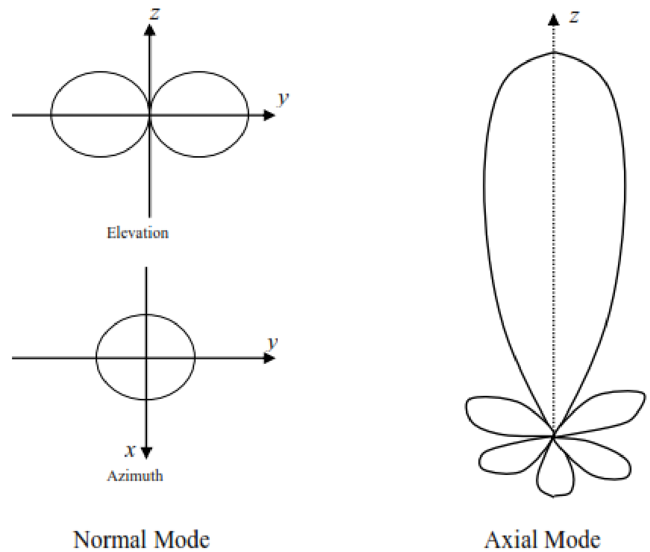


Figure 2. 10: Radiation Pattern of Helix Antenna.

In the axial mode of operation, the antenna radiates as an endfire radiator with a single beam along the helix axis. This mode provides better gain (up to 15dB) [4], and high bandwidth ratio (1.78:1) as compared to the normal mode of operation. For this mode of operation, the beam becomes narrower as the number of turns on the helix is increased. Due to its broadband nature of operation, the antenna in the axial mode is used mainly for satellite communications. Figure 2.10 above shows the radiation patterns for the normal mode as well as the axial mode of operations.

2.1.2 Horn Antennas

Horn antennas are used typically in the microwave region (gigahertz range) where waveguides are the standard feed method, since horn antennas essentially consist of a waveguide whose end walls are flared outwards to form a megaphone like structure [1].

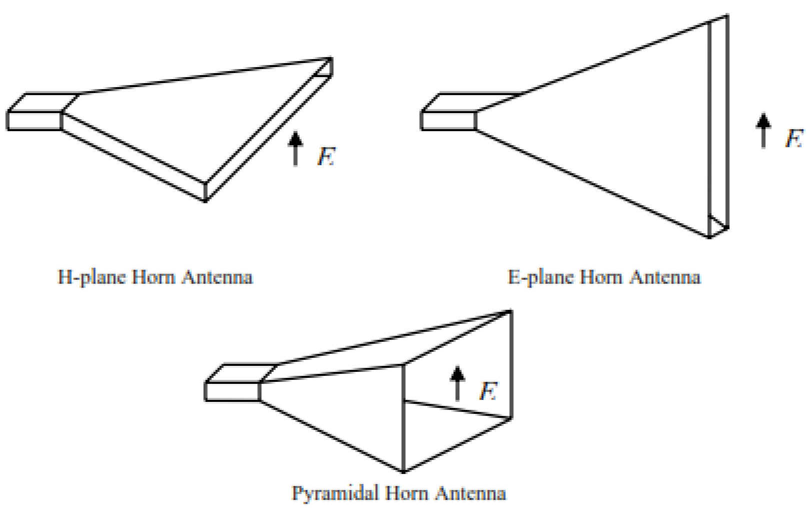


Figure 2. 11: Types of Horn Antenna.

Horns provide high gain, low Voltage Standing Wave Ratio (VSWR), relatively wide bandwidth, low weight, and are easy to construct [2]. The aperture of the horn can be rectangular, circular or elliptical. However, rectangular horns are widely used. The three basic types of horn antennas that utilize a rectangular geometry are shown in figure 2.11. These horns are fed by a rectangular waveguide which have a broad horizontal well as shown in the figure 2.11. For dominant waveguide mode excitation, the E-plane is vertical and H-plane horizontal. If the broad wall dimension of the horn is flared with the narrow wall of the waveguide being left as it is, then it is called an H-plane sectorial horn antenna as shown in the figure 2.11. If the flaring occurs only in the E-plane dimension, it is called an E-plane sectorial horn antenna. A pyramidal horn antenna is obtained when flaring occurs along both the dimensions. The horn basically acts as a transition from the waveguide mode to the free-space mode and this transition reduces the reflected waves and emphasizes the traveling waves which lead to low VSWR and wide bandwidth [2]. The horn is widely used as a feed element for large radio astronomy, satellite tracking, and communication dishes.

2.1.3 MICROSTRIP PATCH ANTENNA

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in figure 2.12. The patch is generally made of conducting material such as copper or gold and can take any possible shape [10]. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

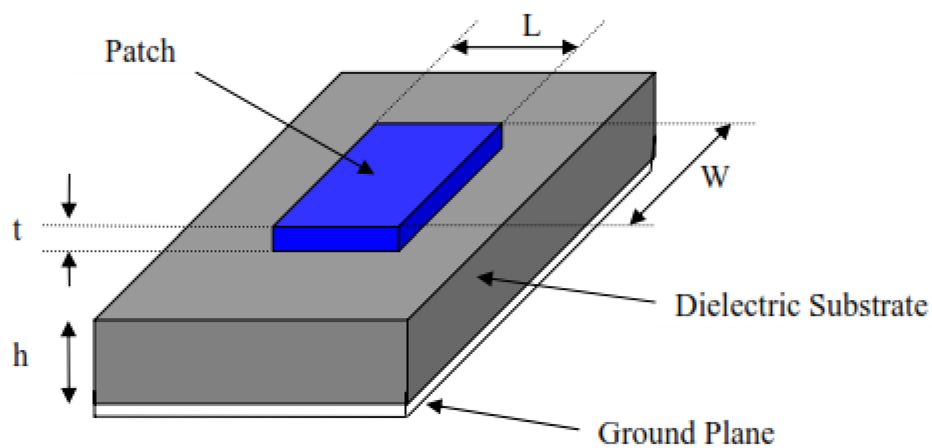


Figure 2. 12: Structure of a Microstrip Patch Antenna.

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in figure 2.13. For a rectangular patch, the length L of the patch is usually $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$, where λ_0 is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda_0$, where *t* is the patch thickness). The height *h* of the dielectric substrate is usually $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$ .The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

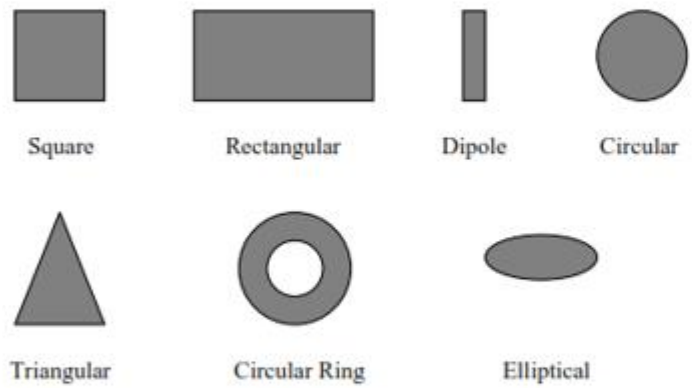


Figure 2. 13: Common shapes of microstrip patch elements.

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [11]. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth [13]. Hence a compromise must be reached between antenna dimensions and antenna performance.

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc... The telemetry and communication antennas on missiles need to be thin and conformal and are often Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication.

2.1.4 Array Antenna

In many applications, it is necessary to design antennas with very directive characteristics, beam scanning and/or steering capability to meet the demand of long distance communication. This can only be accomplished by increasing the electrical size of the antenna. However, achieving this can be done, without necessarily paying the price of large elemental antennas. Instead, we can just form an assembly of the radiating elements termed an array. In most cases the elements of an array are identical. However, this is not necessary but it is simpler and more practical [9].

The total field of an array is determined by the vector addition of the fields radiated by the elements. This assumes that the current in each element is the same as that of the isolated element. This is usually not the case and depends on the separation between the elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space [14]. In an array of identical elements, there are five controls that can be used to shape the overall pattern of the antenna. These are:

1- The geometrical configuration of the overall array (linear, circular, rectangular, spherical, etc…).
2- The relative displacement between the elements.
3- The excitation amplitude of the individual elements.
4- The excitation phase of the individuals elements.
5- The relative pattern of the individual elements.

Antenna arrays may be classified in many ways. The spatial distribution of the elements is a common classification: arrays may be linear, planar or volume. Other classification involve scanning method-phase scanned, time delay scanned, frequency scanned- or antenna structure, conformal or not.

An antenna array is a combination of antennas arranged in one, two or three dimensional planes that can provide the following advantages (Alexiou & Haardt 2004) over a single antenna:

- Increase the overall gain of the system;
- Determine the direction of arrival of desired and interfering signals;
- Cancel interference from particular directions by combining antenna array data;
- Steer array in a particular direction by electronically varying the antenna array radiation pattern (or simply array pattern);
- Maximize signal-to-interference-plus-noise ratio by performing advanced signal processing on the antenna array data.

Antenna arrays can be structured as linear, planar or circular arrays as shown in figure 2.14 to provide the above advantages. Linear arrays form a one dimensional pattern providing a single degree of freedom thus their pattern can be modified in either the elevation or azimuth plane. On the other hand, planar arrays provide array pattern control in both elevation and azimuth plane. Planar arrays are a combination of linear arrays in a two dimensional plane. Circular arrays are a special form of planar array [15].

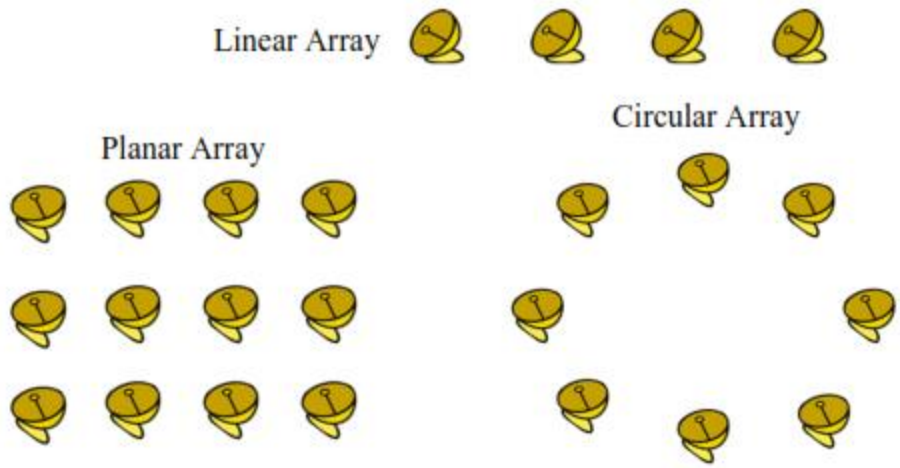


Figure 2. 14: Different types of antenna array structures.

There are several independent factors that can be controlled to modify the array pattern effectively that include:

- Type of array structure (linear or planar)
- Number of antennas (m=1,2,…M)
- Antenna array spacing (relative positioning between r)
- Individual antenna radiation pattern (isotropic or directional)

Sample radiation patterns for a linear array are shown in figure 2.15 .The array patterns are obtained by varying the number of antennas and antenna array spacing.

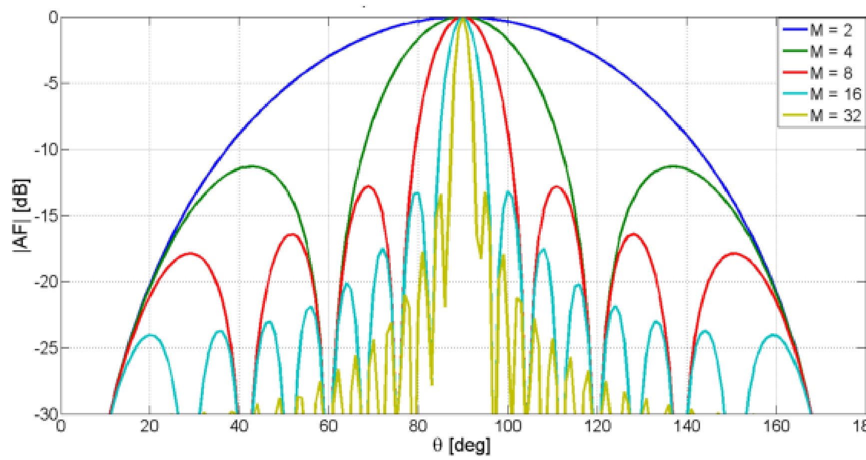


Figure 2. 15: Comparison of array pattern for different numbers of antenna array elements.

2.1.5 FRACTAL Antenna

In modern wireless communication systems wider bandwidth, multiband and low profile antennas are in great demand for both commercial and military applications. This has initiated antenna research in various directions; one of them is using fractal shaped antenna elements. Traditionally, each antenna operates at a single or dual frequency bands, where different antennas are needed for different applications. Fractal shaped antennas have already been proved to have some unique characteristics that are linked to the various geometry and properties of fractals. Fractals were first defined by Benoit Mandelbrot in 1975 as a way of classifying structures whose dimensions were not whole numbers. Fractal geometry has unique geometrical features occurring in nature. It can be used to describe the branching of tree leaves and plants, rough terrain, jaggedness of coastline, and many more examples in nature. Fractals have been applied in various field like image compression, analysis of high altitude lightning phenomena, and rapid studies are apply to creating new type of antennas. Fractals are geometric forms that can be found in nature, being obtained after millions of years of evolution, selection and optimization [16].

There are many benefits when we applied these fractals to develop various antenna elements. By applying fractals to antenna elements:

- We can create smaller antenna size.
- Achieve resonance frequencies that are multiband.
- May be optimized for gain.
- Achieve wideband frequency band.

Most fractals have infinite complexity and detail that can be used to reduce antenna size and develop low profile antennas. For most fractals, self-similarity concept can achieve multiple frequency bands because of different parts of the antenna are similar to each other at different scales. The combination of infinite complexity and self-similarity makes it possible to design antennas with various wideband performances [17].
We need fractal antenna due to the following facts:

- Very broadband and multiband frequency response that derives from the inherent properties of the fractal geometry of the antenna.
- Compact size compared to antennas of conventional designs, while maintaining good to excellent efficiencies and gains.
- Mechanical simplicity and robustness; the characteristics of the fractal antenna are obtained due to its geometry and not by the addition of discrete components.
- Design to particular multi frequency characteristics containing specified stop bands as well as specific multiple pass bands.

There are many fractal geometries [18] that have been found to be useful in developing new and innovative design for antennas. Figure 2.16, below shows some of these unique geometries.

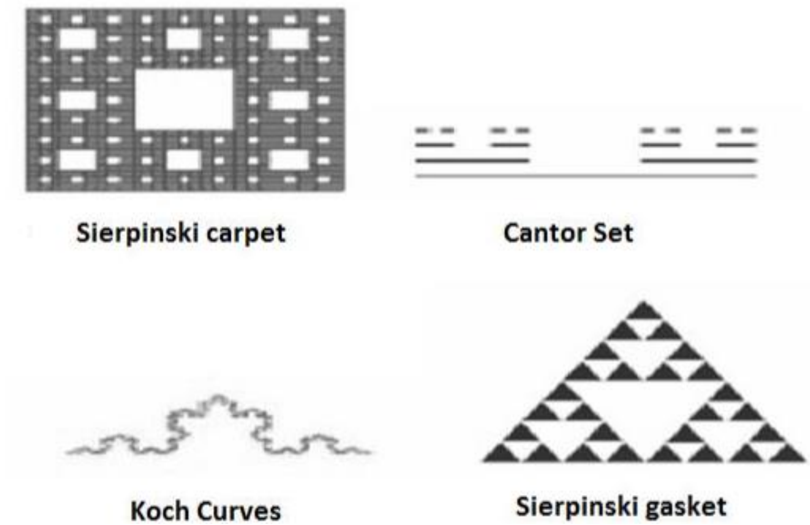


Figure 2. 16: Types of fractal geometries.

2.1.6 Reflector Antenna

Reflector antennas are very attractive candidates for use at high frequencies, because they have high gain and low losses. However, the size of a high gain Reflector antenna can sometimes be too big to be practical in short range communication applications such as backhaul. There are quite a few companies worldwide that manufacture Reflector antennas in the E-band. Most of their products are front-fed parabolic Reflector or cassegrain antennas and their dimensions depend on the gain [18].

The elliptic aperture reflector has the lowest side lobe level and the highest gain, thus the best performance in comparison with the others. The feeding source of the reflector is an ideal conical horn antenna [19].

Another design would be a cylindrical linear fed parabolic reflector whose feed is illuminated by a parallel plate structure. Inside the parallel plate could be an enclosed parabolic reflector, similar to [20] and this could be illuminated by a horn antenna or another type of feed, such as a hat feed. The parallel plate structure makes the antenna compact and the cylindrical shape of the reflector makes it easier to be manufactured than the one with the parabolic shape.

A cylindrical parabolic reflector fed by a printed antenna array is designed at [20] in the frequency range of 57 - 64 GHz. The measured gain at 60 GHz is 34 dBi and the length of the cylindrical parabolic reflector is 100 mm.

Reflector antennas are strongly recommended to be used at high frequencies, due to their excellent performance characteristics in gain and efficiency.

2.1.7 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves [21].

The use of lens antennas in millimeter wave applications has become more popular, because the dimensions of the lenses become smaller and they can be easily integrated with other components. Lens antennas have similar function as reflector antennas, because they have to be fed by a source which is usually a horn or a microstrip antenna or even an open waveguide.

In [22]. They can be used in most of the applications in which the parabolic reflectors are implemented, especially at higher frequencies. One major disadvantage of these antennas is that their dimensions and weight become exceedingly large at low frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape. A convex-plane and concave-plane lens antenna configurations are shown in figure 2.17.

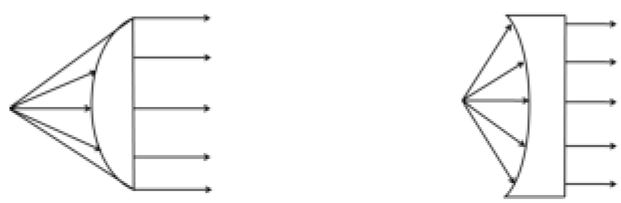


Figure 2. 17: Lens antenna configuration.

2.2 Antenna Parameter

2.2.1 Radiation pattern

One of the most common descriptors of an antenna is its radiation pattern. Radiation pattern can easily indicate an application for which an antenna will be used. For example, cell phone use would necessitate a nearly omnidirectional antenna, as the user location is not known. Therefore, radiation power should be spread out uniformly around the user for optimal reception. However, for satellite applications, a highly directive antenna would be desired such that the majority of radiated power is directed to a specific, known location. According to the IEEE Standard Definitions of Terms for Antennas [8], an antenna radiation pattern (or antenna pattern) is defined as follows:

"A mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity phase or polarization."

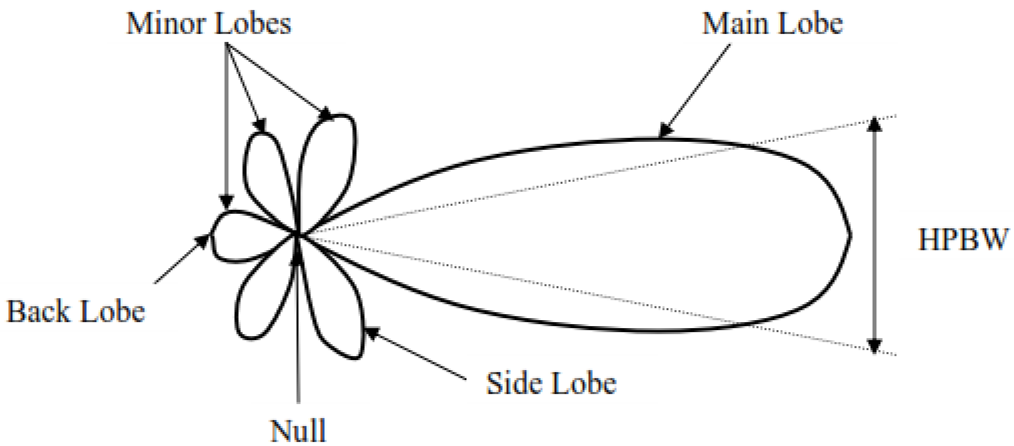


Figure 2. 18: Radiation pattern of a generic directional antenna.

A radiation pattern is usually characterized in the figure 2.18:

- The main lobe is the region around the direction of maximum radiation.
- Sidelobes are the undesired smaller beams away from the main beam and which can never be completely eliminated.
- The Half Power Beam Width (HPBW) is the angular separation in which the magnitude of the radiation pattern decrease by 50% (or equivalently 3 dB) compared to the maximum value of the major lobe.
- The First Null Beam Width (FNBW) is the angular separation between the first nulls around the major lobe.
- Sidelobe level (SL) is another important parameter that defines the maximum value of the sidelobes.

Based on the radiation pattern, antennas are classified as isotropic, omnidirectional and directional antennas (Johnson 1993). Examples of these classes of antennas are shown in figure 2.19. Isotropic antennas provide the same radiation pattern (gain) in all directions whereas omnidirectional antennas provide the same gain only in a single plane. Directional antennas are configurable to provide high antenna gains in a particular direction of interest [3].

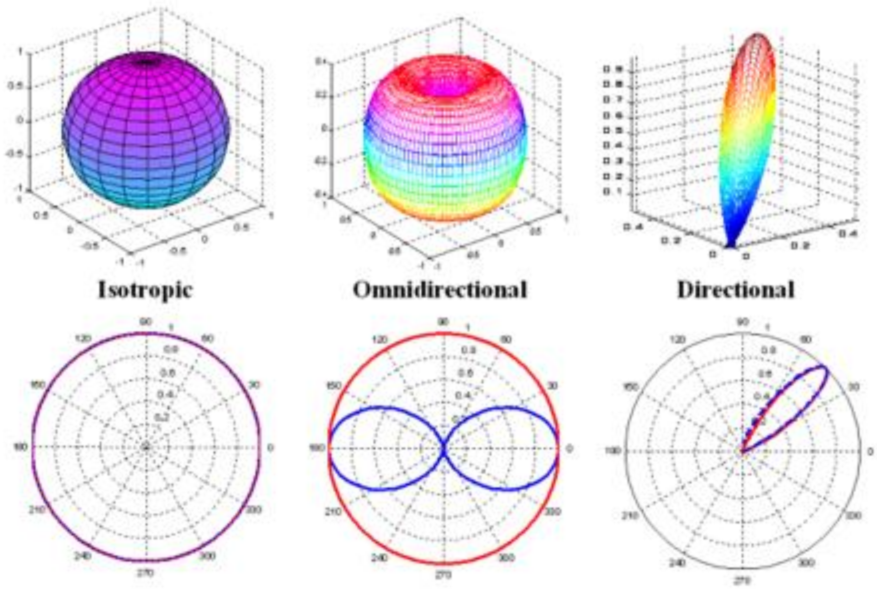


Figure 2. 19: Antenna classification based on the radiation pattern.

2.2.2 Gain

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity [5].

Gain as a parameter measures the directionality of a given antenna. An antenna with low gain emits radiation with about the same power in all directions, whereas a high-gain antenna will preferentially radiate in particular directions. Specifically, the gain, directive gain, or power gain of an antenna is defined as the ratio of the intensity (power per unit surface) radiated by the antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic lossless antenna. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π steadies.

Although the gain of an antenna is directly related to its directivity, antenna gain is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. In contrast, directivity is defined as a measure that takes into account only the directional properties of the antenna, and therefore, it is only influenced by the antenna pattern. If, however, we assume ideal antenna without losses then antenna gain will equal directivity as the antenna efficiency factor equals 1 (100% efficiency). In practice, the gain of an antenna is always less than its directivity.

The gain measurement is referred to the power at the input terminals rather than the radiated power, so it tends to be a more thorough measurement, which reflects the losses in the antenna structure. Gain measurement is typically misunderstood in terms of determining the quality of an antenna. A common misconception is that the higher the gain, the better the antenna. This is only true if the application requires a highly directive antenna. Since gain is linearly proportional to directivity, the gain measurement is a direct indication of how directive the antenna is (provided the antenna has adequate radiation efficiency) [7].

2.2.3 Bandwidth

Bandwidth is a fundamental antenna parameter. It describes the range of frequencies over where the antenna parameters, such as input impedance, radiation patterns, polarization, sidelobes level and gain is within an acceptable value from those at the center frequency.

Often, the desired bandwidth is one of the determining parameters used to decide upon an a ntennaThe bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency [6]. According to [9] these definitions can be written in terms of equations as follows:

$$BW_{broadband} = \frac{f_H}{f_L}$$

$$BW_{narrowband}(\%) = \left[\frac{f_H - f_L}{f_C}\right] 100$$

where f_H = upper frequency
f_L = lower frequency
f_C = center frequency

2.2.4 Beamwidth

The beamwidth of the antenna is usually considered to be the angular width of the half power radiated within a certain cut through the main beam of the antenna where most of the power is radiating. From the peak radiation intensity of the radiation pattern, which is the peak of the main beam, the half power level is 3 dB below such a peak where the two points on the main beam are located; these points are on two sides of the peak, which separate the angular width of the half power. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is 3 dB, so the half-power beamwidth is sometimes referred to as the 3-dB beamwidth. Both horizontal and vertical beamwidths are usually considered [1].

2.2.5 Polarization

Polarization of a radiated wave is defined as the property of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector. It is described by the geometric figure traced by the electric field vector upon a stationary plane perpendicular to the direction of propagation, as the wave travels through that plane. The three different types of antenna polarizations are shown in Figure 2.20. Vertical, and horizontal polarizations are the simplest forms of antenna polarization and they both fall into a category known as linear polarization. It is also possible that antennas can have a circular polarization. Circular polarization occurs when two or more linearly polarized waves add together, such that the E-field of the net wave rotates. Circular polarization has a number of benefits for areas such as satellite applications where it helps overcome the effects of propagation anomalies, ground reflections and the effects of the spin that occur on many satellites [3]. Another form of polarization is known as elliptical polarization. It occurs when there is a mix of linear and circular polarization. This can be visualized by the tip of the electric field vector tracing out an elliptically shaped corkscrew. It is possible for linearly polarized antennas to receive circularly polarized signals and vice versa. But, there is a 3 dB polarization mismatch between linearly and circularly polarized antennas [8].

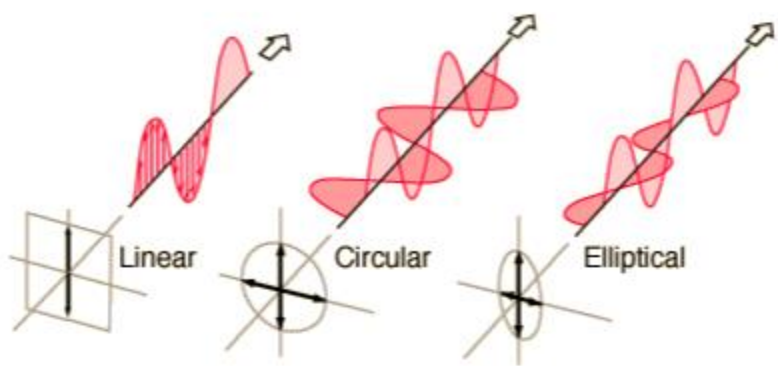


Figure 2. 20: Types of Polarization.

When a wave is travelling in space the property that describes its electric field rotation at a fixed point as a function of time is called wave polarization. It is a parameter which remains constant over the antenna main beam but may vary in the minor loops. Since the electric and magnetic field vectors are always related according to Maxwell's equation, it is enough to specify the polarization of one of them. And generally it is specified by the electric field. Polarization should be defined in its transmitting mode with reference to IEEE Standards. The polarization plane is the plane containing the electric and magnetic field vectors and it is always perpendicular to the plane of propagation. The contour drawn by the tip of the electric field vector describes the wave polarization. This contour is an ellipse, circle or a line. The polarization direction is assumed in the direction of the main beam unless otherwise stated. There are 2 kinds of polarization co-and cross-polarizations.

Co-polarization is the polarization radiated/received by the antenna, while the cross-polarization is perpendicular to it. Polarization is a very important factor in wave propagation between the transmitting and receiver antennas. Having the same kind of polarization and sense is important so that the receiving antenna can extract the signal from the transmitted wave. Maximum power transfer will take place when the receiving antenna has the same direction, axial ratio, spatial orientation and the same sense of polarization as incident wave, otherwise there will be polarization mismatch. If polarization mismatch occurs it will add more losses. Polarization is very important when considering wave reflection [2].

2.2.6 Return Loss

Return loss is traditionally expressed as the ratio between incident and reflected power expressed in dB, however, this report will in accordance with common practice within antenna engineering report return loss with a negative sign that is the fraction of reflected power divided by incident power in dB [8].

$$R_L = 10 \log_{10} \frac{P_r}{P_i}$$

Return loss evaluated at different frequencies of an antenna usually give a good representation of its radiating properties. For example, if the return loss is close to 0 dB, it means that the antenna isn't radiating at that frequency and if the return losses around -10 dB or lower, it means that at least 99% of power either is radiated or absorbed and converted into heat inside the antenna. Microstrip antennas usually have rather poor efficiency, of those 99% typically 70-80% would be radiated power. The reason small antennas have low efficiency is due to the fact that they are working in resonance, allowing the wave to travel through the antenna many times and thereby lose more power [1].

For systems with more than one antenna low return loss and low losses inside the antenna won't necessarily mean the energy is radiated to the far field, it might also get absorbed by other antennas. Hence, it is important to also consider the energy absorbed by the diversity antenna when simulating and measuring MIMO configurations. Simulation software can give direct information about radiation efficiency, but since return loss is much faster to calculate, it is the most common parameter to use as guidance during the design. This is true since calculating radiation efficiency requires knowledge about the radiated far field, while calculating return loss only requires knowledge of the lumped element circuits and the antenna [6].

2.2.7 Antenna Efficiency

Efficiency of an antenna can be divided into radiation efficiency which depends on the antenna structure or the radiation resistance, while the other is the total efficiency which includes the matching of an antenna to the power source or the return loss S11, where the expected value is usually -6dB.

$$\eta total = \eta rad[1 - (|S11|)^2]$$

2.2.8 Input Impedance

The input impedance of an antenna is defined by as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. Hence the impedance of the antenna can be written as:

$$Z_{in} = R_{in} + jX_{in}$$

Where Z_{in} is the antenna impedance at the terminals

R_{in} is the antenna resistance at the terminals

X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance in R_r and the loss resistance R_L. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses [5].

2.2.9 Directivity

The Directivity of an antenna is defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied. The directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source [7]. In a mathematical form, it can be written as

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_{rad}}$$

Where
D = directivity (dimensionless)
U = radiation intensity (W/unit solid angle)
U_o = radiation intensity of isotropic source (W/unit solid angle)
Many times it is desirable to express the directivity in decibels (dB) instead of dimensionless quantities. The expressions for converting the dimensionless quantities of directivity and maximum directivity to decibels (dB) is D (dB) = 10 log10 [D (dimensionless)].

2.3 Small Antenna

2.3.1 Definition of a Small Antenna

Small antennas are referred to as "electrically small antennas" or ESAs. The name is an implication that their physical size is much smaller than a wavelength at the operational frequency. The first definition was proposed by Wheeler [24] as an antenna whose maximum dimension is less than $\lambda/2\pi$ (radian length). Where λ is the wavelength. Another common and an equivalent definition, ESA is an antenna that satisfies the condition

$$ka < 0.5,$$

where k is the wave number = $(2\pi a/\lambda) < 1$.

and 'a' is the radius of the minimum size sphere that encloses the antenna. The sphere is termed as 'Chu sphere'. Another definition given by Hansen is

$$ka < 1$$

This is interpreted as an antenna enclosed inside a sphere of radius equal to one radian length and the sphere is called 'radian sphere'. This represents the boundary between the near and far field radiation for a Hertzian dipole.

Small antennas are treated with a concept that embraces not only electrically small antennas, but also other types of small antennas. Categories used to classify small antennas include functions as well as dimensions, because small antennas being used practically are not only what we call "Electrically Small Antennas," but also simply physically small antennas – antennas of partly electrically small dimensions and antennas equivalently small in terms of functions [23].

Conventionally, Electrically Small Antenna ESA has been the main subject when small antennas are discussed; however, other types of small antenna have comparable significance with the ESA, depending on the situation of the practical applications. The categories used here are ESA, Physically Constrained Small Antenna (PCSA), Functionally Small Antenna (FSA), and Physically Small Antenna (PSA) [28].

A PCSA is an antenna, not having dimensions of ESA, but a part of which has dimensions corresponding to the ESA. A low-profile antenna, for example, with the height over the ground plane or the thickness of say $\lambda/50$ or so, like an Inverted-L antenna, planar antennas such as a patch antenna, a microstrip antenna (MSA), and so forth, can be classified into "Physically Constrained Small Antenna" (PCSA) [25].

Another classification of small antennas relates to antenna functions. When an antenna can attain either additional functions or enhanced performances with the dimensions being kept unchanged, it can be said to have an equivalent reduction in the antenna size, because with normal antennas such enhanced function or improved performance could result only from enlargement of dimensions. An example is an antenna designed to have wideband, multiband performance, radiation pattern shaping, and array thinning without any change in the dimensions. This class of antenna is referred to as "Functionally Small Antenna" (FSA) [26].

A PSA is an antenna, which differs from any of the above, but has physically small dimensions as measured. When the volume of an antenna is bounded by 30 cm or less, we may call the antenna a PSA. There is not any strict physical meaning in the definition, but only a sensual measure based on the common understanding of "smallness" in physical size. An example is a millimeter-wave horn antenna with an aperture size of, say 5 cm approximately. Many of the MSAs may be classified into either PCSA or PSA [27].

2.3.2 Significance of small antennas

The significance of the small antenna is recognized from its important role in various wireless systems, where small antennas are indispensable. In the early days of communications, when electronic devices such as thermionic vacuum tubes were not yet available, antenna technology was essential to extend the communication range. Development of tuning and matching concepts gave impetus to promote further increase in communication capability.

Meanwhile, mobile communications drove development of small antennas, as mobile terminals needed small equipment, for which small-sized, compact, and lightweight antennas were required. So far, creation and invention of small antennas have accelerated rapidly in response to worldwide demands raised urgently by the growth of mobile phone systems. Recent trends are increasing demands arising particularly for newly deployed wireless mobile systems Near Field Communication systems (NFC), including Radio Frequency Identification (RFID), Ultra-Wide Band (UWB), and wireless broadband systems such as Wireless Local Area Networks (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX). Small antennas have already played an obscure but key role in such wireless mobile systems, as the systems do not work without these devices. Antennas in these systems have acted as a key component, since they almost determine the system performance, especially in small wireless equipment, because the systems are designed to exhibit almost the highest achievable electronic performance, and only the antenna can further improve the system performance. Since downsizing of electronic devices and their design technology as well has expedited progress in small wireless equipment, small antennas have become inevitable for these systems. As such, it can also be said that such newly deployed wireless systems owe much in their development to small antennas, and in turn small-antenna technology has advanced by being employed in these wireless systems. Recent urgent demand is application of small antennas to the Multi-Input Multi-Output (MIMO) systems. WiMAX already employs the MIMO system in order to transmit high data rate to the 4G (4th Generation) mobile systems, and other wireless broadband systems where high data rates will be needed will adopt the MIMO system. Small antennas are suitable for small MIMO equipment, where space to install antennas is limited to small areas, and close proximity of antenna elements is unavoidable [23].

2.3.3 Small antenna Parameters

The following characteristic parameters are the most important for a small antenna.

1. Directivity

Small antennas are often believed to have doughnut shaped Omni directional pattern of a Hertzian dipole of directivity D=1.5. The pattern is due to the radiation of TE10 or TM10 spherical modes. But Harrington, Kwon and Pozar have demonstrated unidirectional and bi directional patterns with D from 1 to 3 theoretically. Antennas with higher spherical TE_{mn} and TM_{nm} radiations are not of the small type. Small antennas are also termed super directive, since the directivity D remains unaltered with decrease in size *ka* [24].

2. Radiation Efficiency

Antenna radiation efficiency factor η is the ratio of power radiated to the power delivered to an antenna. The losses other than radiation are modeled as a resistor of value *R loss*

Mathematically is given as:

$$\eta = \frac{R_{rad}}{R_{rad} + R_{loss}} = \frac{R_{rad}}{R_A}$$

The efficiency gets reduced as the antenna dimension *ka* is reduced for the fact that *R loss* dominates. The reduction can be attributed to frequency dependent conduction and dielectric losses [23].

3. Quality factor

The Quality factor *Q* is used to describe the high input reactance and narrow bandwidth of small antennas [29] and is defined as

$$Q = \frac{2\omega_0 \max(W_E, W_M)}{P_A}$$

WE and *WM* are the time average stored electric and magnetic energies and *PA* is the received antenna power. The *Q* value the quantity of our interest is inversely proportional to the antenna bandwidth [29].

Many times, the bandwidth (BW) of an antenna is not clearly defined; therefore the quality factor (Q) has more interest. Q is usually expressed in terms of the VSWR or related to the return loss at the input terminals.

2.4 Bandwidth Enhancement Techniques

The impedance bandwidth of microstrip patch antennas is usually much smaller than the pattern bandwidth [30]. This discussion on bandwidth enhancement techniques will therefore focus on input impedance rather than radiation patterns. There are a number of ways in which the impedance bandwidth of probe-fed microstrip patch antennas can be enhanced. According to Wong [31], the various bandwidth-enhancement techniques can be categorized into three broad approaches:

- Impedance matching.
- The use of multiple resonances.
- The use of lossy materials.

For the purpose of this overview, it has been decided to rather categorize the different approaches in terms of the antenna structures that are normally used. These include:

- Wideband impedance-matching networks.
- Edge-coupled patches.
- Stacked patches.
- Shaped probes.
- Capacitive coupling and slotted patches.
- Capacitive feed probes.
- Overlapped patches which represents the new antenna element that forms the basis of this study.

In terms of Wong's categories, all these approaches can be identified as making use of either impedance matching or multiple resonances. In practice, lossy materials are not frequently used as it limits the radiation efficiency of the antenna. It will therefore not be considered here.

2.4.1 Wideband Impedance-Matching Networks

One of the most direct ways to improve the impedance bandwidth of probe-fed microstrip antennas, without altering the antenna element itself, is to use a reactive matching network that compensates for the rapid frequency variations of the input impedance. As shown in Figure 2.21, this can typically be implemented in microstrip form below the ground plane of the antenna element. The method is not restricted to antenna elements on either thin or a thick substrates, but the thick substrate will of course add some extra bandwidth.

Pues and Van de Capelle [32] implemented the method by modelling the antenna as a simple resonant circuit. A procedure, similar to the design of a bandpass filter, is then used to synthesize the matching network. With this approach, they have managed to increase the bandwidth from 4.2% to 12% for a VSWR of 2:1. Subsequently to that, C.Nauwelaers [33] used the simplified real frequency technique in order to design the matching network for a probe-fed microstrip patch antenna. They have managed to increase the bandwidth of one antenna element from 5.7% to 11.1% for a VSWR of 1.5:1, and that of another from 9.4% to 16.8% for a VSWR of 2:1. Recently, V. Gupta and S. Sinha [34] have shown how a dielectric-resonator loaded suspended microstrip patch antenna can increase the bandwidth from
3.2% to 18% for a VSWR of 1.5:1.

The advantages of using impedance-matching networks are that the antenna elements do not get altered and that the matching network can be placed behind the antenna's ground plane. As such, the radiation characteristics of the antenna element stay unchanged, while radiation from the matching network is also minimized.

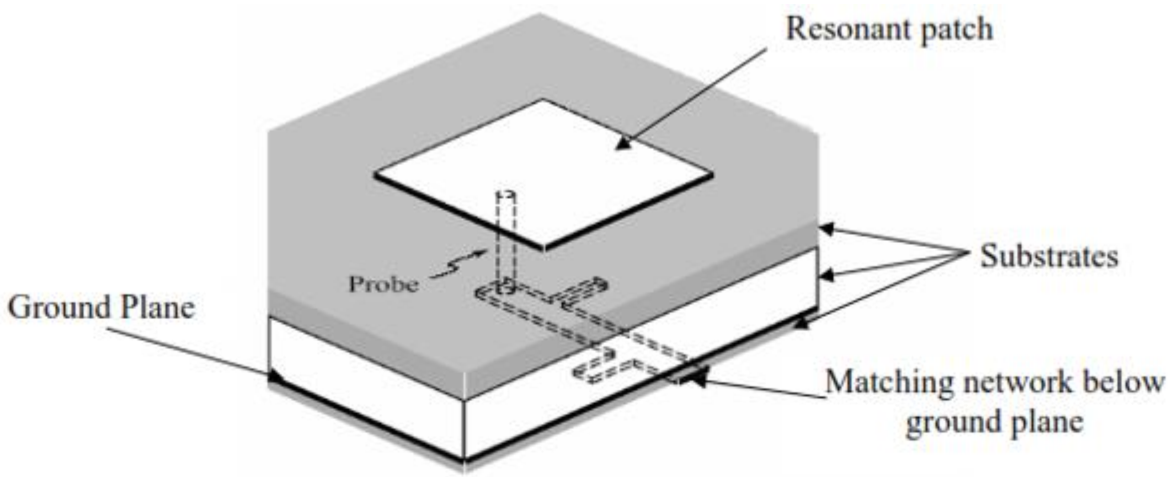


Figure 2. 21: Geometry of a probe-fed microstrip patch antenna with a wideband impedance-matching network.

The drawback of this method is that the matching network can potentially take up space that is very limited when microstrip feed networks are used to excite the individual elements in an antenna array. Another drawback is that, for single-element antennas, more than one substrate layer is required to support the antenna element and the matching network.

2.4.2 Edge-Coupled Patches

The basic idea behind edge-coupled patches, is to increase the impedance bandwidth of a microstrip patch through the introduction of additional resonant patches. By doing so, a few closely-spaced resonances can be created. Only one of the elements is driven directly. The other patches are coupled through proximity effects. An example of such an arrangement is shown in Figure 2.22.

This approach has been investigated by Kumar and Gupta [35]. The parasitic patches can be coupled to either the radiating edges, the non-radiating edges or to both pairs of edges. The approach in [35] uses short transmission lines to couple the parasitic patches directly to the driven patch. With the edge-coupled approach, impedance bandwidths of up to 25.8% have been obtained for a VSWR of 2:1. This was achieved with four parasitic patches coupled to the driven patch.

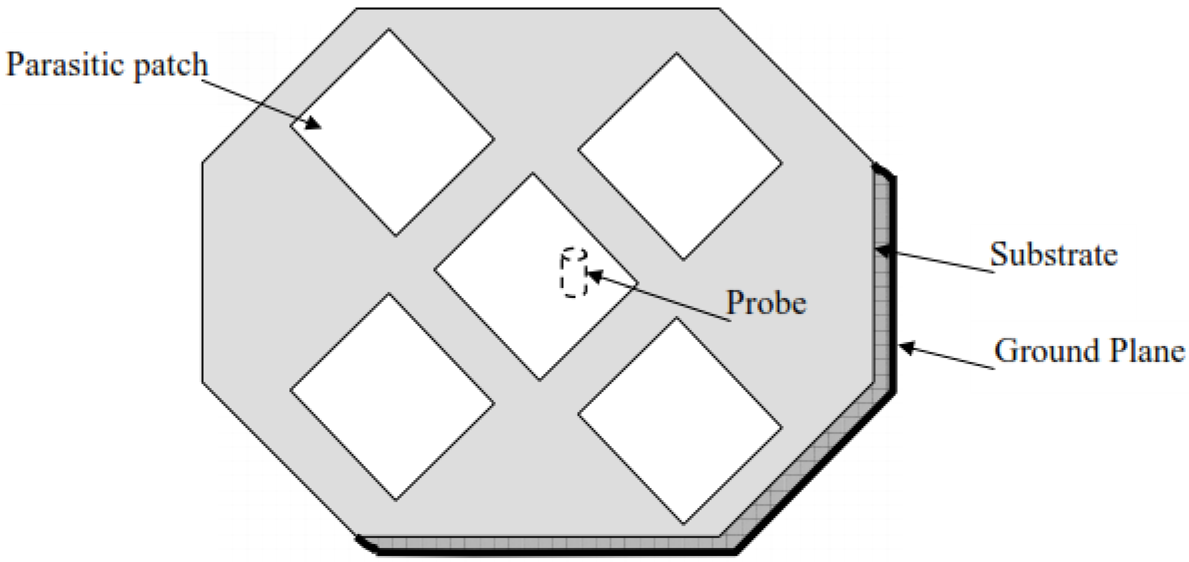


Figure 2. 22: Geometry of a probe-fed microstrip patch element that is edge-coupled to the parasitic patches.

The advantages of the edge-coupled approach include the fact that the structure is coplanar in nature and that it can be fabricated on a single-layer substrate. However, this approach also has a few drawbacks. Due to the fact that the different patches radiate with different amplitudes and phases at different frequencies, the radiation patterns change significantly over the operating frequencies. The enlarged size of the structure can also be a potential handicap in many applications. For example, in phased-array applications, the large separation distances between elements can introduce grating lobes.

2.4.3 Stacked Patches

A very popular technique, which is often used to increase the impedance bandwidth of microstrip patch antennas, is to stack two or more resonant patches on top of each other [31]. As with the edge-coupled resonators, this technique also relies on closely-spaced multiple resonances. However, in this case, the elements take up less surface area due to the fact that they are not arranged in a coplanar configuration. Figure 2.23 shows the geometry of such an antenna element where the bottom patch is driven by a microstrip line and the top patch, which is located on a different substrate layer, is proximity-coupled to the bottom one.

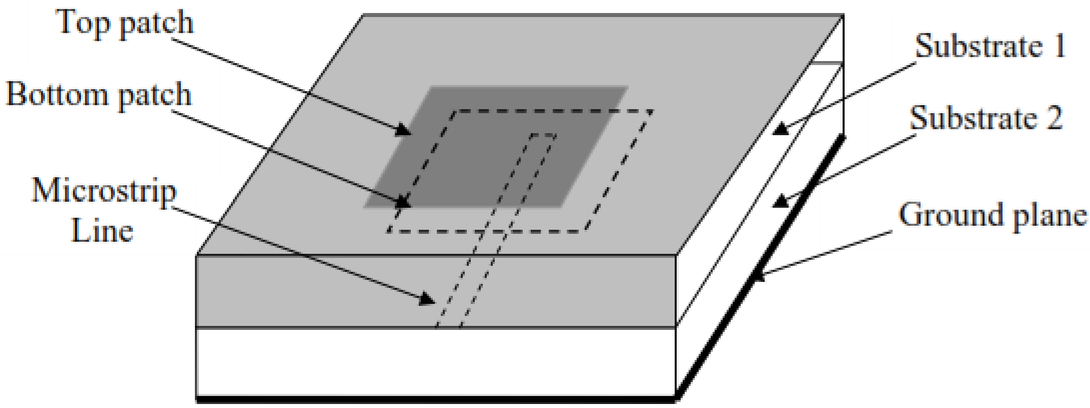


Figure 2. 23: Geometry of a probe-fed stacked microstrip patch antenna.

In practice, the patches are usually very close in size so that the generation of two distinct resonances can be avoided. Different shapes of patches can be used. These commonly include rectangular patches [36], circular patches [37] and annular-ring patches [38]. Waterhouse [36] reported a 26% 10 dB return-loss bandwidth for rectangular patches, Mitchell [37] reported a 33% 10 dB return-loss bandwidth for circular patches, while Kokotoff [38] reported a 22% 10 dB return-loss bandwidth for annular-ring patches.

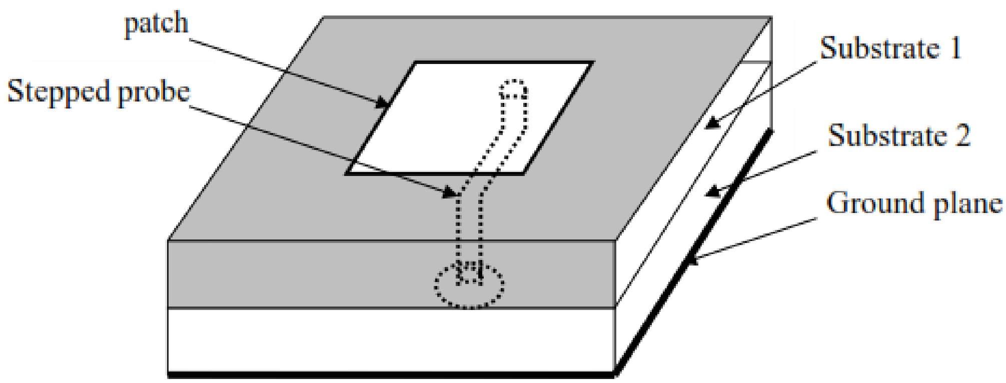
These bandwidths were all obtained for two patches stacked on top of each other. It is possible to stack more patches, but the performance may not be much better than with only two patches [31]. Instead of aligning the patches vertically, some researchers have also used a horizontal offset between the patches [39]. However, due to the structural asymmetry, these configurations exhibit beam dispersion.

The stacked-patch configuration has a number of advantages over the edge-coupled configuration. Since it does not increase the surface area of the element, it can be used in array configurations without the danger of creating grating lobes. Its radiation patterns and phase center also remains relatively constant over the operating frequency band. It has a large number of parameters that can be used for optimization. However, due to this, the design and optimization process can also be very complex. Another drawback of stacked patches, is that it requires more than one substrate layer to support the patches.

2.4.4 Shaped Probes

As was shown in Chapter 1, a thick substrate can be used to enhance the impedance bandwidth of microstrip patch antennas. However, the input impedance of probe-fed microstrip patch antennas become more inductive as the substrate thickness is increased. In order to offset this inductance, some capacitance is needed in the antenna's feeding structure. One way to implement such a capacitive feed is to alter the shape of the probe. There are basically two approaches. In one approach, the probe is connected directly to the patch [40], while in the other approach, the probe is not connected to the patch at all [41].

The direct feed can be implemented as shown in Figure 2.24(a), where the feeding structure consists of a stepped probe. The horizontal part of the probe couples capacitive to the patch. Chen and Chia [40] reported an impedance bandwidth of 19.5% for a VSWR of 2:1. Another option is to add a stub to one of the radiating edges of the patch and to feed the stub directly with a probe. For such an approach, Chen and Chia [42] reported an impedance bandwidth of 25%, once again for a VSWR of 2:1. The proximity-coupled probe is implemented as shown in Figure 2.24(b), where the probe is bent into a L-shape. The horizontal part of the probe runs underneath the patch and also couples capacitive to it. This solution has been implemented for a variety of patch shapes. Maketal. Reported an impedance bandwidth of 36% for a rectangular patch in [43] and 42% for a triangular patch in [44], while Guo et al. reported an impedance bandwidth of 27% for an annular-ring patch in [45]. These bandwidth figures were all quoted for a VSWR of 2:1. Instead of a L-shaped probe. A microstrip patch antenna with a shaped probe, be it directly driven or not, can usually be supported on a single substrate layer. This makes it extremely suitable for antenna arrays where cost has to be minimized.



(a)

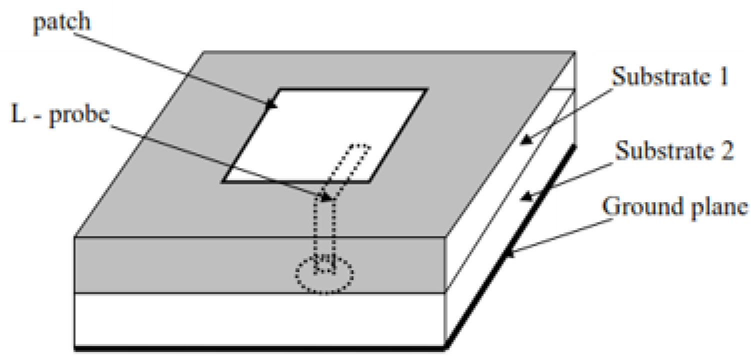


Figure 2. 24: Geometries of microstrip patch antennas with shaped probes. (a) Stepped probe. (b) L-shaped probe.

Most of these elements have radiation patterns with a slight squint in the E-plane and slightly high cross-polarization levels in the H-plane. These are characteristics of probe-fed microstrip patch antennas on thick substrates. The stepped probe, though, exhibits somewhat lower cross-polarization levels. The patches that are directly driven should be more robust that those with the proximity coupled probes. For the latter ones, care has to be taken with respect to the proper alignment of the paths and probes. Another advantage of both approaches is that, since they do not increase the surface area of the element, they can be used in array configurations without the danger of creating grating lobes.

2.4.5 Capacitive Coupling and Slotted Patches

There are two alternative approaches that can also be used to overcome the inductive nature of the input impedance associated with a probe-fed patch on a thick substrate. These are capacitive coupling or the use of slots within the surface of the patch element. Examples of such approaches are shown in Figures 2.25(a) and (b) respectively. It can be argued that these two approaches are structurally quite similar. The approach in Figure 2.25(a) has a small probe-fed capacitor patch, which is situated below the resonant patch [46]. The gap between them acts as a series capacitor. Similarly, the annular slot in Figure 2.25(b) separates the patch into a small probe-fed capacitor patch and a resonant patch. In this case, the slot also acts as a series capacitor. In principle, both of these approaches employ some sort of capacitive coupling and are functionally also, to some degree, equivalent to the L-probe and T–probe.

Liu and kooi [47] combined the capacitive-coupled feed probe with stacked patches and reported a impedance bandwidth of 25.7% for a VSWR of 2:1. To achieve this, they used two stacked patches with a small probe-fed patch below the bottom resonant patch. In another approach, Gonzalez [48] placed a resonant patch, together with the small probe-fed capacitor patch just below it, into a metallic cavity. With this configuration, they managed to obtain a impedance bandwidth of 35.3% for a VSWR of 2:1. Chen and Chia [49] used a small rectangular probe-fed capacitor patch, located within a notch that was cut into the surface of the resonant patch. They managed to obtain an impedance bandwidth of 36% for a VSWR of 2:1.

Some authors also used a rectangular resonant patch with a U-slot in its surface. The metallic area inside the slot is then driven directly with a probe. Here, Tong [50] reported a impedance bandwidth of 27% for a VSWR of 2:1, while Weigand [51] reported an impedance bandwidth of 39 %, also for a VSWR of 2:1. In yet another approach, Nie and Chew [52] placed a circular probe-fed patch within a annular-ring patch, with the circular patch exciting higher-order modes on the annular-ring patch.

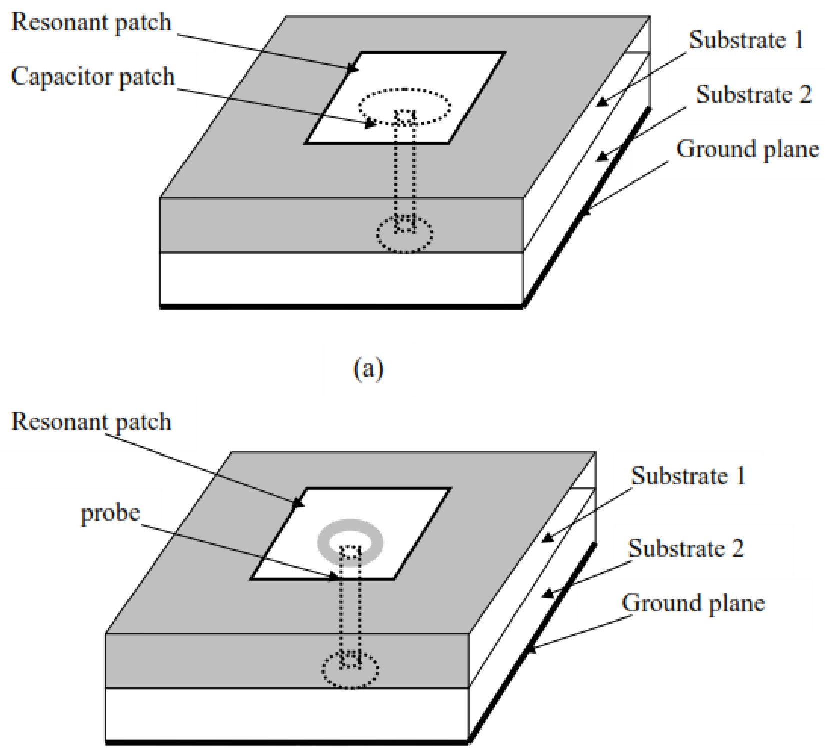


Figure 2. 25: Geometries of probe-fed microstrip patch antennas where capacitive coupling and slots are used. (a) Capacitive coupling. (b) Annular slot in the surface of the patch.

They managed to obtain 8 dB return-loss bandwidth of 20%. Kokotoff [53] placed a small shorted circular probe-fed patch within a annular-ring patch, but with the circular patch exciting the dominant TM11 mode on the annular-ring patch. They reported a 10 dB return-loss of 6.6%.

The advantage of the approach where the capacitor patch is located below the resonant patch, is that the cross-polarization levels in the H-plane are lower than what can be achieved with the approach where the capacitor patch is located within the surface of the resonant patch. However, in order to support the capacitor patch below the resonant patch, an additional substrate layer might be required. In contrast, only one substrate layer is required to support the configuration where the capacitor patch is located inside the surface of the resonant patch. Furthermore, the capacitor patch below the resonant patch is prone to alignment errors and can complicate the fabrication process. On the other hand, when using a capacitor patch within the surface area of a resonant patch, there can potentially be many design parameters that can complicate the design of such antenna elements. Here also, an advantage of both approaches is that, since they do not increase the surface area of the element, they can be used in array configurations without the danger of creating grating lobes.

2.4.6 Capacitive Feed Probes

There is another approach that can also be used to overcome the inductive nature of the input impedance associated with a probe-fed patch on a thick substrate. This is the use of a microstrip patch antenna element with a capacitive feed probe. Figure 2.26 shows the general geometry of the antenna structure. As can be seen, it consists of a rectangular resonant patch with a small probe-fed capacitor patch right next to it. Both patches reside on the same substrate layer. Both circular and rectangular capacitor patches, as shown in Figures 2.26(a) and (b) respectively, can be used.G. Mayhew [54] showed that, for a rectangular resonant patch with a small probe-fed rectangular capacitor patch, a 10 dB return loss bandwidth of 26.4% could be obtained.

For wideband applications, the two patches can be manufactured on a thin substrate with a thick low-loss substrate, such as air, right below it. The antenna element is functionally very similar to most other capacitive-coupled elements. The gap between the resonant patch and the capacitor patch acts as a series thereby offsetting the inductance of the long probe.

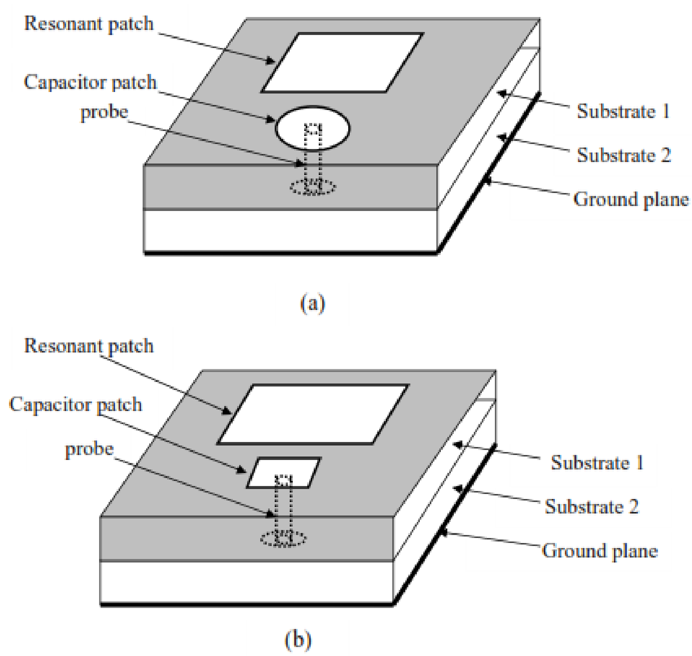


Figure 2. 26: Geometries of the microstrip patch antennas employing capacitive feed probes. (a) Circular capacitor patch. (b) Rectangular capacitor patch.

Once the size of the resonant patch and the thickness of the substrate have been fixed for a certain operating frequency and impedance bandwidth, there are basically two parameters that can be used to control the input impedance of the antenna element. These are the size of the capacitor patch and the size of the gap between the two patches.

The structural properties of this antenna element can be viewed in context. First of all, this antenna element can be manufactured on a single substrate layer due to both the resonant patch and the capacitor patch residing on the same layer. This is very important for large antenna arrays where lamination can be very expensive. The fact that the capacitor patch is driven directly by a probe, gives the structure some rigidity. The structure is also less prone to alignment errors, which can be a factor of merit for antenna elements where the probe does not make physical contact with any of the resonant patches or where the capacitor patch is located on a different layer than the resonant patch. The surface area of the element is not much larger than that of a resonant patch and therefore it is very suitable for use within antenna arrays. An advantage that might not be very obvious at first, is that the antenna element, as opposed to slotted antenna elements, consists of parts that are regular in shape, it has huge benefits for the analysis of such antennas, especially for large antenna arrays. Finally, the design of such an antenna element, as well as tuning of the input impedance, is very straightforward due to the few parameters that have to be adjusted.

2.5 Feed Techniques

There are different techniques available to feed or transmit electromagnetic energy to a microstrip antenna. The four most popular feeding methods are the Microstrip line, coaxial probe, aperture coupling and proximity coupling.

2.5.1 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.27, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

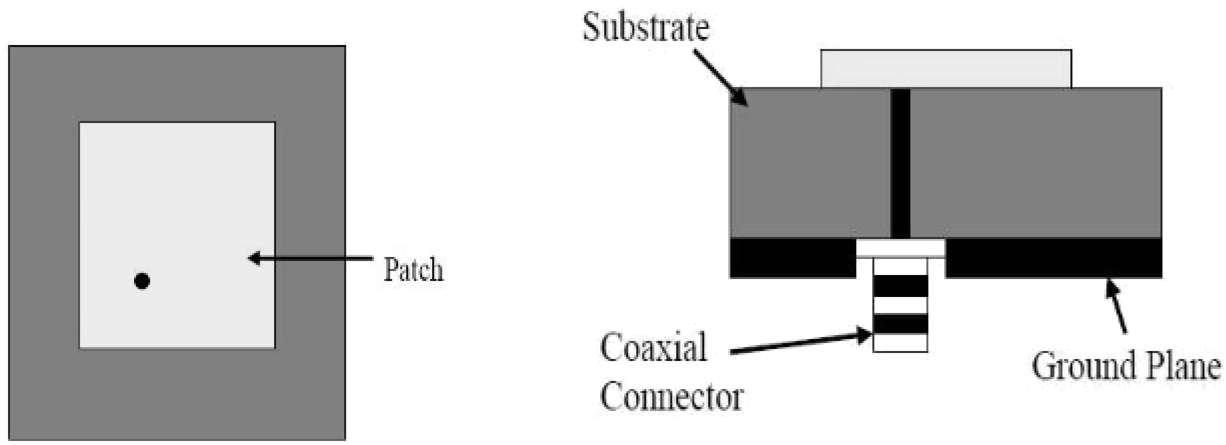


Figure 2. 27: Rectangular Microstrip antenna coaxial feed

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth [58].

2.5.2 Microstrip Feed line

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 2.28. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [57]. The feed radiation also leads to undesired cross polarized radiation.

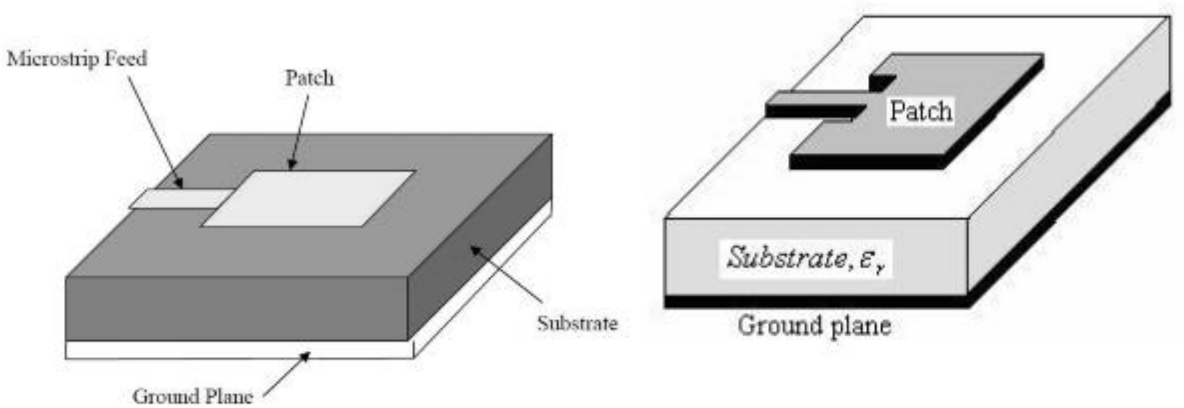


Figure 2. 28: Rectangular Microstrip antenna of Microstrip Line feeding.

2.5.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the Microstrip feed line are separated by the ground plane as shown in Figure 2.29. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [59].

The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth (up to 21%).

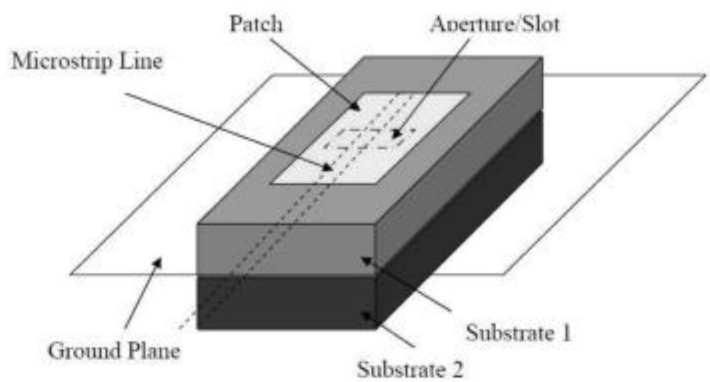


Figure 2. 29: Rectangular Microstrip antenna Aperture coupled feed.

2.5.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.30, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate [60]. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

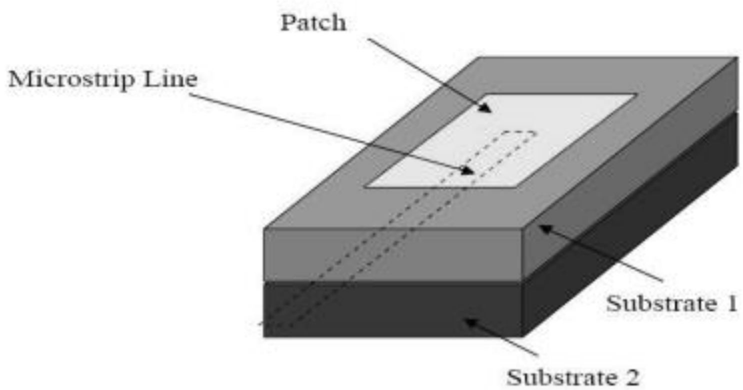


Figure 2. 30: Proximity-coupled Feed.

Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna. Table 2.1 below summarizes the characteristics of the different feed techniques [56].

Table 2. 1: Comparing the Different Feed Techniques[68].

Characteristics	**Microstrip Line Feed**	**Coaxial Feed**	**Aperture Coupled Feed**	**Proximity Coupled Feed**
Spurious feed radiations	More	more	Less	minimum
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
impedance matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%
reliability	better	Poor due to soldering	Good	Good

2.6 OVERVIEW OF MODELLING TECHNIQUES

There are a number of methods that can be used for the analysis of microstrip patch antennas. Most of these methods fall into one of two broad categories: approximate methods and full-wave methods [56]. The approximate methods are based on simplifying assumptions and therefore they have a number of limitations and are usually less accurate. They are usually used to analyze single antenna elements as it is very difficult to model coupling between elements with these methods. However, where applicable, they normally do provide good physical insight and the computation time is usually very small. The full-wave methods include all relevant wave mechanisms and rely heavily upon the use of efficient numerical techniques [61]. When applied properly, the full-wave methods are reasonably accurate and can be used to model a wide variety of antenna configurations, including antenna arrays. These methods tend to be much more complex than the approximate methods and also provide less physical insight. Very often they also require vast computational resources and extensive solution times. In the remainder of this section, an overview of both approximate and full-wave methods will be given.

2.6.1 Approximate Methods

Some of the popular approximate models include the transmission-line model, the cavity model and the segmentation model. These models usually treat the microstrip patch as a transmission line or as a cavity resonator.

3.6.1.1 Transmission-Line Model

The transmission-line model leads to results that are adequate for most engineering purposes and entail less computation. Although this method has its shortcomings, particularly in that it is applicable only to rectangular or square patch geometries, the model offers a reasonable interpretation of the radiation mechanism, while simultaneously giving a simple expression of the antenna's characteristics [62].

The basic concept of the transmission-line model is shown in Figure 2.31. This model is for a rectangular patch fed at the center of the radiating edge. The patch is characterized as a microstrip transmission-line with a length L, width W, and thickness h. Each radiating edge, with length equal to W, is modeled as a narrow slot radiating into a half-space. The width of the slot is, for the sake of convenience, assumed to be equal to the substrate thickness h, As a result, the rectangular patch antenna can be represented by two admittance connected by an equivalent microstrip transmission line as shown in the lower half of Figure 2.31, where the characteristic impedance Z and the propagation constant *ß* for the fundamental mode in the microstrip line are approximated by [63] as:

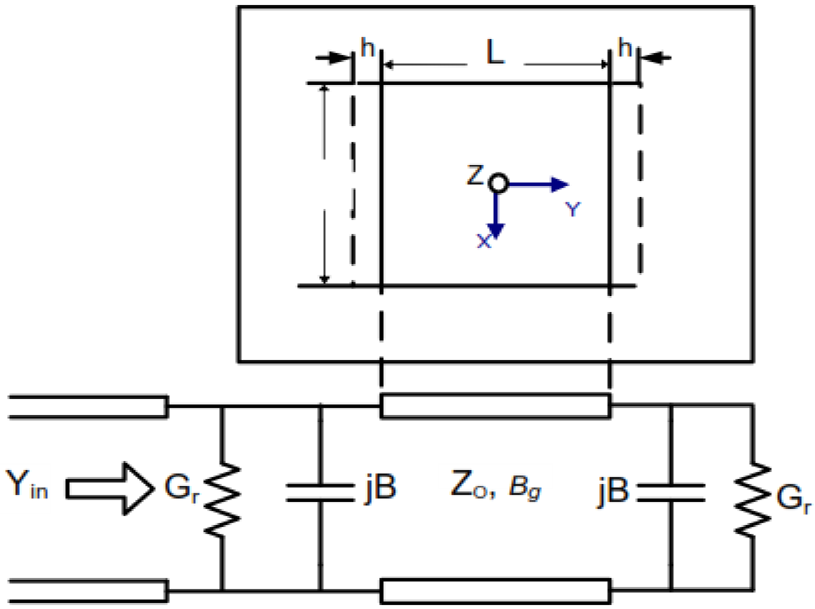


Figure 2. 31: Plane view of rectangular patch antenna and its equivalent circuit.

$$Z_o = \frac{1}{Y_o} \approx \frac{\eta}{\sqrt{\varepsilon_{reff}}}\frac{h}{W} \tag{2.1}$$

$$\beta_g \approx K_o\sqrt{\varepsilon_{reff}} \tag{2.2}$$

where

η_o = The wave impedance in free space.

K_o = The propagation constant in free space.

ε_{reff} = Effective dielectric constant.

ε_{reff} is related to the intrinsic dielectric constant ε_r of the substrate as follows [58]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]\text{^}(-\frac{1}{2}) \tag{2.3}$$

Notice that the value of ε_{reff} is slightly less thenε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air.

The capacitive component, *B*, and the conductive component, *Gr*, which form each admittance, are related to the fringing field and the radiation loss, and are respectively approximated by [64] as:

$$\beta_g \approx \frac{K_o \Delta l}{Z_o}\sqrt{\varepsilon_{reff}} \tag{2.4}$$

$$G_r \begin{cases} \frac{W^2}{90{\lambda_o}^2} & W < 0.35\lambda_o \\ \frac{W}{120} - \frac{1}{60\pi} & 0.35\lambda_o \le W \le 2\lambda_o \\ \frac{W}{120\lambda} & 2\lambda_o < W \end{cases} \tag{2.5}$$

where ΔL signifies the line extension due to the fringing effect. This value can be approximated by using the following equation [9]:

$$\Delta l \approx 0.412\, h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{2.6}$$

The effective length of the patch Leff now becomes:

$$L_{eff} = L + 2\Delta L \tag{2.7}$$

This effective length is given by [1] as:

$$L_{eff} = \frac{C}{2\, f_r \sqrt{\varepsilon_{reff}}} \tag{2.8}$$

where *C* is the speed of light in free space, and *fr* is the resonance frequency of the microstrip antenna.

From the equivalent circuit in Figure 2.31. The input admittance of this patch antenna can be shown to be the following, if it is regarded as two slot antennas connected by a transmission line having characteristic admittance and propagation constant of *Yo* and *ßg* approximated by Eqs. (2.1) and (2.2):

$$Y_{in} = G_r + jB + Y_o \frac{(G_r + jB) + jY_o \tan(\beta_g L)}{Y_o + j(G_r + jB)\tan(\beta_g L)} \tag{2.9}$$

In this case, the resonance condition is given by

$$\mathrm{Im}\{Yin\} = 0 \tag{2.10}$$

Where Im{Yin} represents the imaginary part of Yin. From Equation (2.10), the following condition can be derived:

$$\tan(\beta_g\, L) = \frac{2Y_oB}{{G_r}^2 + B^2 - {Y_o}^2} \tag{2.11}$$

The condition above is used to determine the resonant frequency when the patch length L is given. The input admittance at resonance can be found by substituting Eq. (2.11) into (2.9):

$$Yin = 2\,Gr \tag{2.12}$$

This result is, of course, easily deduced from the equivalent circuit of Figure 2.7. For an efficient radiation, a practical width that leads to good radiation efficiencies is given in [4] as:

$$W = \frac{C}{2\,f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2.13}$$

In the typical design procedure of a rectangular patch antenna, the thickness and dielectric constant of the substrate must be known. Once they are given or determined, a patch antenna that operates at the required resonance frequency can be designed by following the flow chart shown in Figure 2.32 [57].

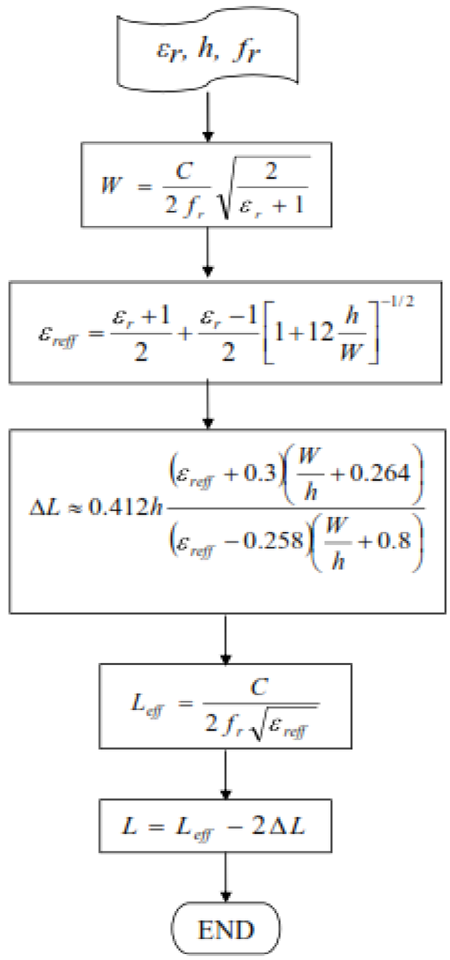


Figure 2. 32: Flow chart for the design procedure of a rectangular patch antenna.

2.7 Finite element method

The Finite Element Method (FEM) is a very versatile technique because it allows the analysis of complex structures. It has been used in a wide variety of problems like modeling waveguides and transmission lines, cavities, etc. It is also computationally efficient because it yields sparse matrices [55].

The FEM frequency domain based on full-wave computational technique is used for antenna structure optimal design and performance simulation. A full wave computational technique provide complete solution to Maxwell's equation within the computational space for all conductors and materials. In contrast, the FEM allows for arbitrary specification of the material within the volume, which is an inherent advantage of FEM over numerical methods. FEM is a very powerful tool for solving complex engineering problems, the mathematical formulation of which is not only challenging but also tedious [65].

It was introduced to the electromagnetic community towards the end of the 1960's. Since then, a great progress has been made in terms of its application to electromagnetic problems. In addition, the FEM is a well-known frequency-domain technique which is highly capable of modeling 3D complex structures within homogeneities. Typical full wave EM analyzes in the FEM is shown in Figure 2.31.

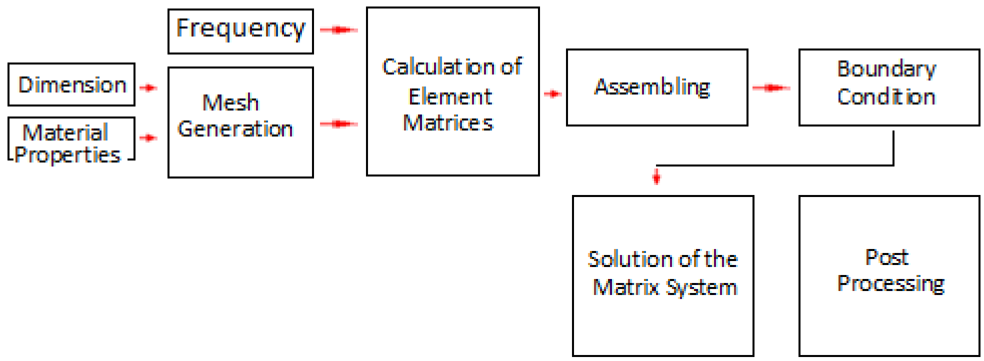


Figure 2. 33: Full-wave EM analysis in the FEM.

When using the FEM for electromagnetic problems, the electric field is the unknown variable that has to be solved for, the method is implemented by discrediting the entire volume over which the electric field exists, together with its bounding surface, into small elements. In which triangular elements are used for surface meshes and tetrahedron elements for volumetric meshes. Simple linear or higher-order functions on the nodes, along the edge or on faces of the elements, are to model the electric field. For antenna problems, the volume over which the electric field exists will have one boundary on the antenna and another boundary some distance away from the antenna [65].

The latter boundary is an absorbing boundary, which is needed to truncate the volume. One view point from which the FEM can be derived is that of variation analyze. The method starts with the partial differential equation (PDE) from Maxwell's equations and finds a variation functional from which the minimum (or external point) corresponds with the solution of the PDE, subject to the boundary conditions. An example of such a functional is the energy functional, which is an expression describing all the energy associated with the configuration being analysis, in terms of the electric field. After the boundary conditions have been enforced, a matrix equation is obtained. This equation can then be solved to yield the amplitudes that are associated with the functions on the elements used to model the electric field. The matrix associated with the FEM is a sparse matrix due to the fact that every element only interacts with the elements in its own neighborhood. Other parameters, such as the magnetic field, induced currents and power loss, can be obtained from the electric field. The major advantage of the FEM is that the electrical and geometrical properties of each element can be defined independently. Therefore, very complicated geometries and in homogenous materials can be treated with relative ease. This implies that the analysis of microstrip antennas with finite ground plane and layers is also possible [66].

2.8 HFSS

Ansys's electromagnetic computer modeling software, High Frequency Structure Simulator (HFSS), has become an industry standard. Its user friendly graphical user's interface is intuitive enough to help even the most novice RF, microwave, and electromagnetic engineers create anything that starts in the deepest recesses of their imaginations. The software opens up and gives its user free reign to draw, scale, and measure whatever his heart and needs dictate. Once designed, the software offers a myriad of simulation options; ranging from power based solutions to incident wave modeling. Then the simulations can be conducted thoroughly or quickly and with as much data across as many frequencies as warranted. Once all of the data has been generated, HFSS allows the user to process and analyze it in any way that satisfies its user's requirements. HFSS is an extremely versatile software package that has played no small part in assisting the world's engineers and scientists to advance the field of electromagnetism.

Ansys designed HFSS to use the FEM for solving complex microwave structures. This method will divide a structure into smaller pieces and define a "finite element." HFSS breaks objects down into many tetrahedrons and the combination of the separate tetrahedrons is called a mesh. Each individual tetrahedral is solved using Maxwell's equations while keeping each piece connected at its boundaries. A field solution is obtained for the entire structure by constructing the solutions from each piece. Once the field solution has been obtained for the entire form, an S-parameter matrix is generated. Because Maxwell's equations are the basis of the simulator, HFSS does not solve objects by using electric circuit parameters like voltages and currents; instead it uses electric and magnetic fields. These fields must be able to exist within the evaluated structures in order for HFSS to work properly.

HFSS does not just spit out information after a user presses "run," it forms a mesh and iteratively constructs and refines it, particularly in the areas where the fields are most complicated, to ensure it is computing the correct results. This process of redefining and updating meshes to approach the most correct solution is called an adaptive solution. The user can determine how much room for error will be allowed in the HFSS solution by defining the program's adaptive sweep settings.

Before HFSS begins to adaptively solve anything and after the user creates the model, the kind of solution the solver should work toward, the boundaries, and the excitations all have to be set. There are three solution types available in HFSS: driven modal, driven terminal, and eigenmode. The driven modal solution is the most common and is used when evaluating simple transmission line, microstrip, and waveguide structures. It presents its data in a conventional S-matrix. Driven terminal is similar to driven modal, but it is mainly used to solve transmission lines with multiple signals for Signal Integrity (SI) purposes. It also presents an S-matrix, but it is based on voltages and currents. The last solution type is the eigenmode solution. It provides a detailed report on the resonances in a structure and the fields at those resonant points.

Boundaries in HFSS are used to either create an electromagnetic model or to simplify and contain a geometric model. There are twelve boundary options to choose from, depending on the needs of the user. The most relevant one to this thesis is the Radiation boundary. This boundary type will create an open model and is applied to the outer surfaces of the user-defined area which is a quarter of a wavelength away from the simulated model. The radiation boundary is intended to set a point at which waves that will radiate to infinity will be truncated in order to keep the simulation as simple as possible.

There are seven excitation options in HFSS and they allow the user to indicate field, voltage, charge, and/or current sources to drive the simulation. Only two will be presented here. The wave port excitation is one of the most commonly used with transmission lines and is used in this thesis. It provides S, Y, and Z parameters and will also relay port impedance information. Because the wave port is seen as a waveguide when energy enters it, the port's size is an important consideration to take into account.

Drawing a structure, initializing "simulation rules," and determining how something should be solved are all it takes to use the electromagnetic solving capabilities of HFSS. The rendered solution can be as exact or approximate as the user wishes. The exact options and choices that were made concerning this thesis topic will be discussed as the project is presented [67].

In this work, the MSPA have been simulated by using the software Ansoft-HFSS based on Finite Element Method (FEM). The simulation technique was used to calculate the three dimensional electromagnetic fields inside a structure. The principle of this method is to divide the study area into many small regions (tetrahedrons), then calculating the local electromagnetic field in each element. The local fields tetrahedron elements from the following equations [55].

To validate the proposed structure, Ansoft HFSS was used to simulate the performance of the antenna. The commercial EM software version HFSS 15 is used for simulation and optimization. HFSS automatically generates field solutions, port characteristics, and s-parameters. It is able to quickly calculate antenna metrics such as gain, directivity, far-field pattern cuts, far field 3D plots, and 3dB beamwidth. The main advantage of the FEM is that, because the volume is discredited in tetrahedral, the shape of the antenna can be more accurately represented [55].

References

[1] Warren L. Strutzman and Gary A. Thiele, "Antenna theory and design", *John Wiely & Sons, Inc*, 1981.

[2] Constantine A. BALANIS, "Antenna theory: analysis and design" Third edition, *John Wiley & sons Inc*., 2005.

[3] Rappaport, Theodore S., Wireless Communications: Principles and Practice, Prentice Hall Communications Engineering and Emerging Technologies Series, 1999.

[4] Derek S. Linden, "Automated design and optimization of wire antennas using genetic algorithms", PhD thesis, Massachusetts *institute of technology*, 1997.

[5] Sophocles J. Orfanidis, "Electromagnetic waves and antennas", *ECE department, Rutgers University*. *Greece*. (www.ece.rutgers.edu/~orfanidis/ewa)

[6] C. A. Balanis, Antenna Theory: Analysis and Design, 2 nded., John Wiley and Sons:
` New York, 1997.

[7] A. W. Rudge, K. Milne, A. D. Olver, P. Knight, The Handbook of Antenna Design: Volume I, Peter Peregrinus Ltd.: London, 1982.

[8] T. A. Milligan, Modern Antenna Design, McGraw Hill: New York, 1985.

[9] L. V. Blake, Antennas, John Wiley and Sons: New York, 1966.

[10] Garg, R., Bhartia, P., Bahl, I., Ittipiboon, A., Microstrip Antenna Design Handbook, Artech House, Inc, 2001.

[11] K. Wong, Compact and Broadband Microstrip Antennas, John Wiley and Sons, New York, 2002.

[12] Kumar, G. and Ray, K.P., Broadband Microstrip Antennas, Artech House, Inc, 2003.

[13] James, J.R., and P.S. Hall, Handbook of Microstrip Antennas, Vol. 1, London: Peter Peregrines Ltd., 1989.

[14] Mailloux R. J. (1994), Phased Array Antenna Handbook, Artech House.

[15] Schelkunoff S. A. (1943), "A Mathematical Theory of Linear Arrays," *Bell System Technical Jour-nal*, Vol. 22, pp. 80–107.

[16] D. H. Werner and S. Gangul. An overview of fractal antenna engineering research. IEEE Antennas and Propagolion, 45, February 2003.

[17] P. Simedrea. Design and implementation of compact microstrip fractal antennas. Master's thesis, The University of Western Ontario, March 2004.

[18] Nathan Cohen. Fractal antenna applications in wireless telecommunications. Electronic Industries Forum of New England, Professional Program Proceedings, May 1997.

[19] G. Aulisio, H. Palacios, J. Vassallo, A 70 GHz Cassegrain antenna using a Fresnel reflector.

[20] M. Enlund, M. Sadrai, A. Derneryd, U. Engstrom, M. Johansson, B. Svensson, Parallel plate waveguide antenna for point - to - multipoint communication at millimeter-wave frequencies, Electronics letters Vol. 41.

[21] T. Komljenovic, Lens antennas - Analysis and synthesis at mm-waves.

[22] A. Neto, I. E. Lager, Non. dispersive, UWB leaky lens antenna for millimeter and sub-millimeter wave frequencies.

[23] K.Fujimoto et al.,Small Antenna, Research Studies Press, UK, 1987, p. 4.

[24] H. A. Wheeler, Fundamental Limitatioms of Small Antenna, Proceedings of IRE, vol. 35, Dec. 1947. Pp. 1479-1484.

[25] S. A. Schelkunoff and H. T. Friis,Antennas and Theory, John Wiley and Sons, 1952, chapter 10.

[26] R. W. P. King, the theory of Linear Antennas, Haravard University Press, 1956, p. 184.

[27] H. R. Stuart and A. Pilwerbetsky, Electrically Small Antenna Elements Using Negative Permittivity Resonator, *IEEE Transactions on Antennas and Propagation*, vol. 54, 2006, no. 6, pp. 1644–1653.

[28] J. L. Volakis, C.-C. Chen, and K. Fujimoto, *Small Antennas, Miniaturization Techniques and Applications*, McGraw-Hill, 2010, chapter 6.

[29] H. D. Folts and J. S. McLean, Limits on the Radiation Q of Electrically Small Antennas Re-Estimated to Oblong Bounding Regions, *IEEE Antennas and Propagation Society International Symposium*, July 1999, vol. 4, pp. 2702–2705.

[30] Sanchez-Hernandez, D., Robertson, I. D., “A survey of broadband microstrip patch antennas,” *Microwave Journal*, pp. 60-82, Sept. 1996.

[31] K. Wong, Compact and Broadband Microstrip Antennas, John Wiley and Sons, New York, 2002.

[32] H. F. Pues and A. R. Van de Capelle, “Impedance-matching technique for increasing the bandwidth of microstrip antennas,” *IEEE Transactions on Antennas and Propagat.*, vol. AP-37, no. 11, pp. 1345-1354, Nov. 1989.

[33] H. An., B. K. J. C. Nauwelaers, and A. R. Van de Capelle, “Broadband microstrip antenna design with the simplified real frequency technique,” *IEEE Transactions on Antennas and Propagat.*, vol. 42, no. 2, pp. 129-136,Feb. 1994.

[34] Vijay Gupta, Sumit Sinha, Shiban K. Koul, and Bharathi Bhat,“Wideband dielectric-resonator loaded suspended microstrip patch antennas,” *Microwave and Optical Technology Letters*, vol. 37, no. 4, pp. 300-302, May 2003.

[35] G. Kumar and K. C. Gupta, “Directly coupled multiple resonator wideband microstrip antenna,” *IEEETrans. Antennas Propagat.*, vol. AP-33, pp. 588–593, June 1985.

[36] R. B. Waterhouse, “Design of probe-fed stacked patches,” *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 12, pp. 17801784, Dec. 1999.

[37] A. Mitchell, M. Lech, D. M. Kokotoff, and R. B. Waterhouse, “Search for high-performance probe-fed stacked patches using optimization,” *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 2, pp. 249-255, Feb. 2003.

[38] D. M. Kokotoff, J. T. Aberle, and R. B. Waterhouse, “Rigorous analysis of probe-fed printed annular ring antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 2, pp. 384-388, Feb. 1999.

[39] H. R. Hassani and D. Mirshekar-Syahkal, “Analysis of stacked rectangular patch antennas with nonaligned patches or unequal patch sizes,” *IEEE Transactions on Antennas and Propagation*, vol. 42, no. 9, pp. 1333-1336, Sept. 1994.

[40] Z. N. Chen and M. Y. W. Chia, “Broad-band suspended probe-fed plate antenna with low cross-polarization levels,” *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 2, pp. 345-346, Feb. 2003.

[41] Y.-X. Guo, C. L. Mak, K. M. Luk, and K. F. Lee, “Analysis and design ofL-probe proximity-fed patch antennas,” *IEEE Transactions on Antennas* for designing broad-band microstrip antennas in multilayered planar structures,” *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 9, pp. 1416-1420, Sept. 1999.

[42] Z. N. Chen and M. Y. W. Chia, “Design of broadband probe-fed plate antenna with stub,” *IEE Proceedings on Microwaves, Antennas and Propagation*, vol. 148, no. 4, pp. 221-226, Aug. 2001.

[43] C. L. Mak, K. M. Luk, K. F. Lee, and Y. L. Chow, “Experimental study of a microstrip patch antenna with a L-shaped probe," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 5, pp. 777-783, May 2000.

[44] C. L. Mak, K. M. Luk, and K. F. Lee, “Wideband triangular patch antenna,” *IEE Proceedings on Microwaves, Antennas and Propagation*, vol. 146, no. 2, pp. 167-168, Apr. 1999.

[45] Y.-X. Guo, K.-M. Luk, and K.-F. Lee, “L-probe proximity-fed annular ring microstrip antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 49, no. 1, pp. 19-21, Jan.2001.

[46] G. A. E. Vandenbosch and A. R. Van de Capelle, “Study of the capacitively fed microstrip antenna element,” *IEEE Transactions on Antennas and Propagation*, vol. 42, no. 12, pp. 1648-1652, Dec. 1994.

[47] Z. F. Liu, P. S. Kooi, L. W. Li, M. S. Leong, and T. S. Yeo, “A method for designing broad-band microstrip antennas in multilayered planar structures,” *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 9, pp. 1416-1420, Sept. 1999.

[48] M. A. Gonzalez de Aza, J. Zapata, and J. A. Encinar, “Broad-band cavity backed and capacitively probe-fed microstrip patch arrays,” *IEEETransactionson Antennas and Propagation*,vol. 48, no. 5, pp.784-789,May2000.

[49] Z. N. Chen and M. Y. W. Chia, “Broadband suspended plate antenna with probe-fed strip,” *IEE Proceedings on Microwaves, Antennas and Propagation*, vol. 148, no. 1, pp. 37-40, Feb. 2001.

[50] K. F. Tong, K. M. Luk, K. F. Lee, and R. Q. Lee, "A broad-band U-slot rectangular patch antenna on a microwave substrate," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 6, pp. 954-960, June 2000.

[51] S. Weigand, G. H. Huff, K. H. Pan, and J. T. Bernhard, "Analysis and design of broad-band single-layer rectangular U-slot microstrip patch antennas," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 3, pp. 457-468, Mar. 2003.

[52] Z. Nie, W. C. Chew, and Y. T. Lo, "Analysis of the annular-ring-loaded circular-disk microstrip antenna," *IEEE Transactions on Antennas and Propagation*, vol. 38, no. 6, pp.806-813, June 1990.

[53] D. M. Kokotoff, R. B. Waterhouse, and J. T. Aberle, "An annular-ring coupled to a shorted patch," *IEEE Transactions on Antennas and Propagation*, vol. 45, no. 5, pp. 913-914, May1997.

[54] Gordon Mayhew-Ridgers, "Development and modeling of new wideband microstrip patch antennas with capacitive feed probes," Ph. D. thesis, Dept. of Elect. and Comp. Eng., University of Pretoria, July 2004.

[55] A. Hoorfar and V. Jamnejad, "electromagnetic modeling and analysis of wireless communiation antennas," *IEEE Microwave Magazine*, vol. 4, no.1, p. 51, 2003.

[56] J. R. James, and P. S. Hall, Handbook of Microstrip Antennas, Peter eregrinus Ltd. London United Kingdom 1989.

[57] I. J. Bahl, and P. Bhartia, Microstrip Antennas, Artech House, Dedham, MA, 1980.

[58] S. Weigand, G. H. Huff, K. H. Pan, and J. T. Bernhard, "Analysis and design of broad-band single-layer rectangular U-slot microstrip patch antennas," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 3, pp. 457-468, Mar. 2003.

[59] S. D. Targonski, R. B. Waterhouse, and D. M. Pozar, "Design of wideband aperture-stacked patch microstrip antennas," *IEEE Trans. Antennas Propagat.*, vol. 46, no. 9, pp.1245-1251, September 1998.

[60] S. Gao, and A. Sambell, "Broadband dual-polarized proximity coupled circular patch antenna," *Microwave and optical Technology Letters*, vol. 47, no. 3, pp. 298-302, November 2005.

[61] Gordon Mayhew-Ridgers, Johann W. Odendaal, and Johan Joubert, “Entire-domain versus subdomain attachment modes for the spectral domain method of moments analysis of probe-fed microstrip patch antennas,” *IEEE Trans. Antennas Propagat.*, vol. 52, no. 6, pp.1616-1620, June 2004.

[62] Kazuhiro Hirasawa, Misao Haneishi, Analysis, Design, and measurement of small and low-profile Antennas, Artech House, Inc., Boston, London, 1992.

[63] E. O. Hammerstad, “Equations for microstrip circuit design,” *proc. 5 European Microwave Conf.*, pp. 268-272, 1975.

[64] A. G. Derneryd, “Linearly polarized microstrip antennas,” *IEEE Transactions on Antennas and Propagation*, vol. Ap-24, pp. 846-850, *Th* November 1976.

[65] M. A. Gonzalez de Aza, J. Zapata, and J. A. Encinar, “Broad-band cavity backed and capacitive probe-fed microstrip patch arrays,” *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 5, pp. 784-789,May 2000.

[66] David. B. D. (Ed.). (2011). *Computational electromagnetics for RF and microwave engineering.* Cambridge University press,

[67] Ansys Corporation, *HFSS Online Help.*

[68] http://www.slideshare.net/totitarek/microstrip-antenna-15491076

Chapter 3

Bandwidth enhancement of Microstrip Patch Antenna using New Feeding Technique (indirect probe feed)

3.1: Introduction to Antenna design

The design parameters and results for a rectangular microstrip patch antenna in HFSS software is explained and the results obtained from the simulations are demonstrated. The microstrip patch design is achieved by using probe and use new technique is indirect feed technique will be demonstrated later. It offers high bandwidth and consistency gain where parametric solutions were proved it.

For conventional probe-fed microstrip antennas with a thick substrate, the major problem associated with impedance matching is the large probe reactance owing to the required long probe pin in the thick substrate layer. To solve this problem, a variety of designs with modified probe feeds have been reported [1].

The geometries of antenna design are shown in figure 3.1 in three dimensions, the air-based substrate having ε_r = 1 is h = 5 mm in thickness, 12 cm along the *x*-axis and 11 cm along the *y*-axis. The feed probe (coaxial) has a characteristic impedance of 50 ohms. The patch is a rectangle of 6 cm along the x-axis and 5.31 cm along the y-axis. The rectangular part of the ground plane is (12 cm×11 cm). A coaxial probe is connected to the patch at a location (0.6cm, 2.19cm).

In this thesis, the proposed antenna is designed using HFSS software, whose dimensions were calculated according to the transmission line model equations as mentioned in chapter 2 equations. After simulation and optimization, the final dimensions are shown in the figure 3.1.

The essential parameters for the design of a rectangular microstrip Patch Antenna are:

- Patch length along the X axis (lx): The length along the X axis was adjusted to be 6 cm in order to obtain better results.
- Patch length along the Y axis (ly): The length along the Y axis was adjusted to be 5.31 cm in order to obtain better results.
- Frequency of operation (f_o): The resonant frequency of the antenna must be selected appropriately. The resonant frequency selected for our design is 2.5 GHz.

- Dielectric constant of the substrate (ε_r): The dielectric material selected for our design has a dielectric constant of 1.

- Height of dielectric substrate (h): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is 5 mm.

- Length of substrate (l): The dielectric material selected for our design has a the length along the X axis was adjusted to be 12 cm

- Width of substrate (w): The dielectric material selected for our design has a the width along the Y axis was adjusted to be 11 cm

- Length of probe feed (Lf):The length of probe feed selected for our design has a the length along Z axis was adjusted to be 2 cm

- Radius of probe feed (Rf): The radius of probe feed selected for our design was adjusted to be 1 mm

- Position of probe feed (Pf): The position of probe feed selected for our design was adjusted to be (0.6cm, 2.19cm)

Hence, the essential parameters for the design are:

- l_x= 6 cm
- $l_{y=}$= 5.31 cm
- f_o = 2.5 GHz
- ε_r = 1
- h = 5 cm
- l = 12 cm
- w = 11 cm
- Lf= 2 cm
- Rf = 0.34 cm
- Pf = (0.6cm, 2.19cm)

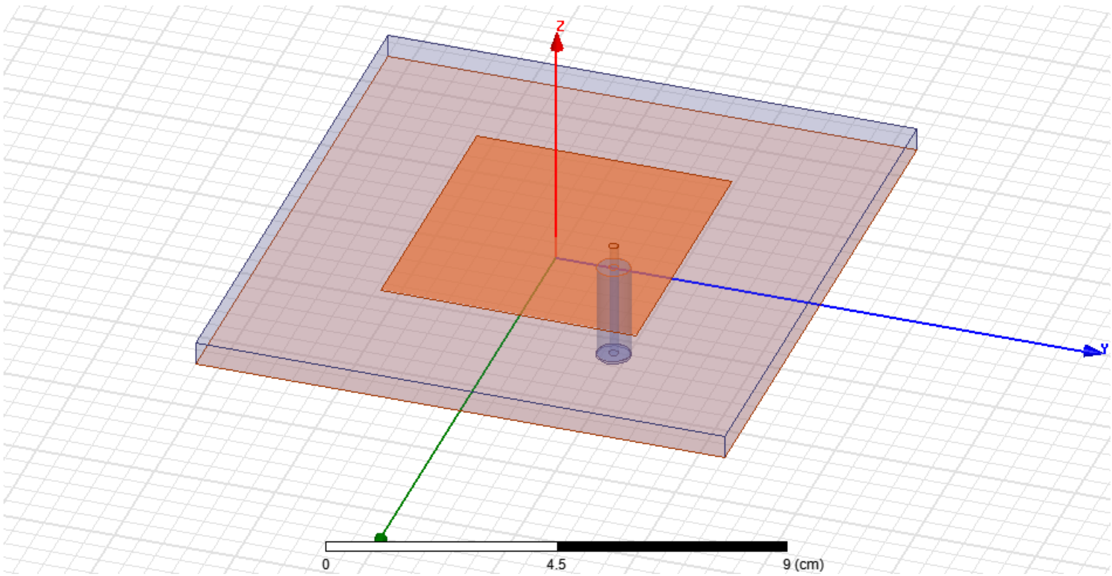


Figure 3. 1: The proposed microstrip patch in HFSS 15 environment in 3D.

The antenna with pervious parameter is simulated by HFSS. From the figure 3.2, frequency f_l is taken as 2.40 GHz and f_h is taken as 2.51 GHz. And the gain of antenna is 9.5 dB as shown in figure 3.3. Therefore the bandwidth is obtained after doing calculation as 4% as shown in Table 3.1. The input impedance versus the frequency is shown figure 3.4.

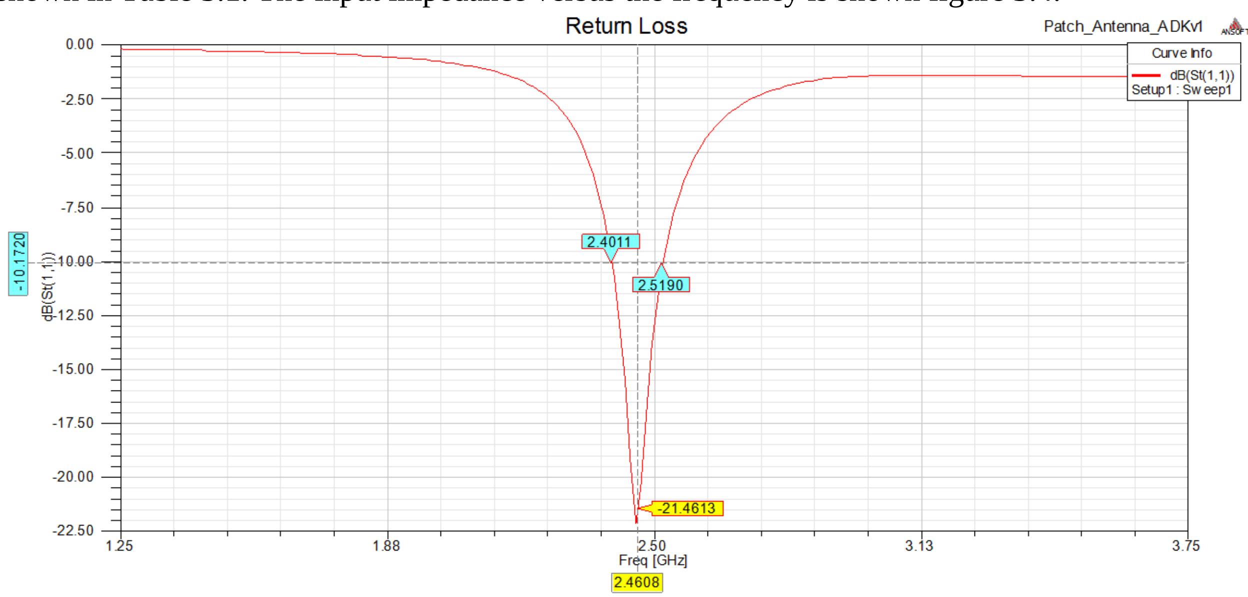


Figure 3. 2: Return loss of microstrip patch antenna.

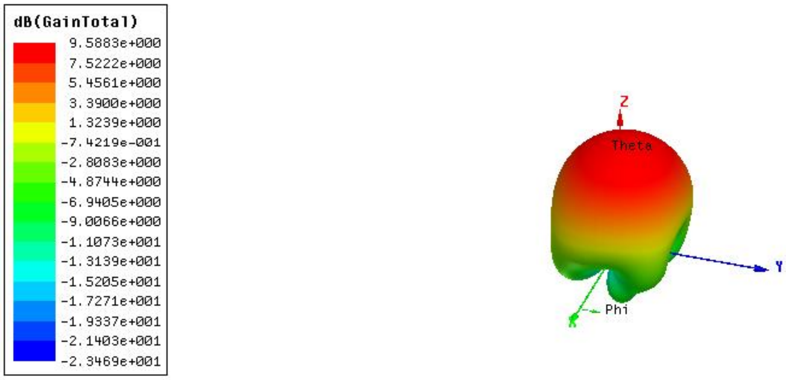


Figure 3. 3: Gain of microstrip patch antenna.

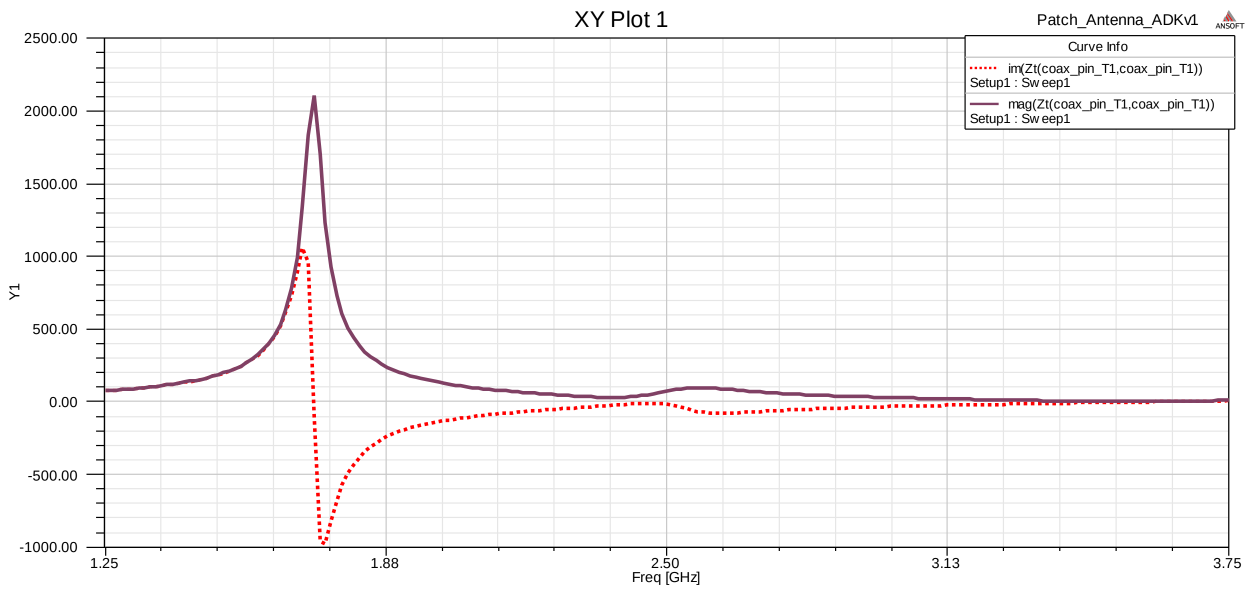


Figure 3. 4: Input impedance of microstrip patch antenna.

Parameters	Value
f_h	2.5 GH
f_l	2.4 GHz
f_o	2.46 GHz
BW= $f_h - f_l$	100 MHz
BWr%=$\frac{BW}{fo}$ * 100	4 %

Table 3. 1: Results of MSP antenna.

3.2: MSP antenna with parasitic

In this section we used parasitic patch with the same parameter of basic antenna and we used parasitic patch dimensions 1 cm x 2.5 cm as shown in figure 3.5.

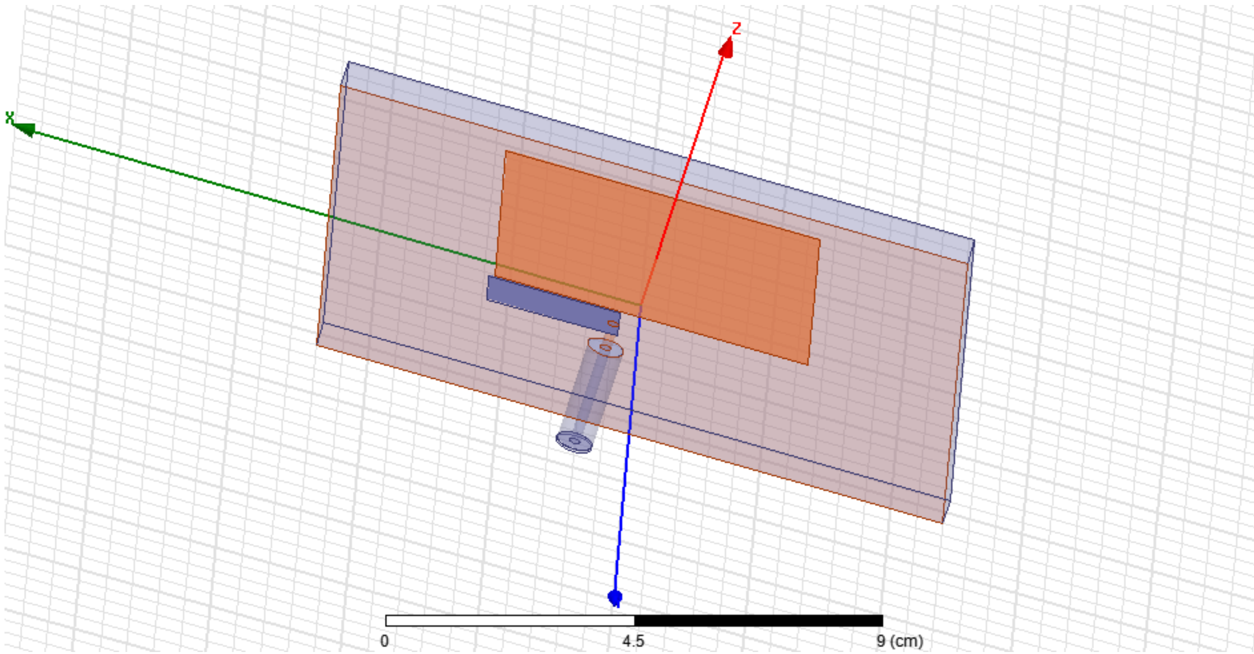


Figure 3. 5: The proposed MSP antenna with parasitic.

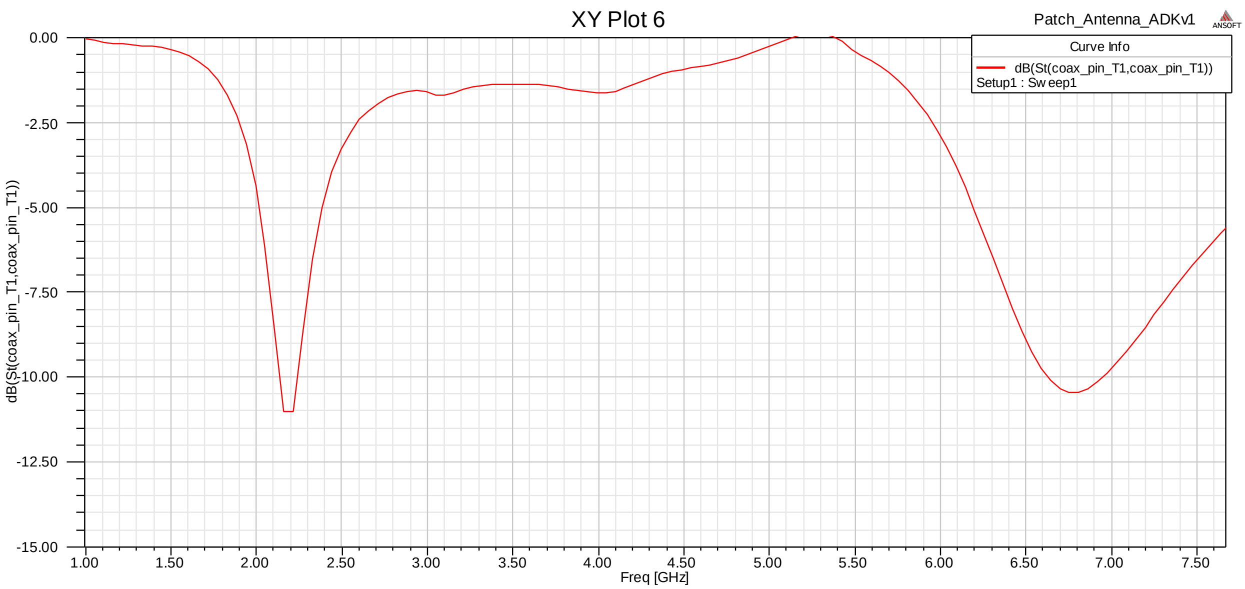


Figure 3. 6:Return loss of MSP antenna with parasitic.

Return loss results shown in figure 3.6 at resonance frequency (fo) are very bad. In table 3.2 we find the height and low frequency are shifted and the bandwidth ratio increased 0.5 %.

Parameters	Value
f_h	2.13 GHz
f_l	2.24 GHz
f_o	2.20 GHz
BW= $f_h - f_l$	100 MHz
BWr%= $\frac{BW}{fo} * 100$	4.5 %

Table 3. 2: Results of MSP antenna with parasitic

Also in figure 3.7 we find that the gain decreased from 9.5 dB to 8.6 dB. By comparing between Input impedance in basic antenna at figure 3.1 and the input impedance in parasitic patch antenna at figure 3.8 we find that a parasitic was worse.

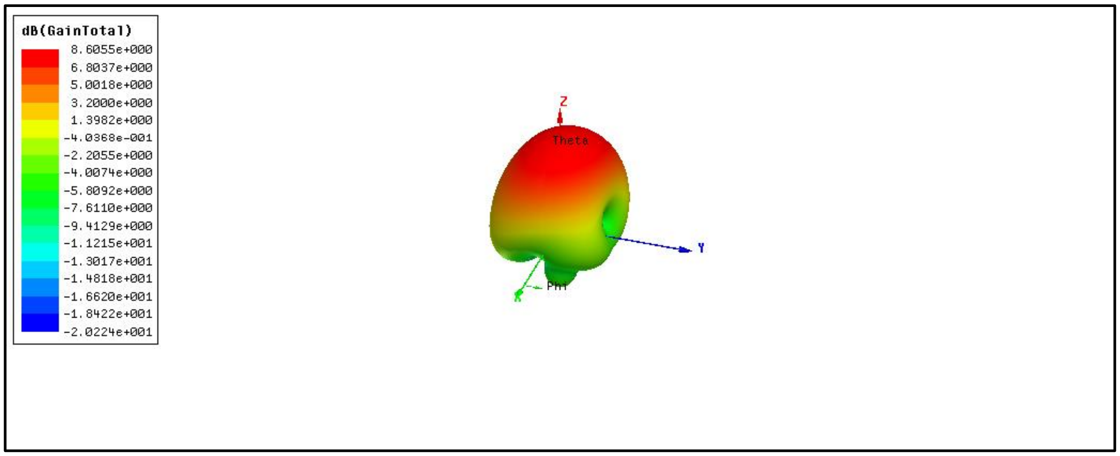


Figure 3. 7: Gain of MSP antenna with parasitic.

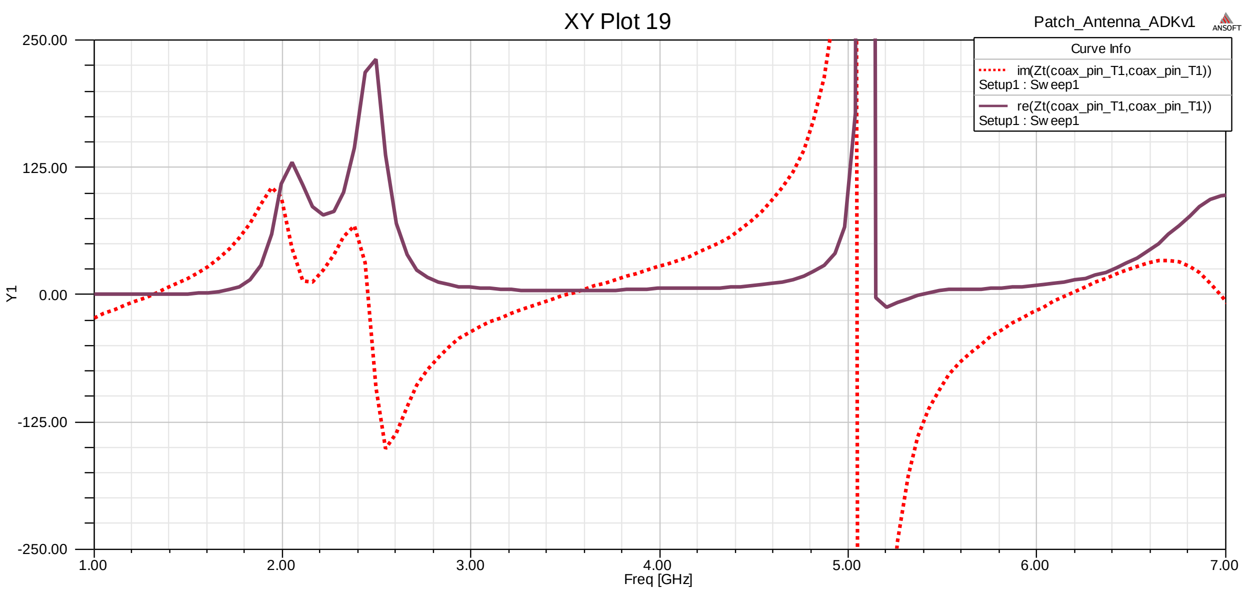


Figure 3.8: Input impedance of MSP antenna with parasitic.

3.3: Bandwidth enhancement of antenna using new feeding technique IPF.

The goal of this section is to enhance bandwidth of microstrip antenna by trying connect the probe feed and patch indirectly by using stripline connecting between the patch and probe feed.

Dimensions of indirect probe feed length is 0.5 cm and width is 1 cm and position is 0cm form edge of the patch on Y-axis and dimension of stripline is 2.5 cm x 1 cm as shown in the figure 3.9.

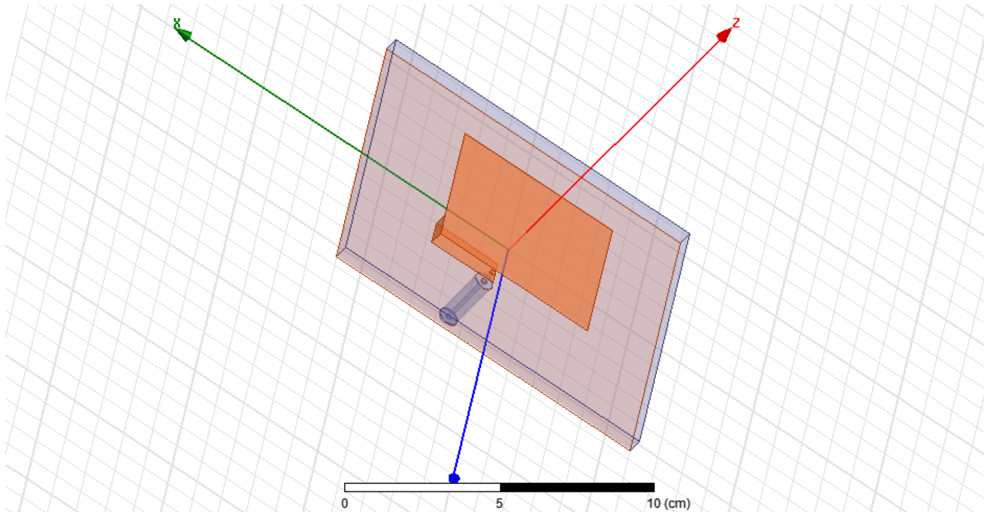


Figure 3. 9: MSP antenna with IPF at stripline position = 0cm.

Based on simulation it on HFSS,in figure 3.10 we mention there are Bandwidth is enhanced for microstrip patch antenna 6.2 % from the basic antenna as shown in table 3.3 and there are multiband frequency with different gain as shown in table 3.4.

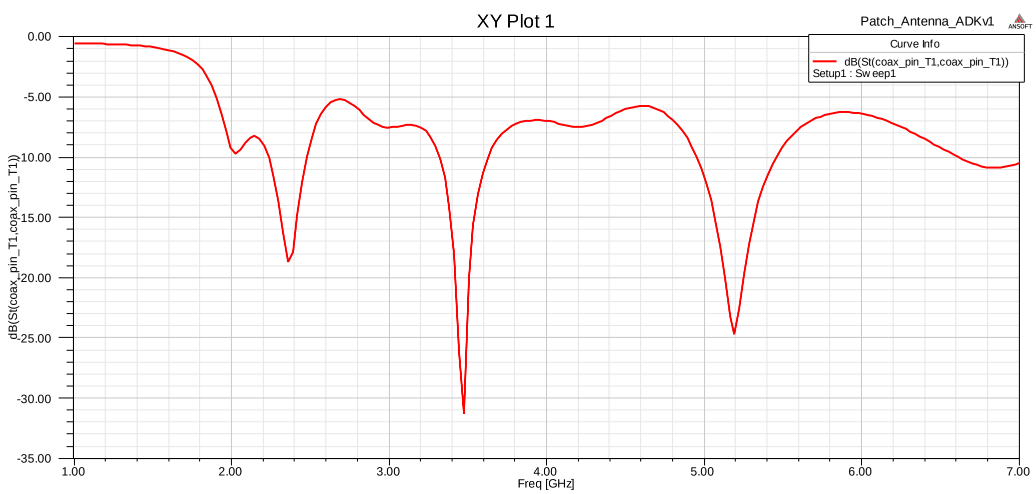


Figure 3. 10: Return loss of MSP antenna with IPF position = 0cm.

Parameters	Value
f_h	2.23 GHz
f_l	2.47 GHz
f_o	2.35 GHz
$BW= f_h - f_l$	241 MHz
$BWr\%=\frac{BW}{fo} * 100$	10.28 %

Table 3. 3: Results of MSP antenna with IPF.

IPF position= 0 cm	F_r (GHz)	S_{11}(dB)	BW (MHz)	Gain dB
First band	2.35	-18.72	241	9.6
Second band	3.47	-31.29	300	8.17
Third band	5.19	-24.65	500	9.5

Table 3. 4: MSP antenna parameters with IPF position = 0cm.

The input impedance was also within the range from 32Ω to 35Ω at resonance frequencies as illustrate in the figure 3.11.

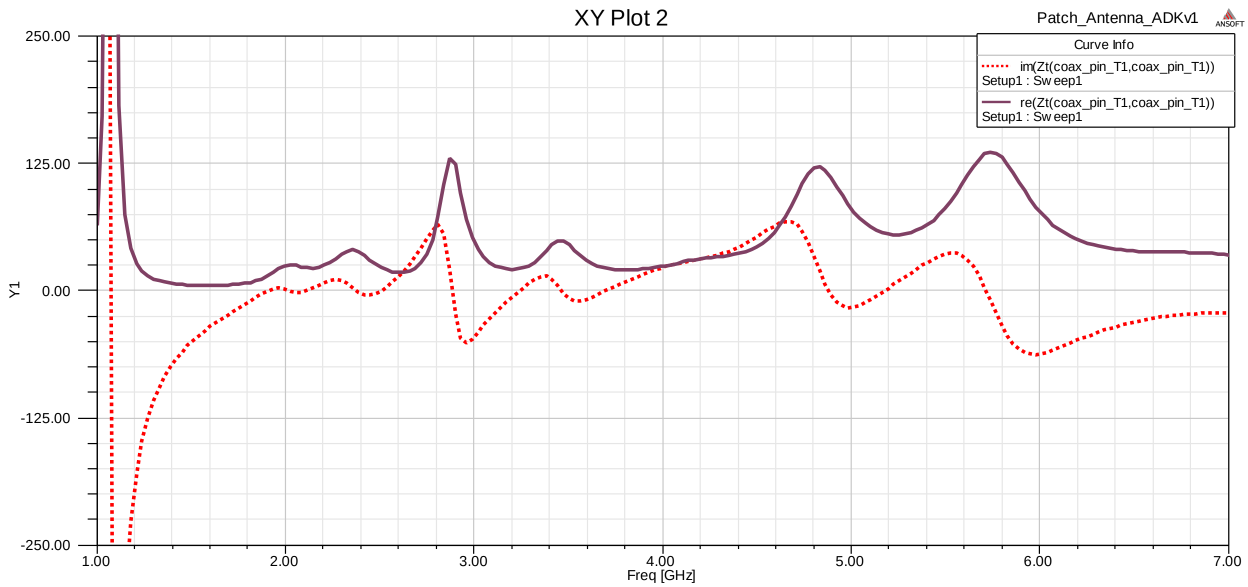


Figure 3. 11: Input impedance of gain MSP antenna with IPF position = 0cm.

3.4: Change the position of with indirect probe feeding

In this section we want to change the position of stripline on Y-axis to find the optimum result where this change factor is y=.86 cm.

At IPF position on y As shown in figure 3.12

We find the return loss change as shown in figure 3.13 also from table 3.5 we find that the return loss worse than the previous position and the gain 9.6 dB as shown in figure 3.14 also the input impedance versus with resonance frequencies shown in figure 3.15 .

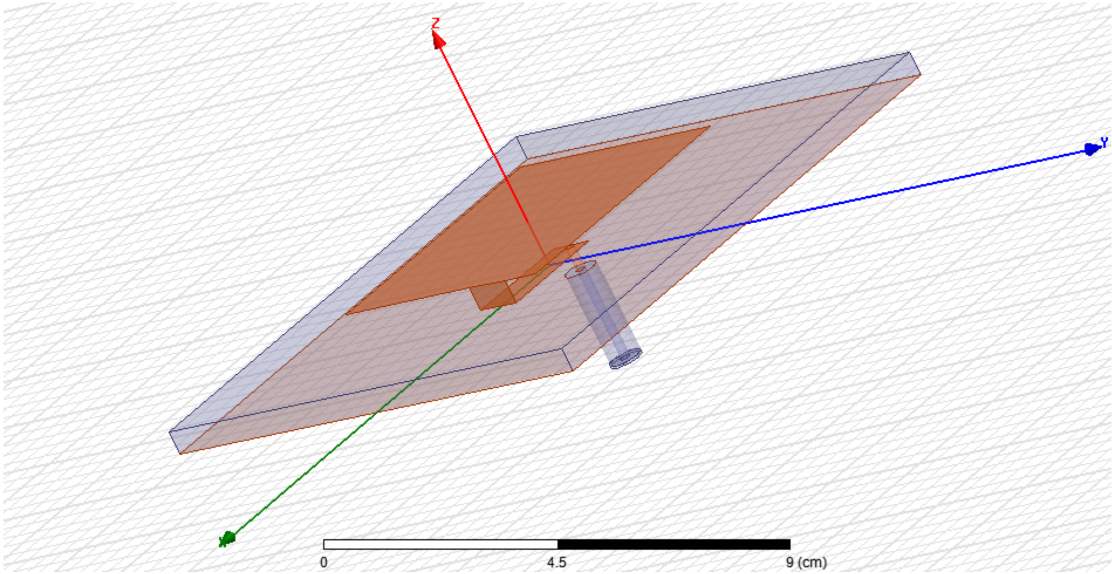


Figure 3. 12: MSP antenna with IPF position = y cm.

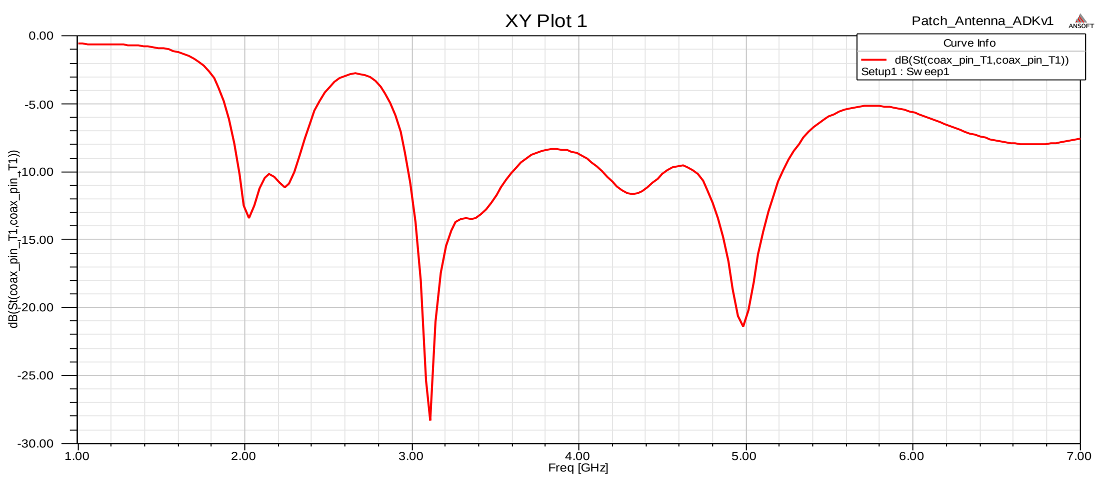


Figure 3. 13: Return loss of MSP antenna with IPF position =y cm.

IPF position = y cm	F_r (GHz)	S_{11} (dB)	BW (MHz)
First band	2.02	-13.41	335
Second band	3.11	-28.25	624
Third band	4.97	-21.39	523

Table 3. 5: MSP antenna parameters with IPF position = y cm.

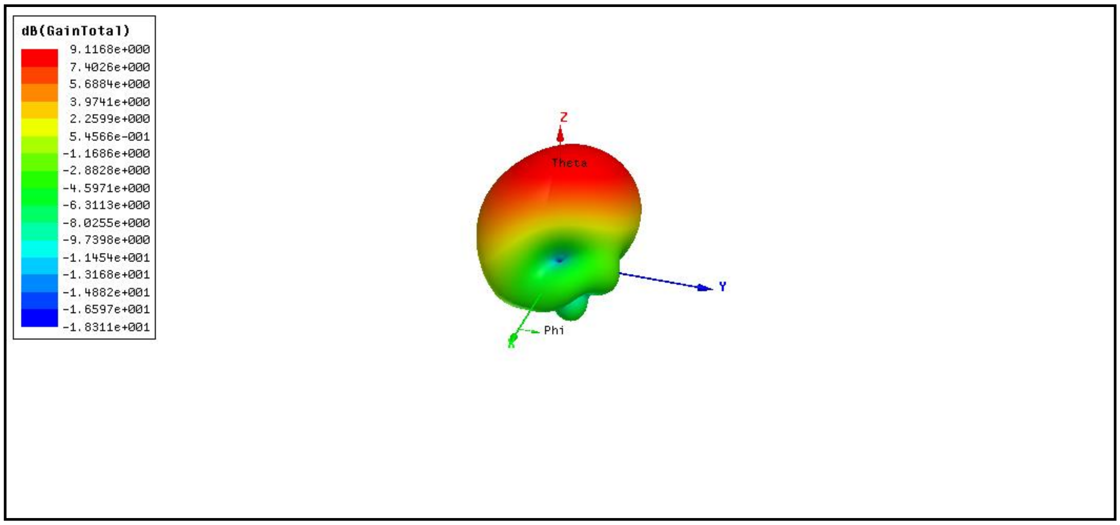


Figure 3. 14: Gain of MSP antenna with IPF position = y cm.

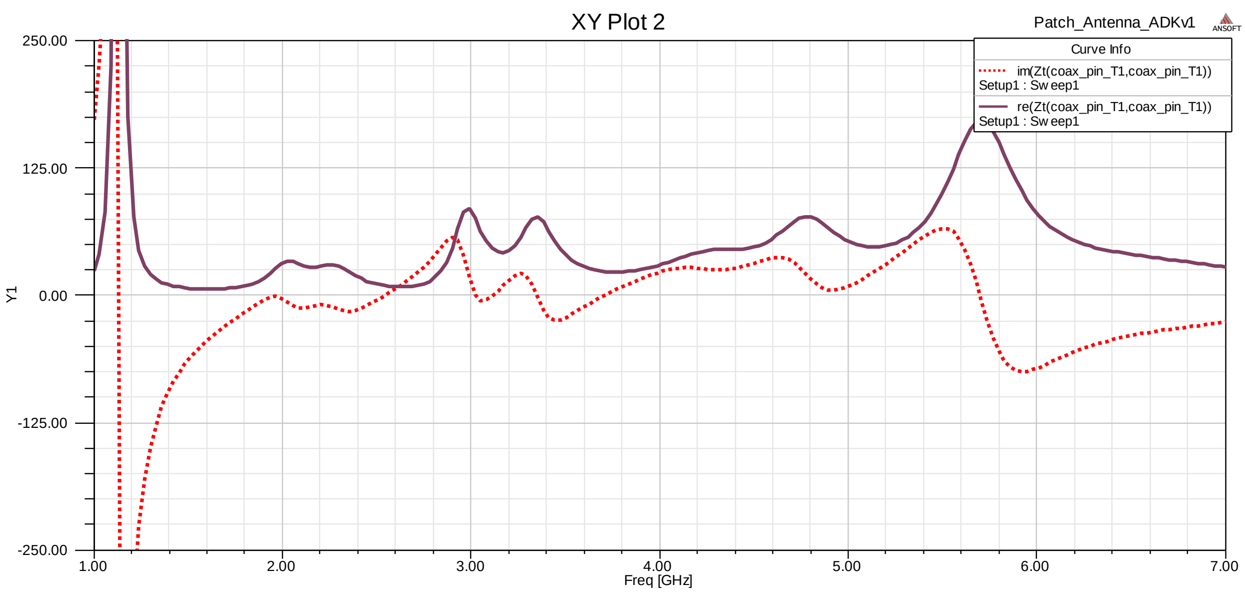


Figure 3. 15: Input impedance of MSP antenna with IPF position = y cm.

At IPF position on 2y cm as shown in figure 3.16

From figure 3.17 we find that the return loss change by change the position and the multiband decreased to be two multiband comparing the return loss to the basic position 0 cm show that better than but the bandwidth decreased as shown in table 3.6 , figure 3.18 show that the gain decrease. The input impedance show in figure 3.18 show that versus with the frequencies within 50 Ω to 75 Ω.

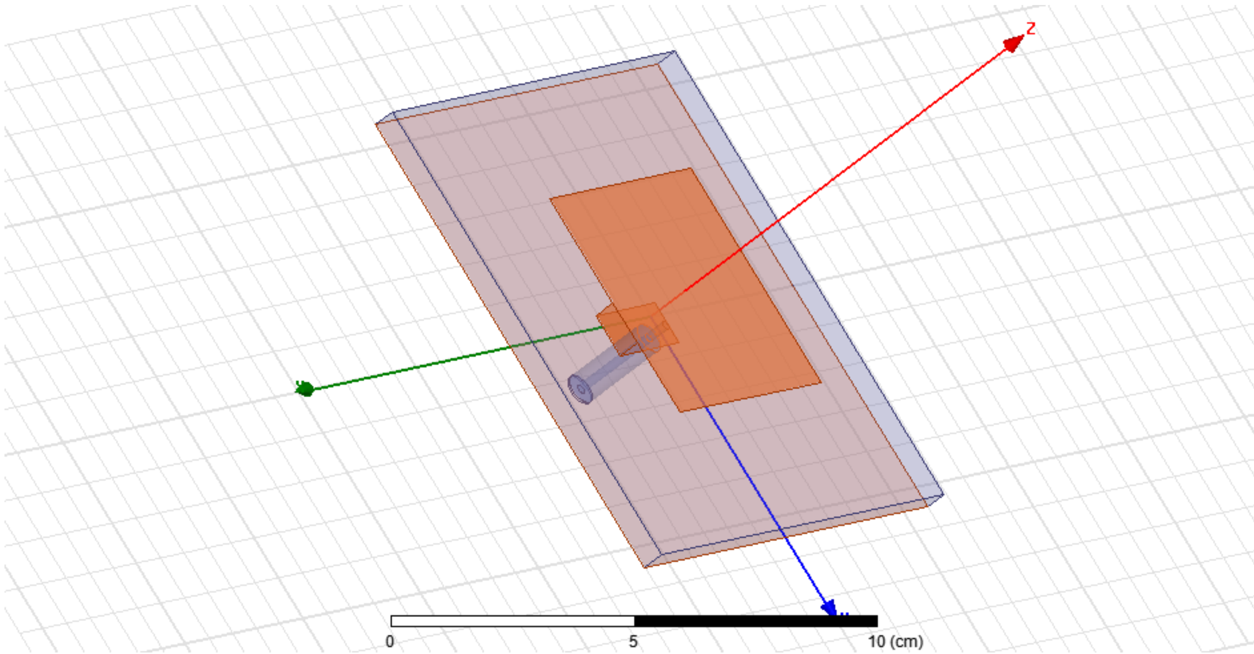


Figure 3. 16: MSP antenna with IPF position = 2y cm.

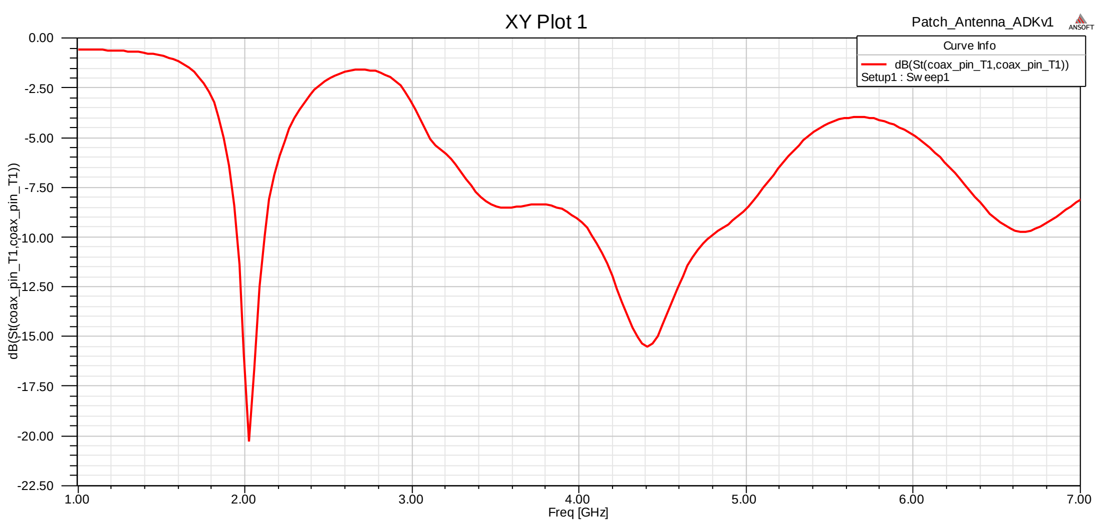


Figure 3. 17: Return loss of MSP antenna with IPF position = 2y cm.

IPF position = 2y cm	F_r	S_{11}	BW
First band	2.025GHz	-20.25dB	162MHz
Second band	4.4GHz	-15.47dB	684 MHz

Table 3. 6: MSP antenna parameters with IPF position = 2y cm.

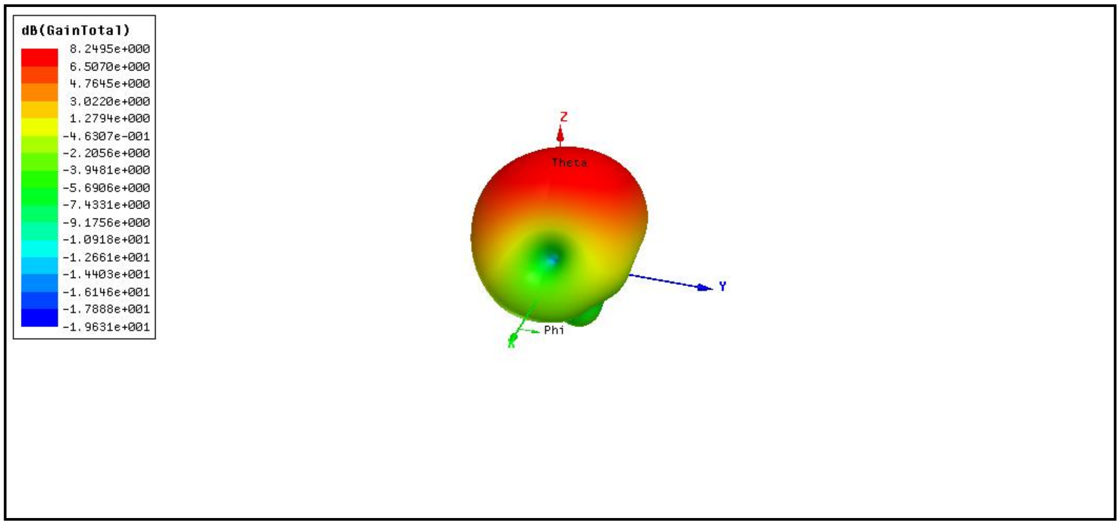


Figure 3. 18: Gain of MSP antenna with IPF position = 2y cm.

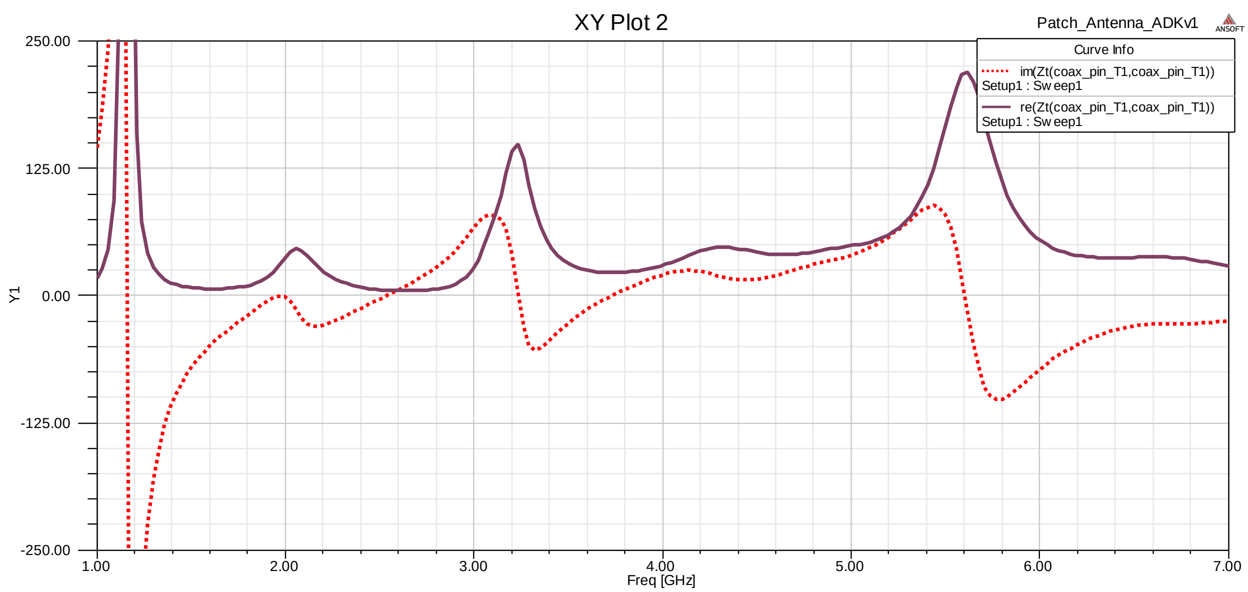


Figure 3. 19: Input impedance of MSP antenna with IPF position = 2y cm.

At IPF position on 3y cm as shown in figure 3.20

From figure 3.21 show that the return loss of the antenna it be two multi band and two resonant frequencies it be the nearly the same value compare with the previous position of IPF =-1.72. Gain and input impedance from figure 3.22, 3.23 as shown below there are nearly the same value of previous position

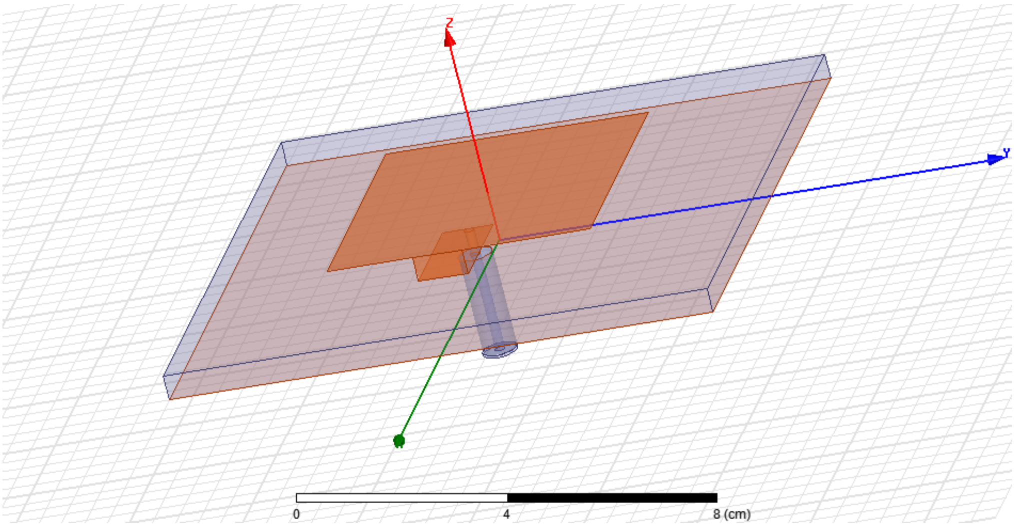


Figure 3. 20: MSP antenna with IPF position = 3y cm.

Figure 3. 21: Return loss of MSP antenna with IPF position = 3y cm.

IPF position = 3y cm	F_r	S_{11}	BW
First band	2.025GHz	-18.61dB	180MHz
Second band	4.4GHz	-15.46dB	644 MHz

Table 3. 7: MSP antenna parameters with IPF position = 3y cm.

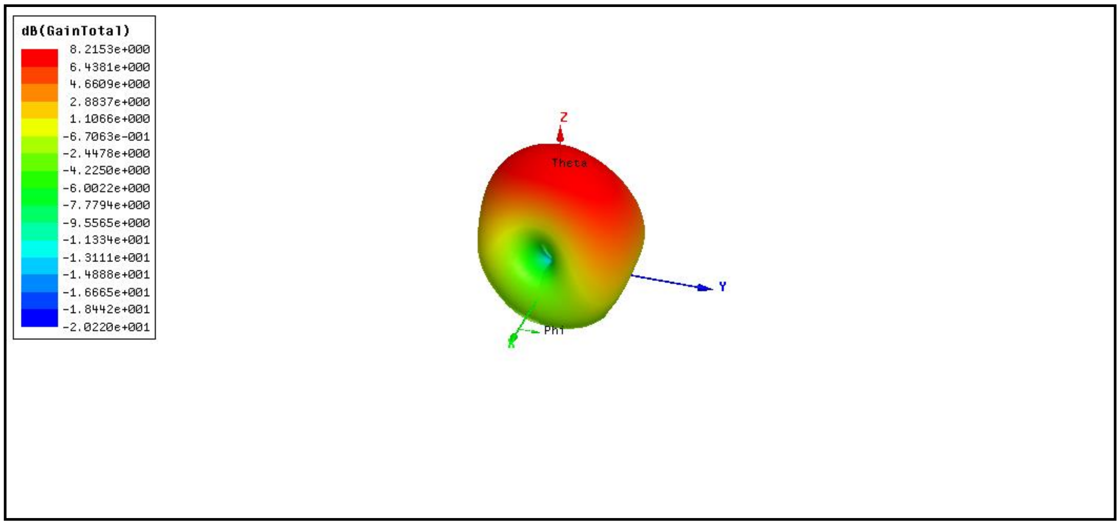


Figure 3. 22: Gain of MSP antenna with IPF position = 3y cm.

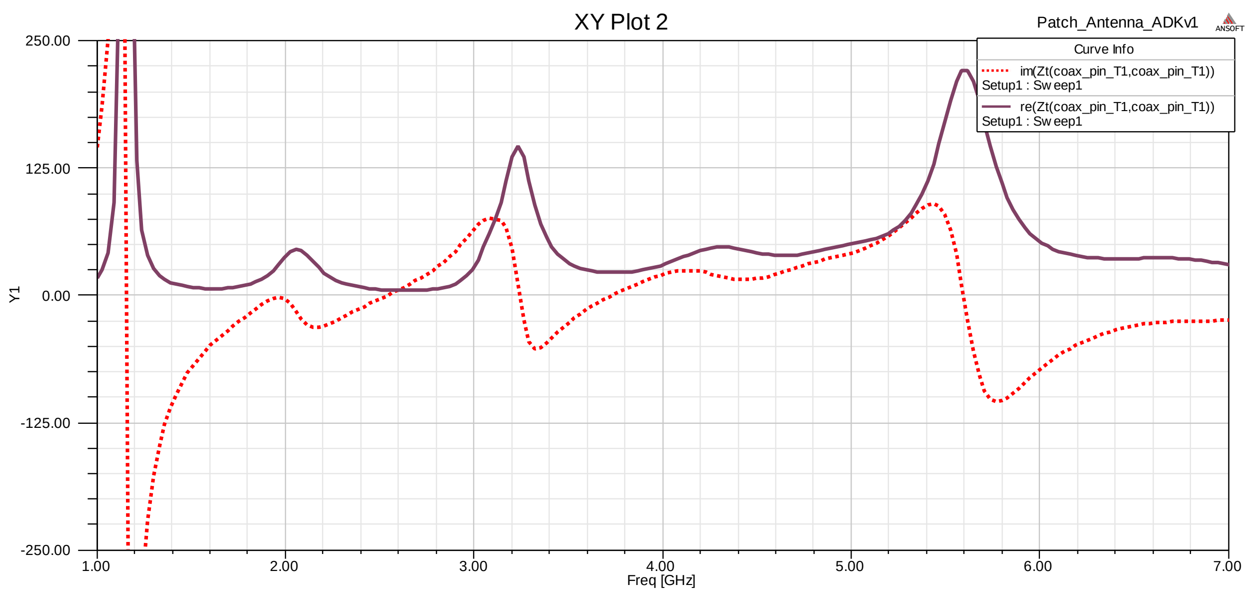


Figure 3. 23: Input impedance of MSP antenna with IPF position = 3y cm.

At IPF position on 4y cm as shown in figure 3.24

From figure 3.25, figure 3.26 figure 3.27 and table 3.8 shows that the result be the nearly the same with position IPF= y cm.

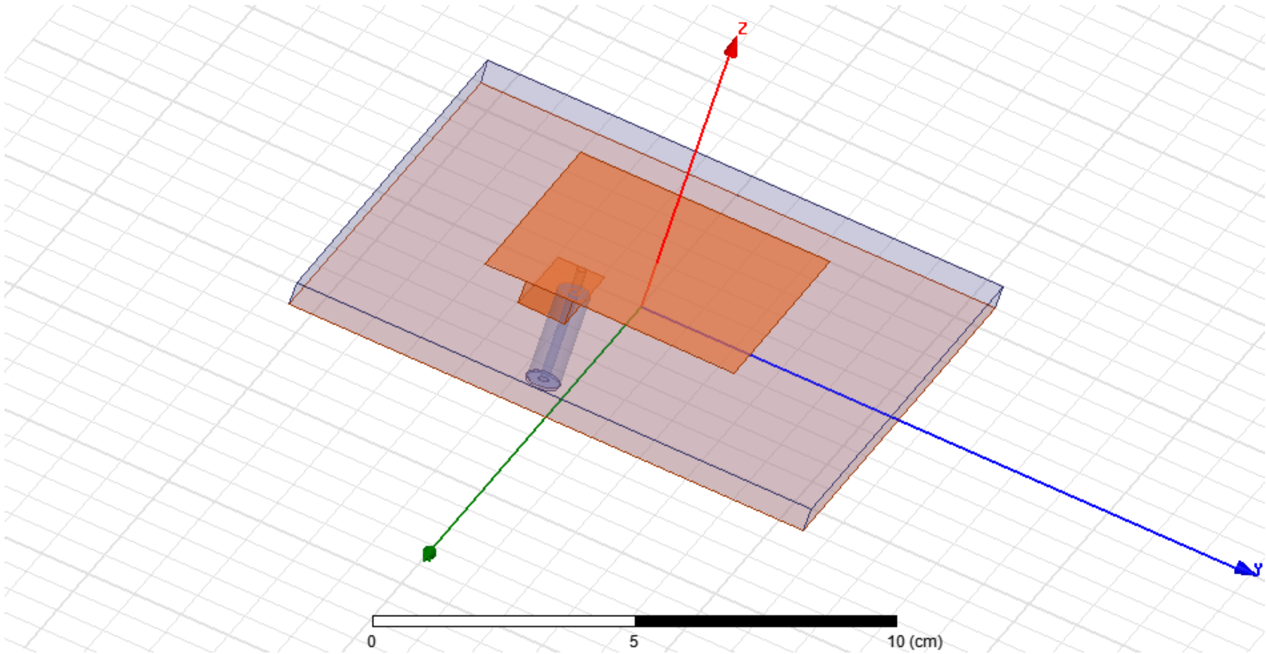


Figure 3. 24: MSP antenna with IPF position = 4y cm.

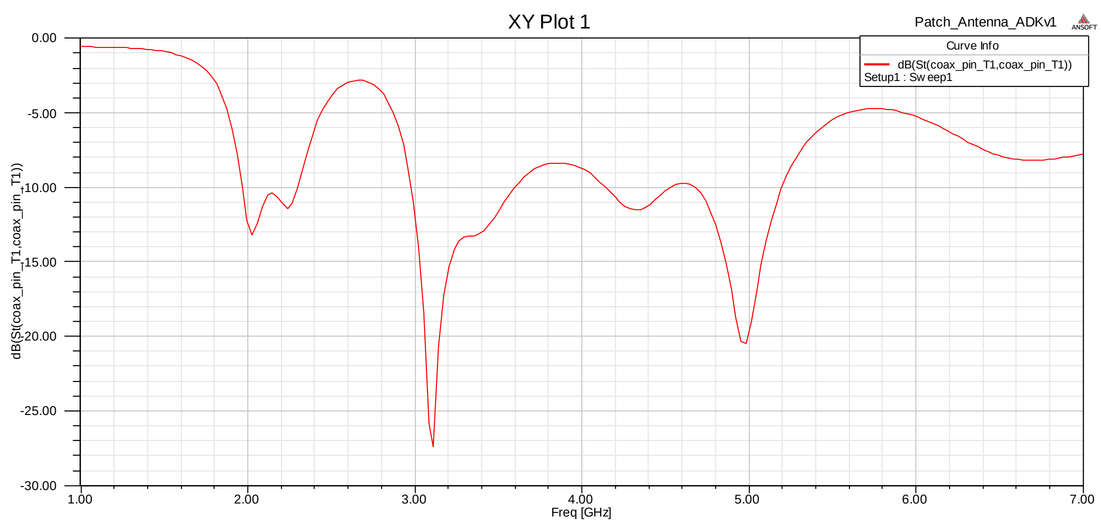


Figure 3. 25: Return loss of MSP antenna with IPF position = 4y cm.

IPF position = 4y cm	F_r	S_{11}	BW
First band	2.14	-10.37	334
Second band	3.11	-27.39	611
Third band	4.97	-20.42	523

Table 3. 8: MSP antenna parameters with IPF position = 4y cm.

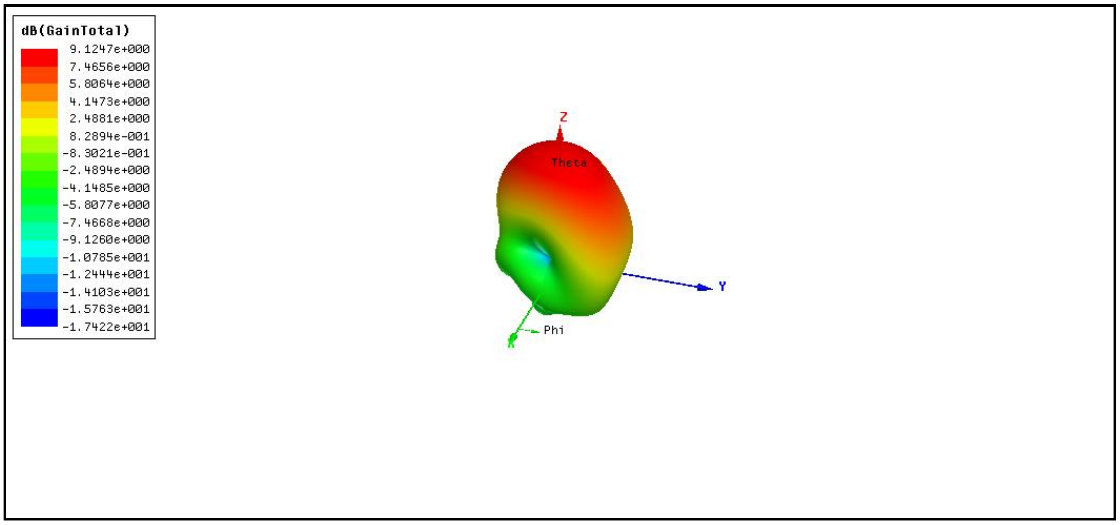


Figure 3. 26: Gain of MSP antenna with IPF position = 4y cm.

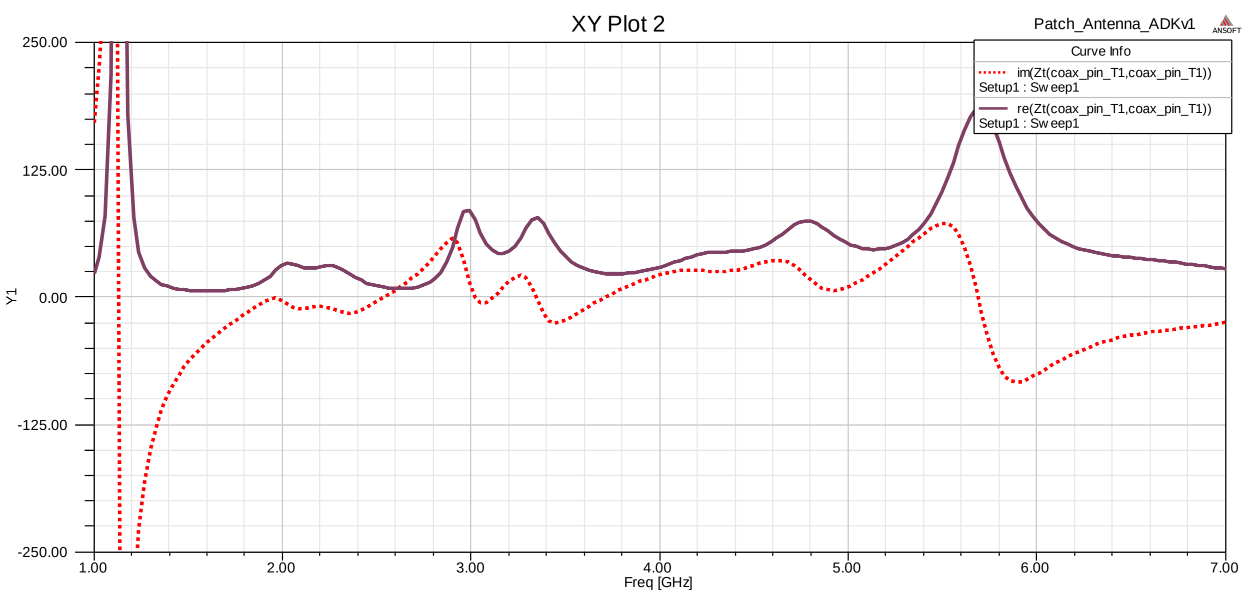


Figure 3. 27: Input impedance of MSP antenna with IPF position = 4y cm.

At IPF position on 5y cm as shown in figure 3.28

It shows that the antenna result again it value in the other side of patch as shows in figure 3.29, figure 3.30 , figure 3.31 and table 3.9. From results of simulation show that the best result when the antenna on the side.

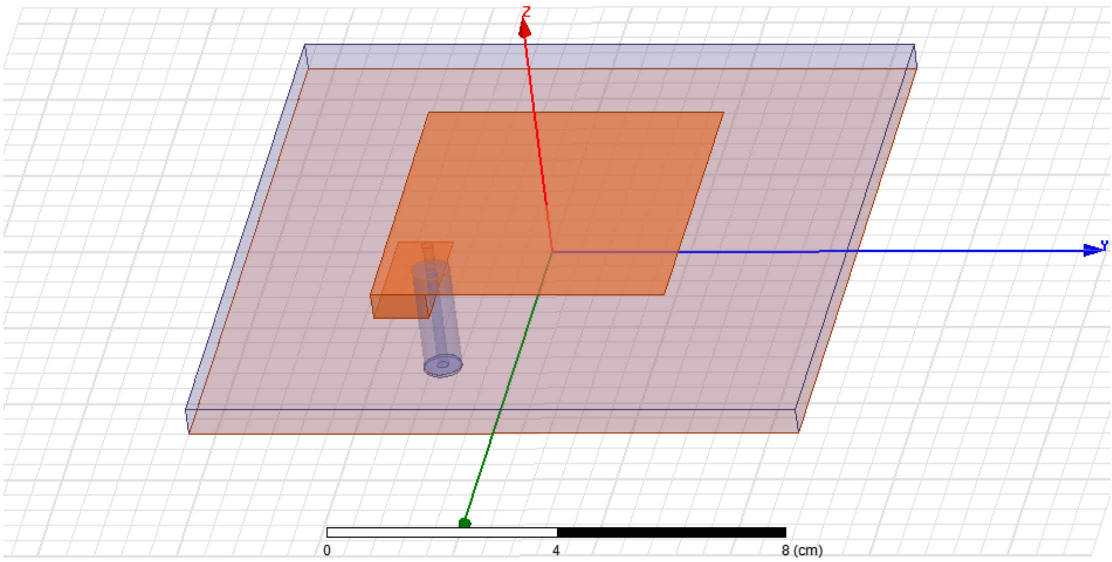


Figure 3. 28: MSP antenna with IPF position = 5y cm.

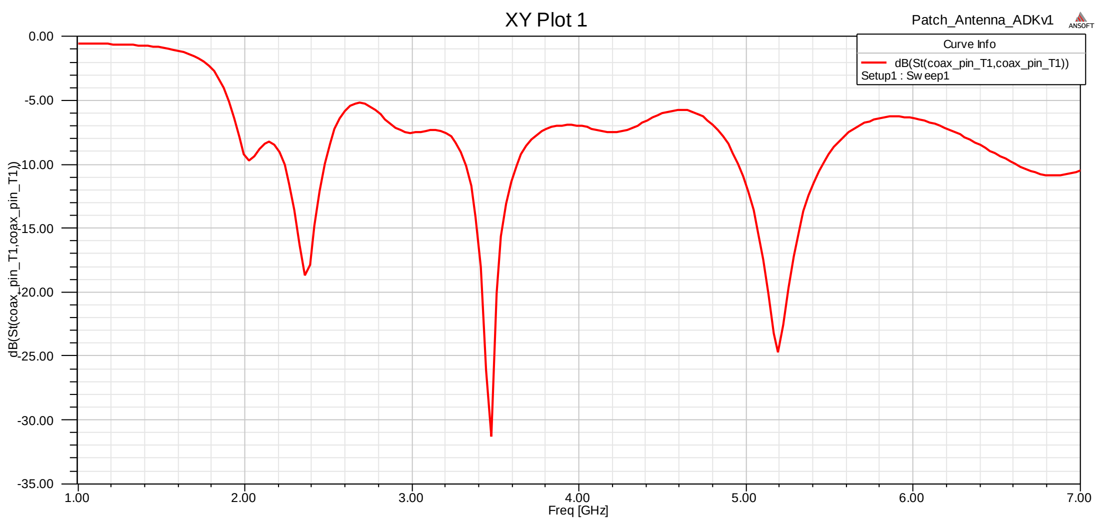


Figure 3. 29: Return loss of MSP antenna with IPF position =5y cm.

IPF position = 0 cm	F_r (GHz)	S_{11}(dB)	BW (MHz)	Gain dB
First band	2.35	-18.72	241	9.6
Second band	3.47	-31.29	300	8.17
Third band	5.19	-24.65	500	9.5

Table 3. 9: MSP antenna parameters with IPF position =5y cm.

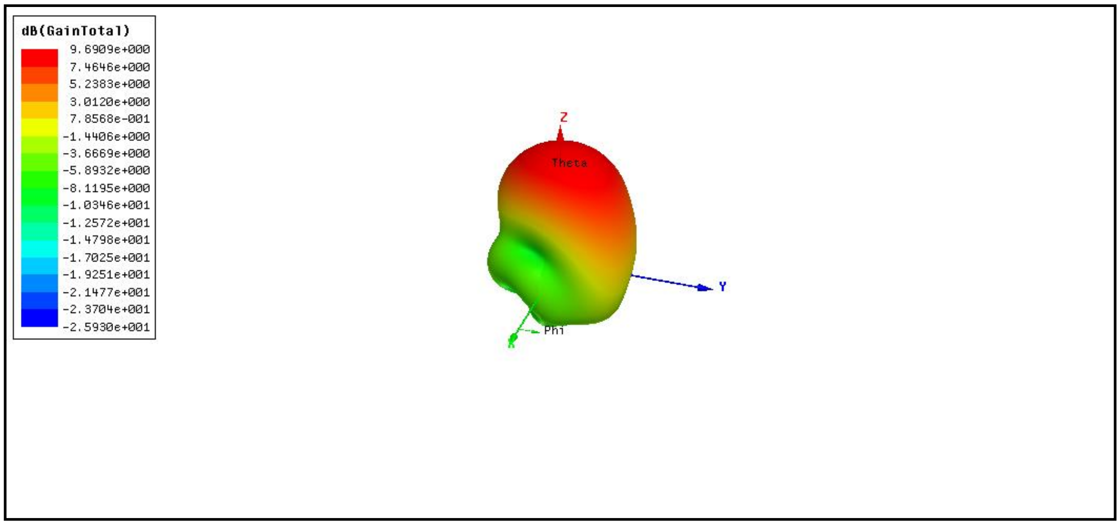


Figure 3. 30: Gain of MSP antenna with IPF position = 5y cm.

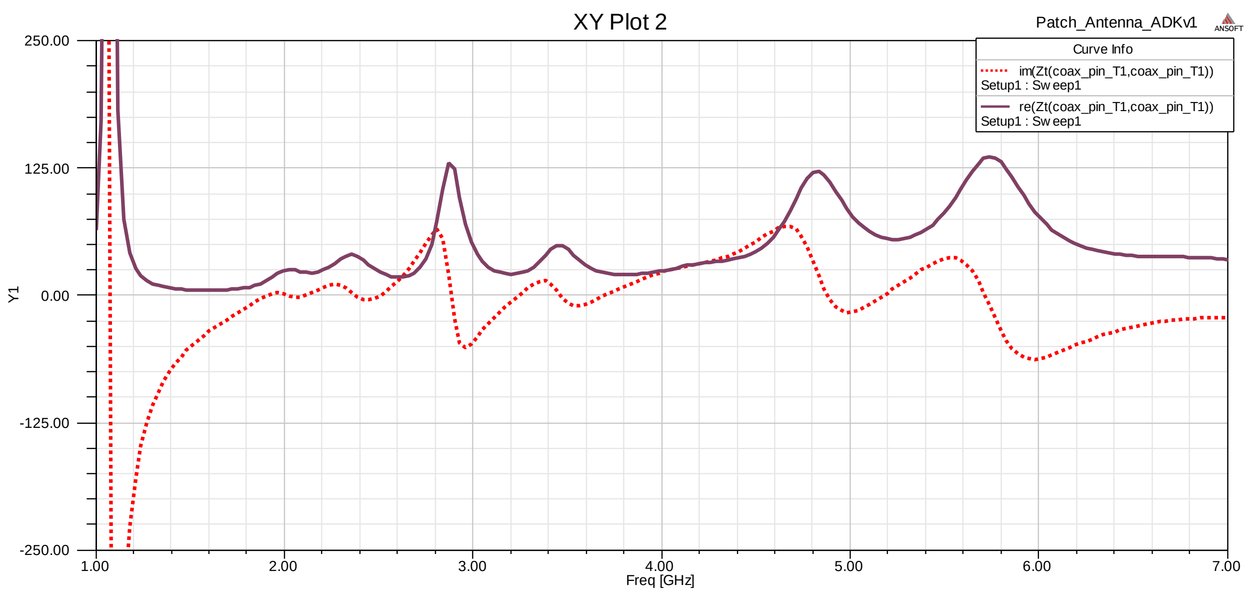


Figure 3. 31: Input impedance of MSP antenna with IPF position 5ycm.

The analysis of the antenna for different indirect probe feed positions values has been done by varying and keeping others as constant. It is carried out here to parametric study the flexibility in designing this of single layer patch antenna with indirect probe feed. The return loss of the different indirect probe feed positions in the antenna design is shown in figure 3.32, which clearly clarifies the explanation of the proposed antenna. By changing the IPF position on Y-axis give the same result at the side of axis like a mirror.

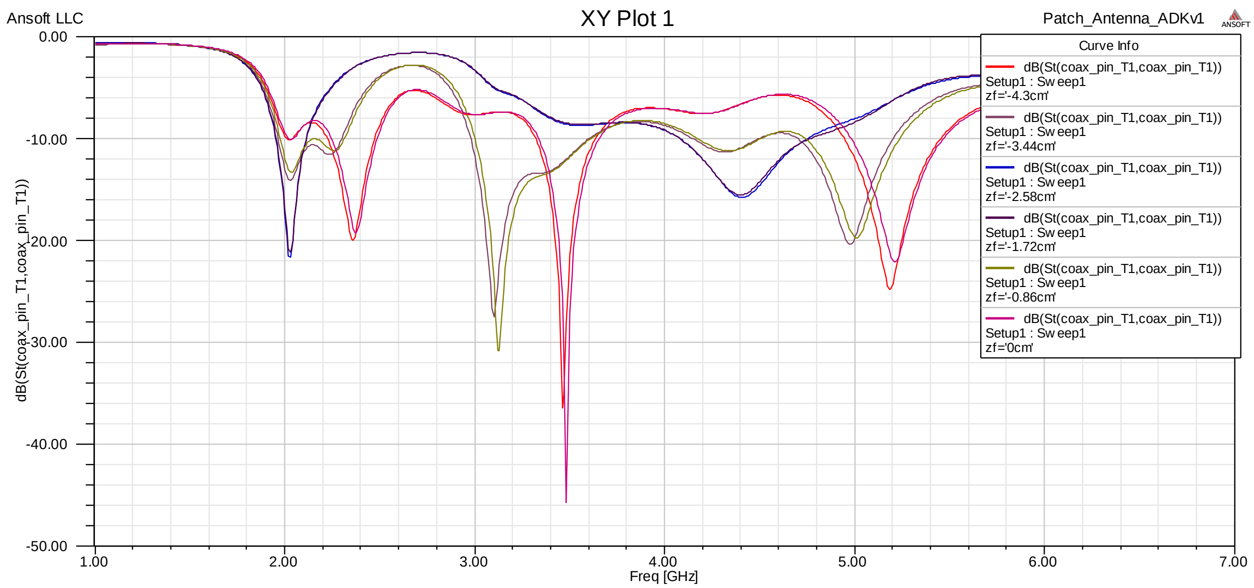


Figure 3. 32: Return loss Results compared by varying indirect probe feed positions.

in.feed position	freq1	re.loss	b.w	freq2	re.loss	b.w	ferq3	re.loss	b.w	ferq4	re.loss	b.w
0	2.3789	-19.219	0.2282	3.4888	-34.9879	0.3152	5.2175	-22.0345	0.4642	0	0	0
-0.86	2.042	-13.2284	0.3361	3.1323	-30.7858	0.6047	4.3363	-11.2616	0.3251	5	-19.7569	0.4931
-1.72	2.0291	-21.2049	0.1552	4.3969	-15.5593	0.6782	0	0	0	0	0	0
-2.58	2.0291	-21.2049	0.1552	4.3969	-15.5593	0.6782	0	0	0	0	0	0
-3.44	2.0291	-14.1173	0.3348	3.1121	-26.3818	0.6201	4.3161	-11.3507	0.3402	4.9821	-20.2754	0.5
-4.3	2.3587	-20.0113	0.24	3.4616	-36.3933	0.2942	5.1906	-24.6752	0.4932	0	0	0

Table 3. 10: S-parameter Study by varying indirect probe feed rectangular patch by varying probe feed point position.

3.5: Change the position of probe feed indirect probe feeding

In this section we want to change the probe feed position over the IPF static at the side of patch on IPF=0 cm because the result in this location is the best, so we change the probe feed over X-axis to get the optimum result and values to the antenna this change factor is x=.45 cm.

At probe feed x cm as shown in figure 3.33.

The return loss as shown in figure 3.34 the return loss is very good as shown in table 3.11 and bandwidth enhance than the basic antenna and the gain not change when probe feed = -0.45 cm as shown in figure 3.35 , from figure 3.36 we can see that the input impedance versus within the frequencies (35 Ω -50Ω).

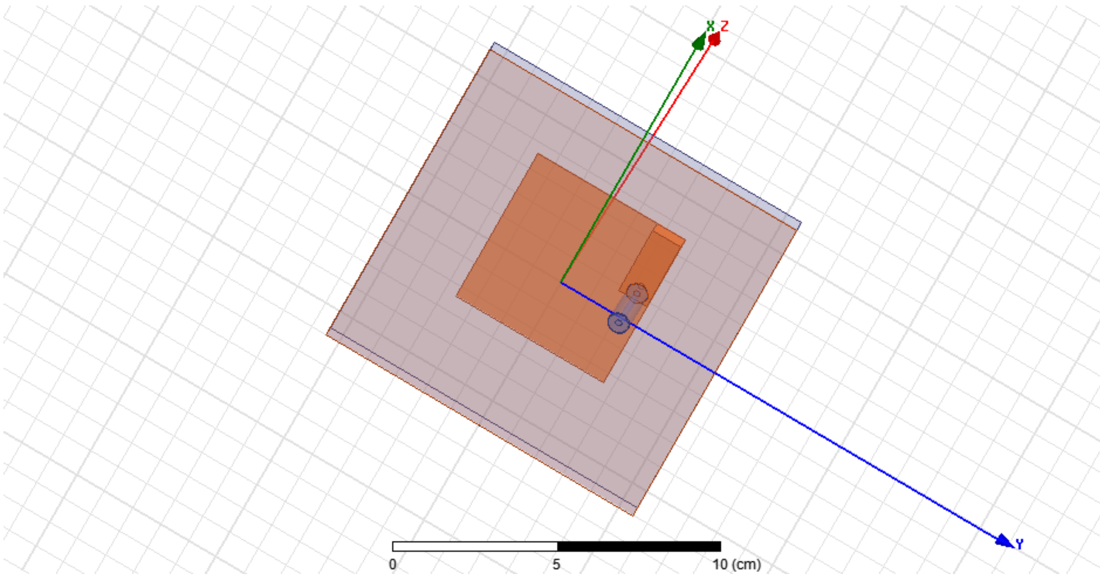


Figure 3. 33: MSP antenna with probe feed position = x cm.

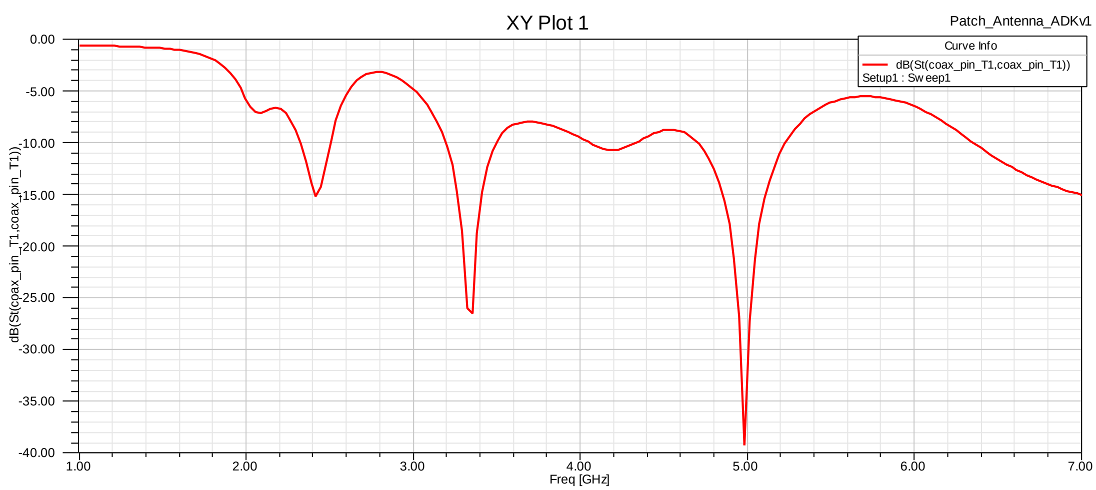


Figure 3. 34: Return loss of MSP antenna at probe feed position = x cm.

IPF position = 0 cm	F_r GHz	S_{11} GHz	BW MHz
First band	2.41GHZ	-15.17dB	241
Second band	3.35GHZ	-26.46dB	315
Third band	4.97GHz	-39.23dB	483

Table 3. 9: MSP antenna parameters with PF position = x cm.

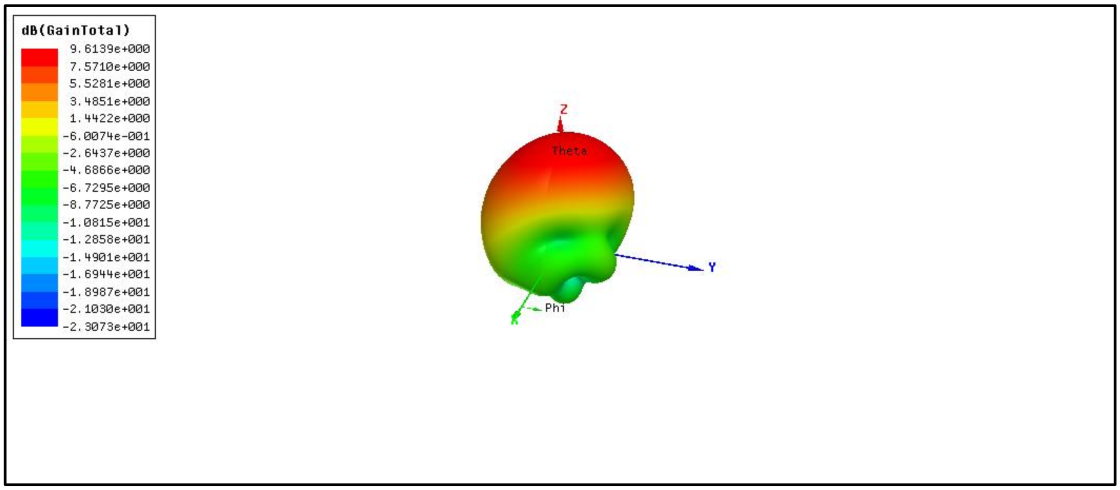


Figure 3. 35: Gain MSP antenna with probe feed position = x cm.

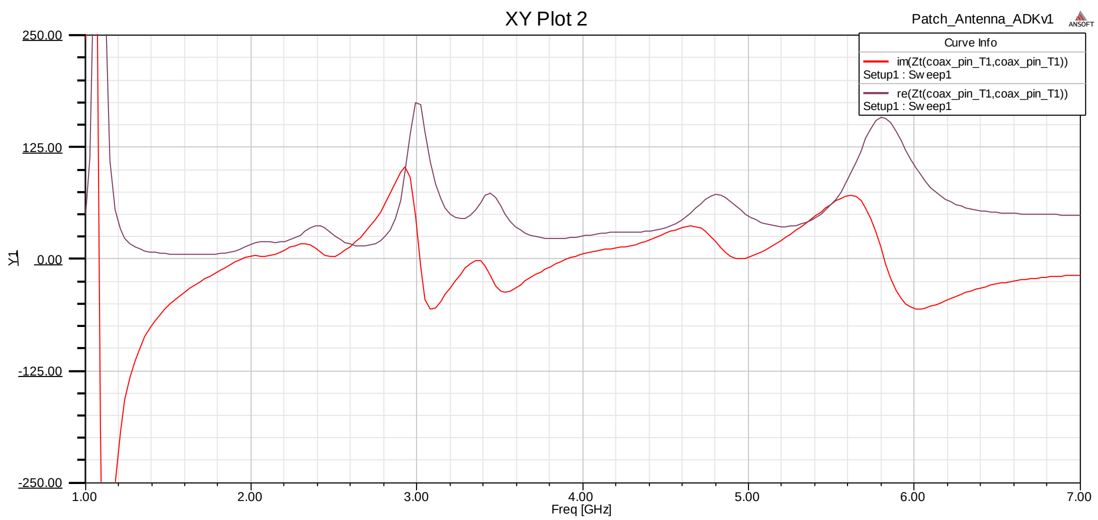


Figure 3. 36: Input impedance of MSP antenna with probe feed position = x cm.

At probe feed 2x cm as shown in figure 3.37.

From figure 3.38 shows that the return loss very worth than the previous result and not necessary to get gain and input impedance.

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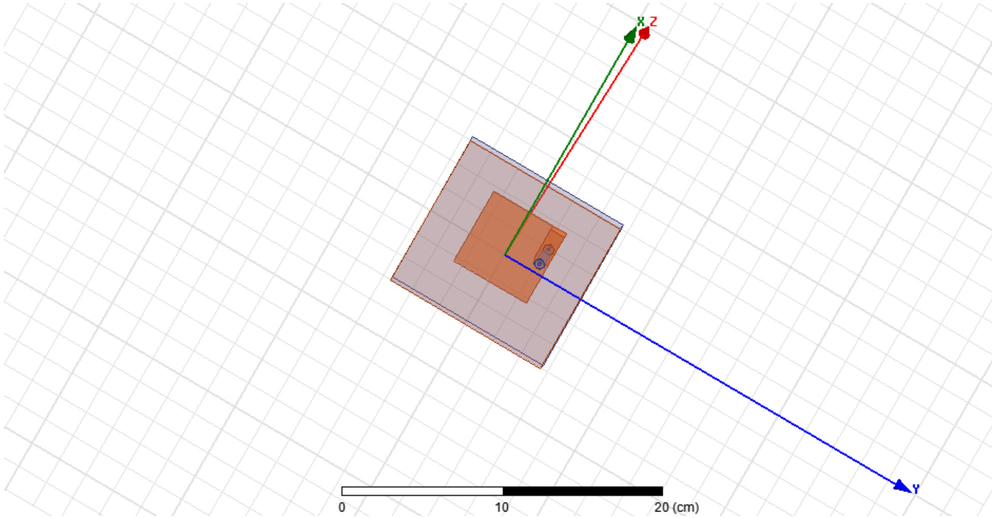

Figure 3. 37: MSP antenna with probe feed position = 2x cm.

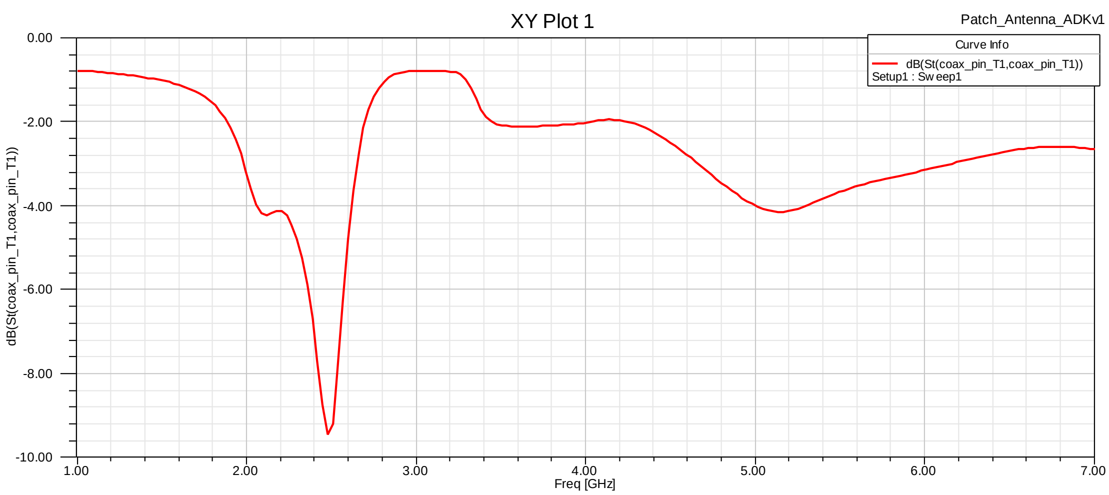

Figure 3. 38:Return loss of MSP antenna at probe feed position = 2x cm.

At probe feed 3x cm as shown in figure 3.39.

Like a previous position that the return loss shown in figure 3.40 .

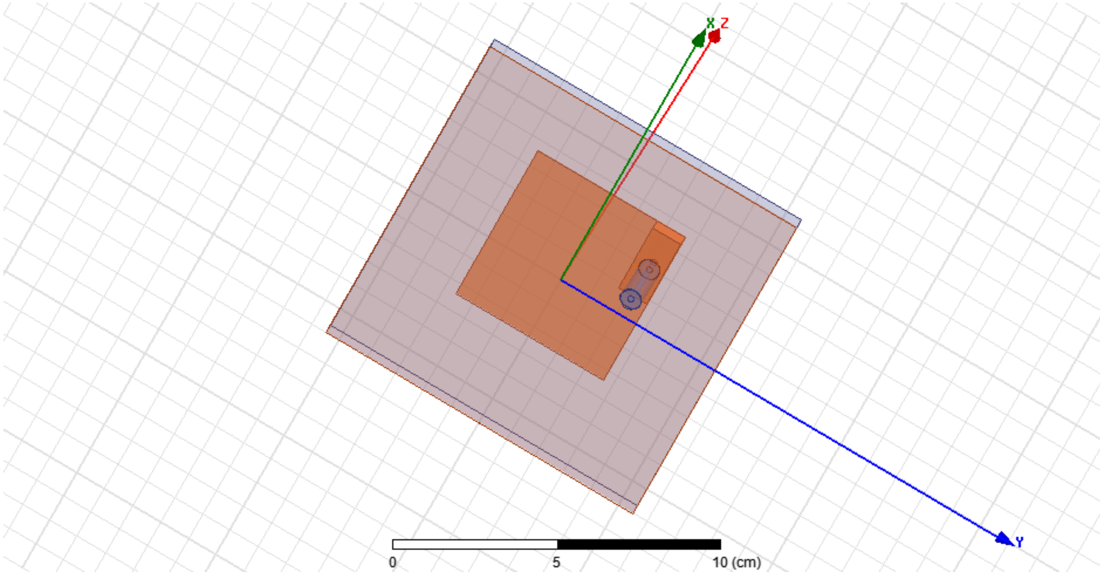

Figure 3. 39: MSP antenna with probe feed position = 3x cm.

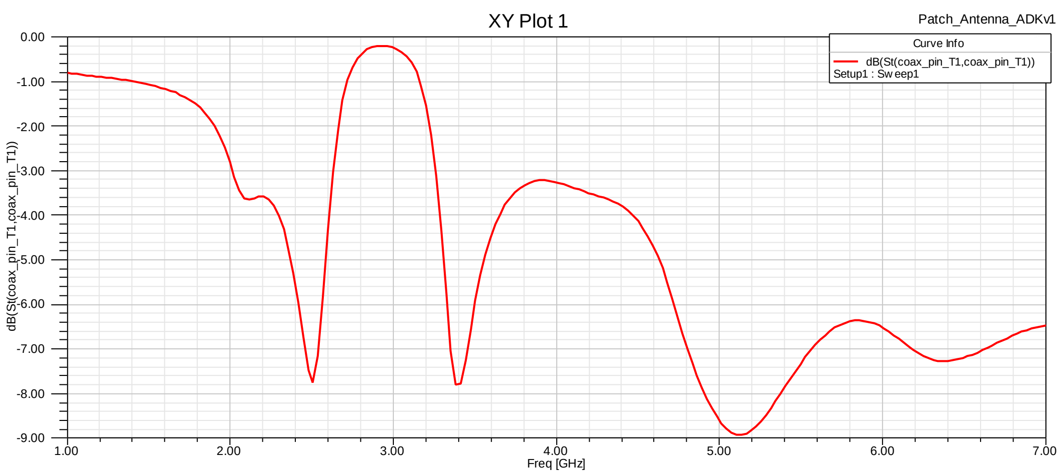

Figure 3. 40: Return loss of MSP antenna at probe feed position = 3x cm.

At probe feed 4x cm as shown in figure 3.41.

From figure 3.42 show that the return loss above -10 dB.

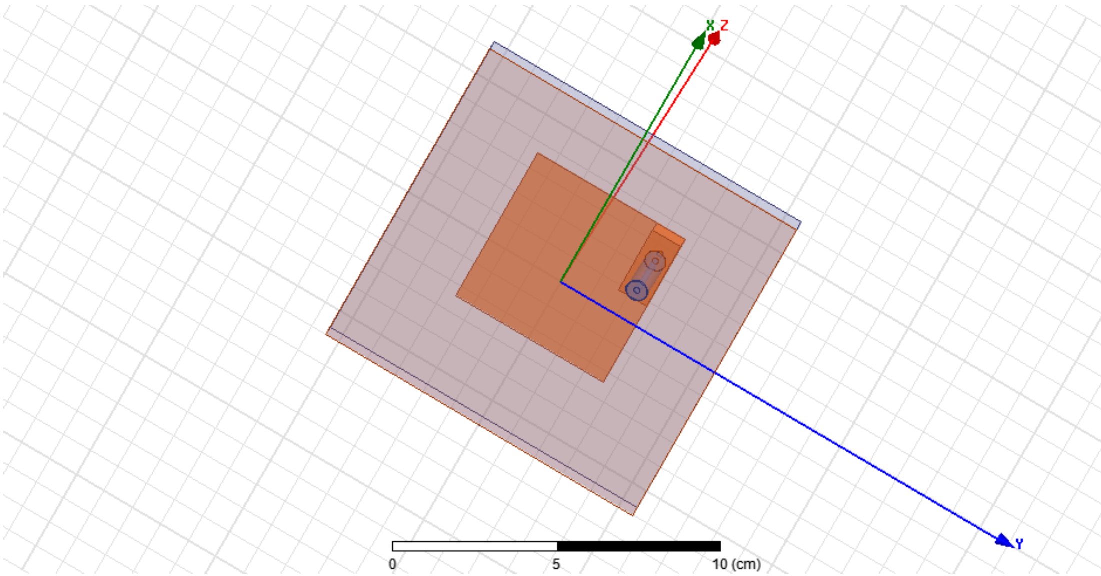

Figure 3. 41: MSP antenna with probe feed position = 4x cm.

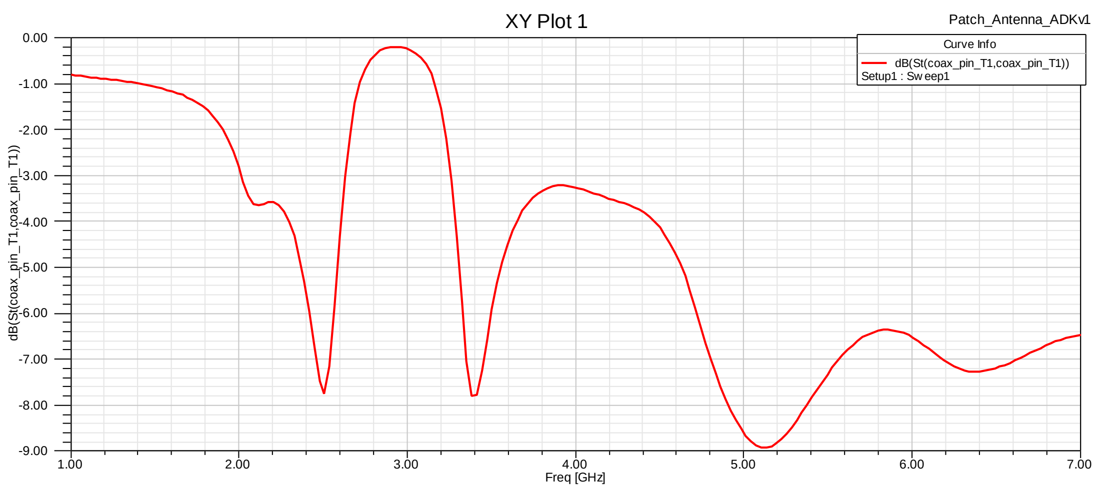

Figure 3. 42: Return loss of MSP antenna at probe feed position = 4x cm.

At probe feed 5x cm as shown in figure 3.43.

Finally the last position of previous probe feed shown in figure 3.44 give the same result of previous position .

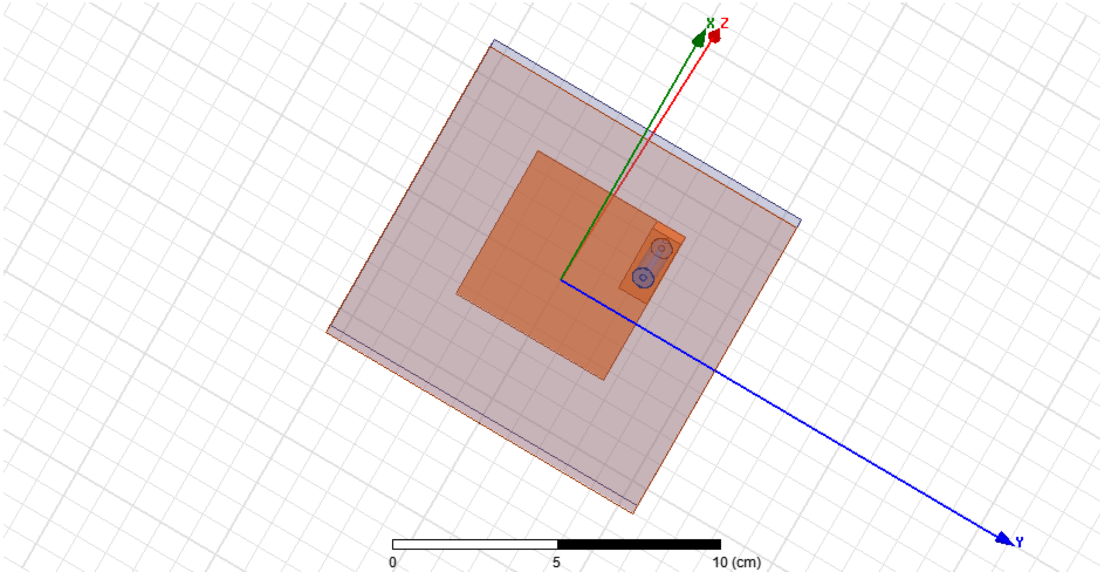

Figure 3. 43: MSP antenna with probe feed position = 5x cm.

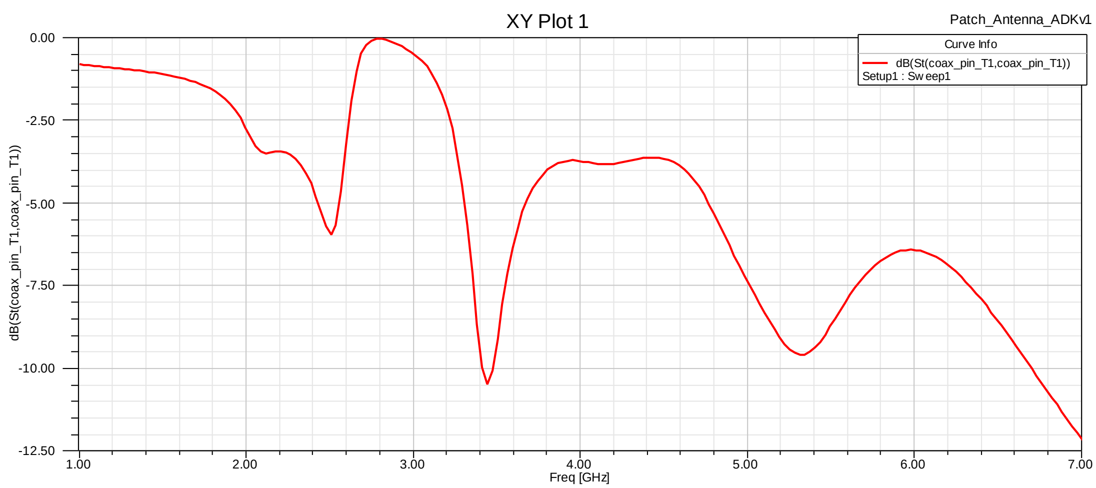

Figure 3. 44: Return loss of MSP antenna at probe feed position = 5x cm.

The results of the antenna analysis for return loss properties are introduced in Figure. 3.45. After changed more than six times of the probe feed position along IPF length, we choose the optimum result of probe feed position at -0.45cm and 0cm. It is noted that a bandwidth of 2.38GHz (2.241-2.483) GHz for probe feed position at -0.45cm is achieved and the percentage bandwidth is 10.12% at minimum return loss –18.37dB is obtained while the percentage bandwidth of 10% with return loss of -15.17dB is obtained for antenna with probe feed position at 0cm. On the other hand, return loss results (very bad) are gotten by changing probe feed positions at 0.45 cm, 0.9 cm, 1.35 cm and 1.8 cm for the proposed microstrip patch antenna, it is noticed that bandwidth was not enhanced as compared with changing indirect probe feed position.

So we had investigated through different parametric studies using HFSS simulation software. The proposed antennas have achieved good bandwidth and high gain. Currently, microstrip patch antenna is simulated using parametric solutions of changing probe feed positions. Return loss table of parametric solution about probe feed position with different positions was set in the parametric solution using HFSS simulator in the figure 3.45, to get the best results compute in Table 3.12.

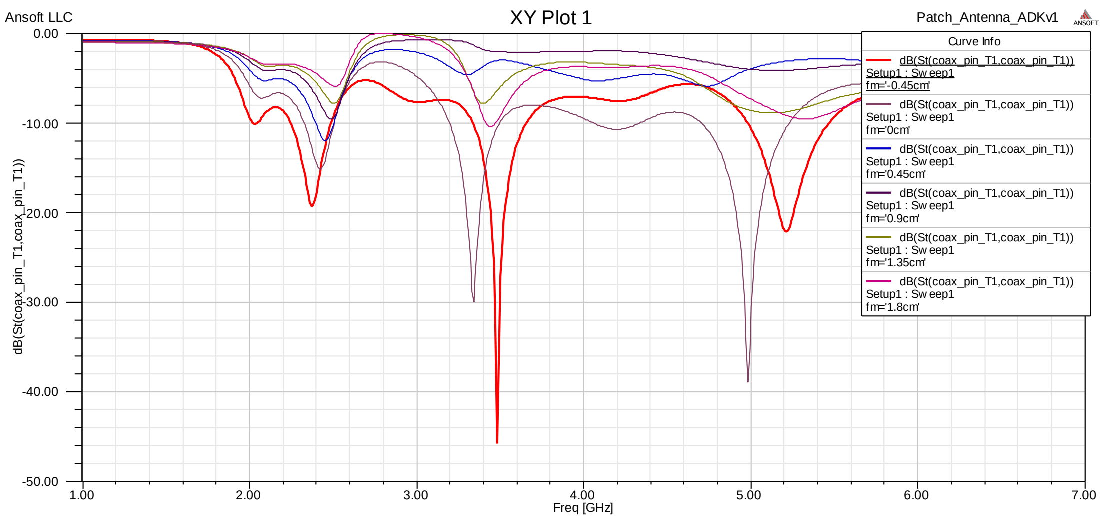

Figure 3. 45: Return loss for this parametric solution comparing the results obtained by varying Feed feed position.

The table below, showing the above comparisons in a tabular format so that we can conclude the effect of variations probe feed positions on resonance frequency and bandwidth. As you can see in Table 3.12, there is no regular pattern of increment of bandwidth by varying probe feed position in one direction or the other, the s-parameter variation is studied at different probe feed positions in x-axis direction all over the microstrip patch. Simulated results for indirect probe feed patch antenna is shown Table 3.12.

probe feed position	freq1	re.loss	b.w	freq2	re.loss	b.w	ferq3	re.loss	b.w	ferq4	re.loss	b.w
-0.45	2.3789	-19.219	0.2282	3.4888	-34.9879	0.3152	5.2175	-22.0345	0.4642	0	0	0
0	2.426	-15.1591	0.1735	3.3408	-29.9926	0.2976	4.1883	-10.7149	0.2628	4.9888	-35.6552	0.5213
0.45	2.4529	-11.984	0.1041	0	0	0	0	0	0	0	0	
0.9	0	0	0	0	0	0	0	0	0	0	0	0
1.35	0	0	0	0	0	0	0	0	0	0	0	0
1.8	0	0	0	3.4552	-10.3376	0.0534						

Table 3. 10: Simulated results for different probe feed positions for microstrip patch antenna.

3.6: Changing the inner radius of probe feed.

In this section we try to change the inner radius probe feed to the standard inner radius from 1mm to 0.73 mm to shows the change in result we chose the position of IPF over Y-axis 0 cm and the probe feed position over X-axis is -0.45 cm because that is the best result of pervious simulations, as shown in figure 3.45 the new design of antenna with new inner radius.

The return loss of the antenna can be seen on figure 3.46 show that new value multiband antenna this value better than the previous design. From table 3.13 show that the bandwidth enhance over the previous enhancement.

Gain enhancement in the broadside direction as shown in figure 3.47. The maximum gain of proposed antenna with changing radius of inner probe feed is achieved at resonance frequency 2.44 GHz with 9.68 dBi in the broadside direction. The input impedance was also within the range from 37Ω to 59Ω at resonance frequencies as illustrate in the figure 3.48.

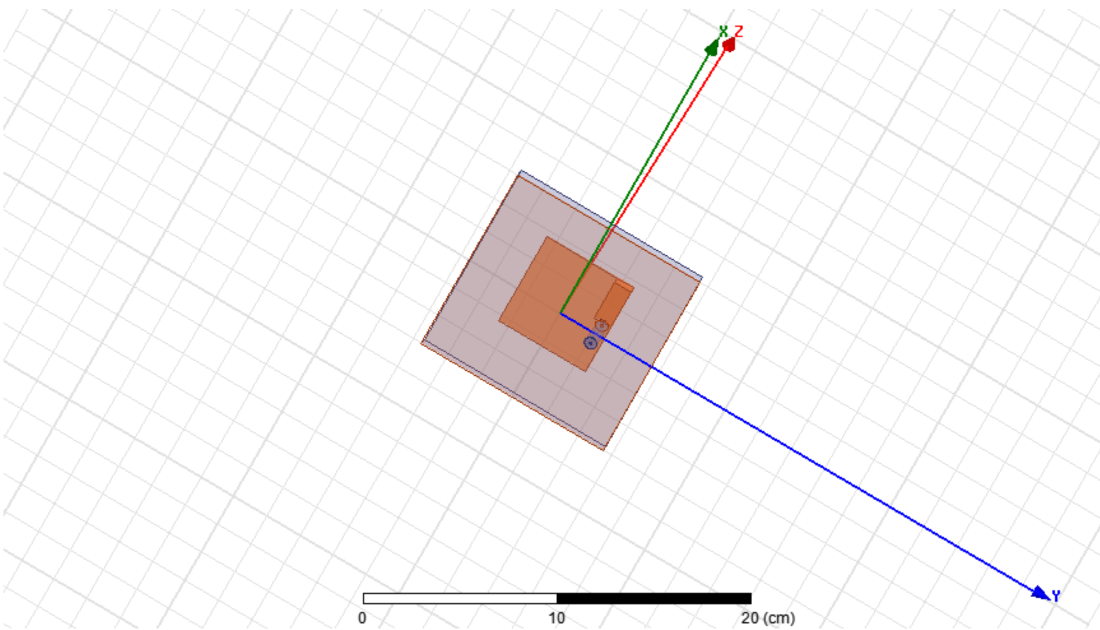

Figure 3. 46: MSP antenna with change inner radius of probe feed to 0.073cm.

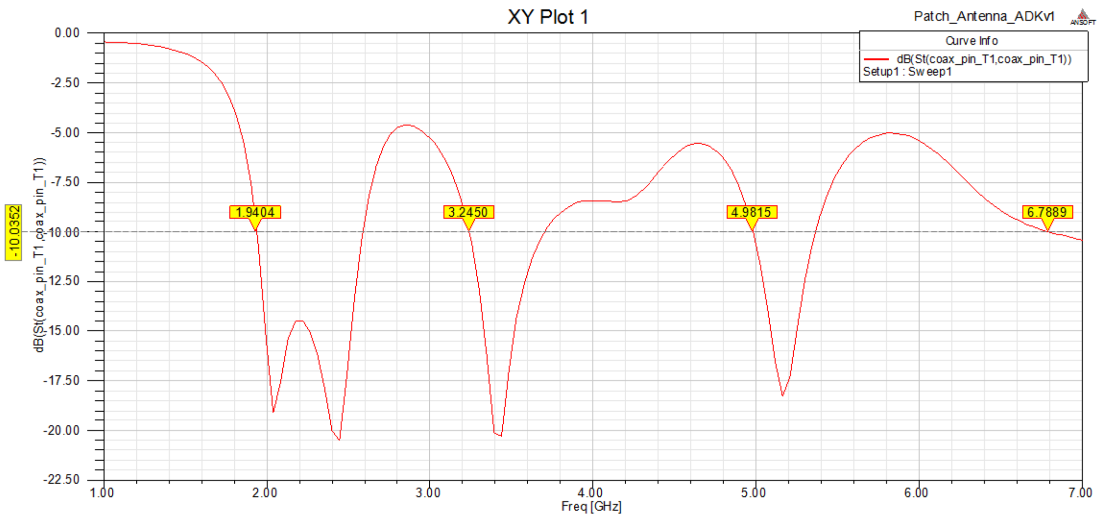

Figure 3. 47: Return loss of MSP antenna with inner radius of probe feed at 0.073cm.

Radius of inner probe feed	Fr GHz	S11 GHz	BW MHz
First band	2.44	-20.44	649
Second band	3.44	-20.23	443
Third band	5.16	-18.27	382

Table 3. 11: Parameters of MSP antennas with radius of inner probe feed is 0.073cm.

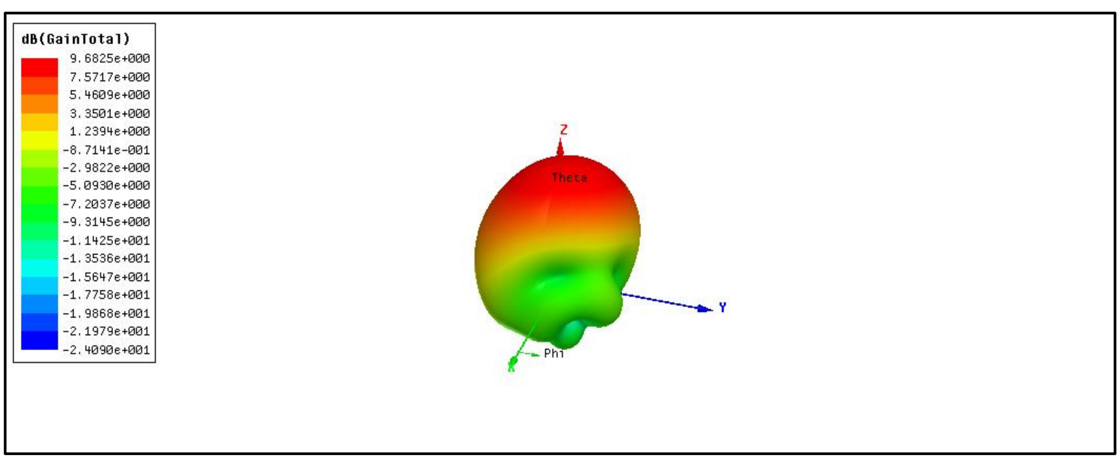

Figure 3. 48: Gain of MSP antenna with inner probe feed radius at 0.073cm.

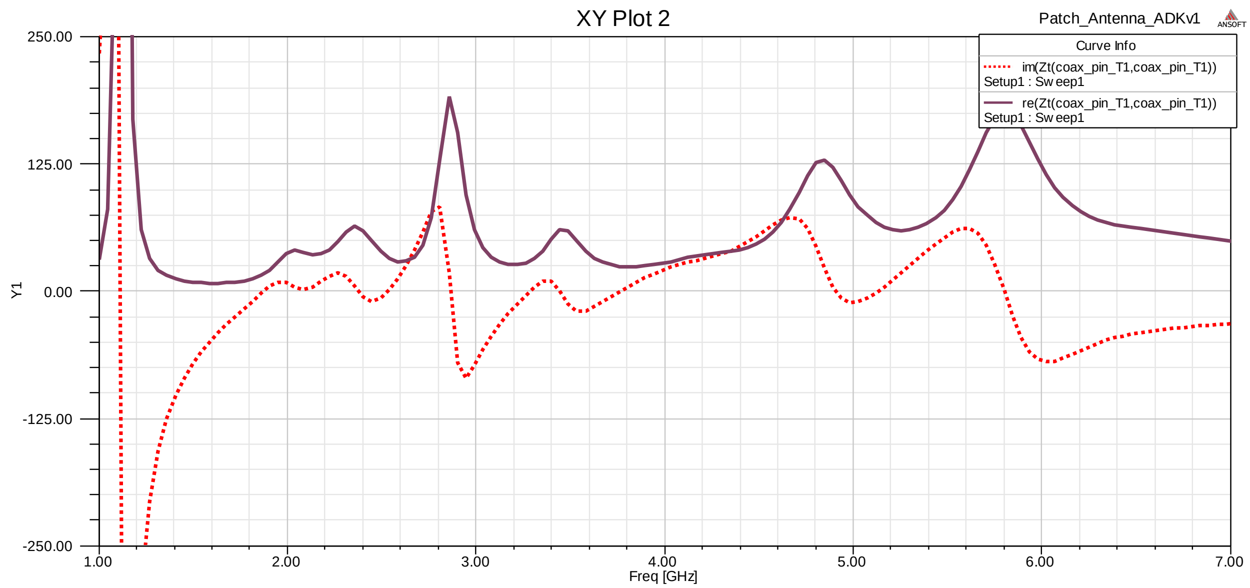

Figure 3. 49: Input impedance of MSP antenna with inner probe feed radius at 0.073cm.

3.7: Changing the length of stripline

When Change the length of IPF in x-axis in order to be smallest as shown in the figure 3.50. Two resonant frequencies (2.41GHz and 3.38GHz) for two bands of operation are obtained as shown in figure 3.51. The bandwidth of 138MHz with return loss of -13.80dB at 2.41GHz, 212 MHz with return loss of -21.74dB at 3.38GHz, The maximum gain of proposed antenna with changing IPF length for smallest length is achieved 9.33 dB in the broadside direction as illustrate in the figure 3.52. The input impedance was also within the range from 30Ω to 35Ω at resonance frequencies as illustrate in the figure 3.53.

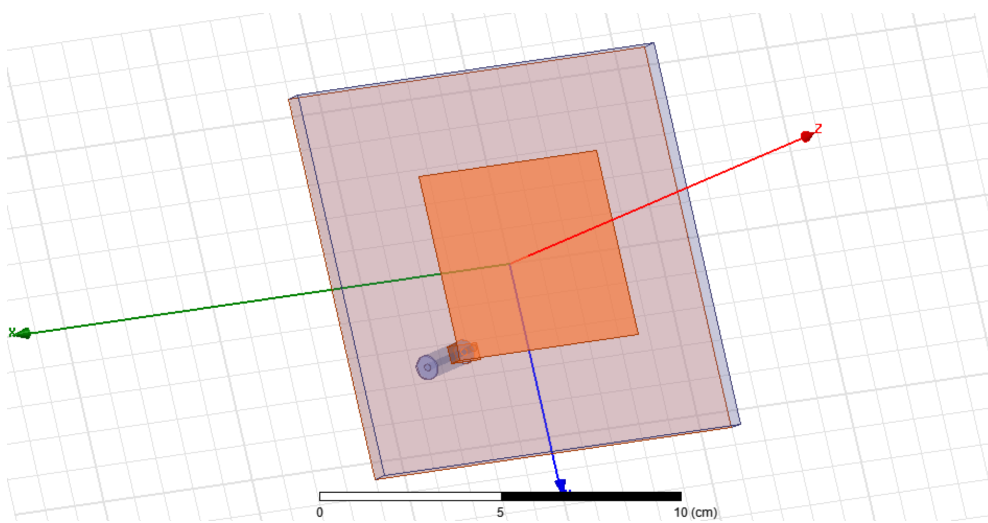

Figure 3. 50: MSP antenna with the length of IPF on x axis in order to be smallest.

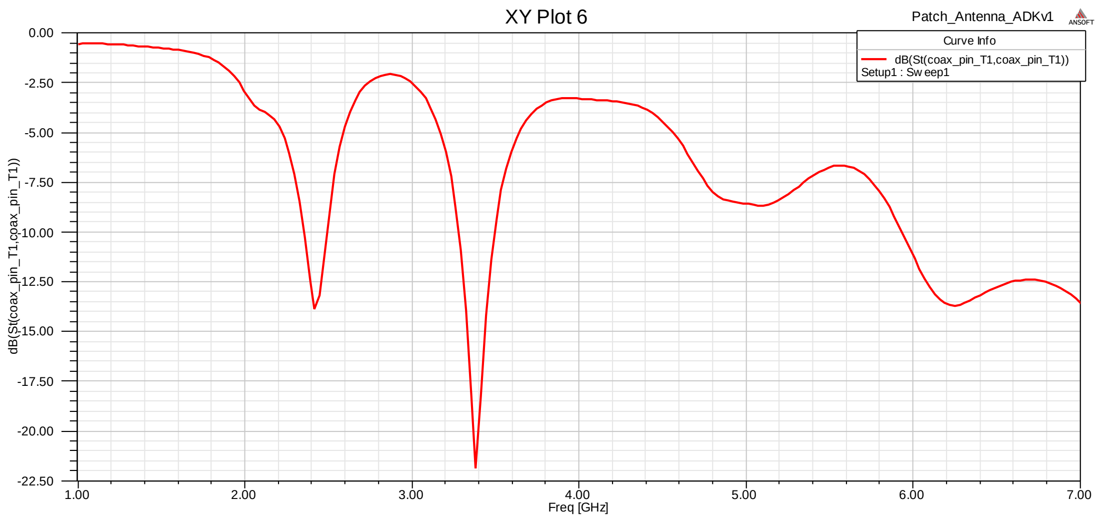

Figure 3. 51: Return loss if MSP antenna with the length of IPF on x axis in order to be smallest.

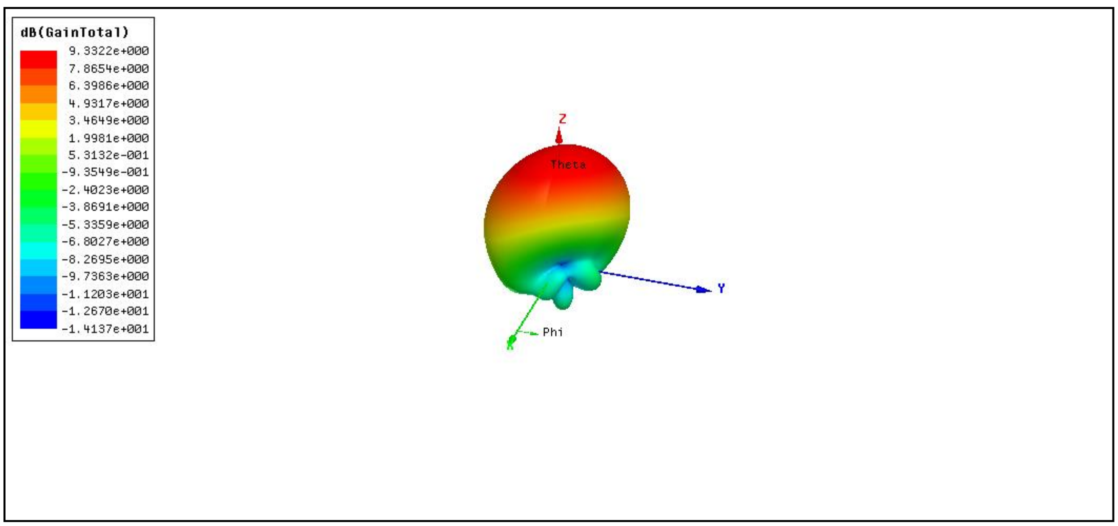

Figure 3. 52: Gain MSP antenna with the length of IPF on x axis in order to be smallest.

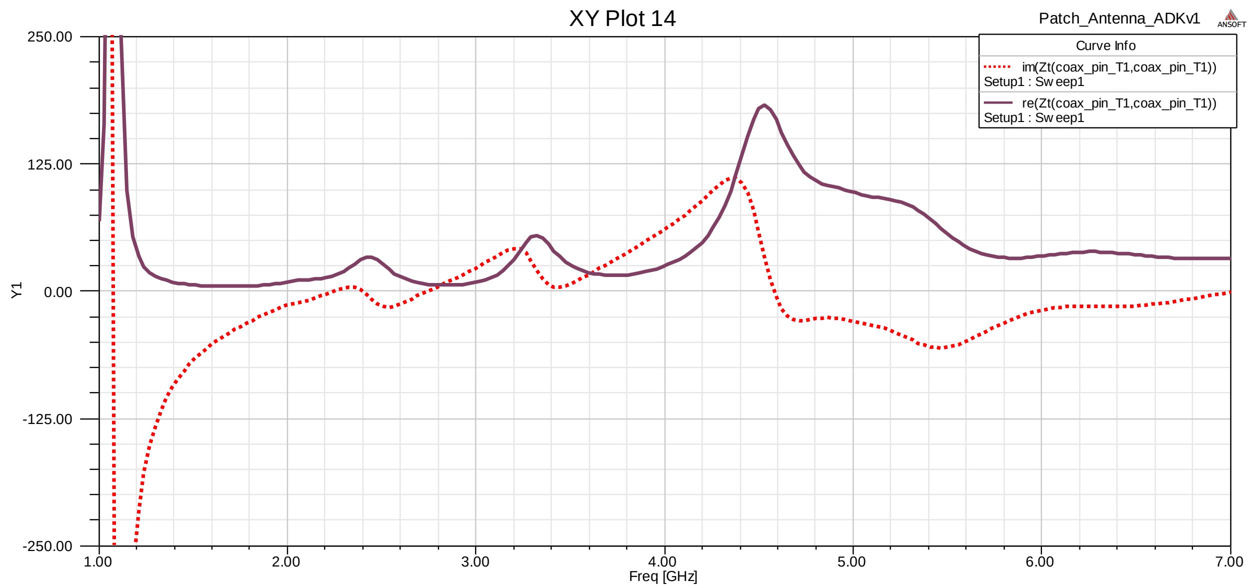

Figure 3. 53: Input impedance of MSP antenna with the length of IPF on x axis in order to be smallest.

Moreover, changing the length of IPF on x-axis in order to be the same length of the patch as shown in the figure 3.54. Many resonant frequencies are appeared for multi-bands of operation are obtained as shown in figure 3.55. The bandwidth of 137MHz with return loss of -12.13dB at 2.35GHz, 219 MHz with return loss of -14.61dB at 3.38GHz and 319 MHz with return loss of -28.36dB at 3.80GHz and 543 MHz with return loss of -33.14dB at 5.16GHz. The maximum gain of proposed antenna with changing IPF length in order to be the same length the patch is achieved 8.49 dBi in the broadside direction as shown in the figure 3.56. The input impedance was also within the range from 37Ω to 50Ω at resonance frequencies as illustrate in the figure 3.57.

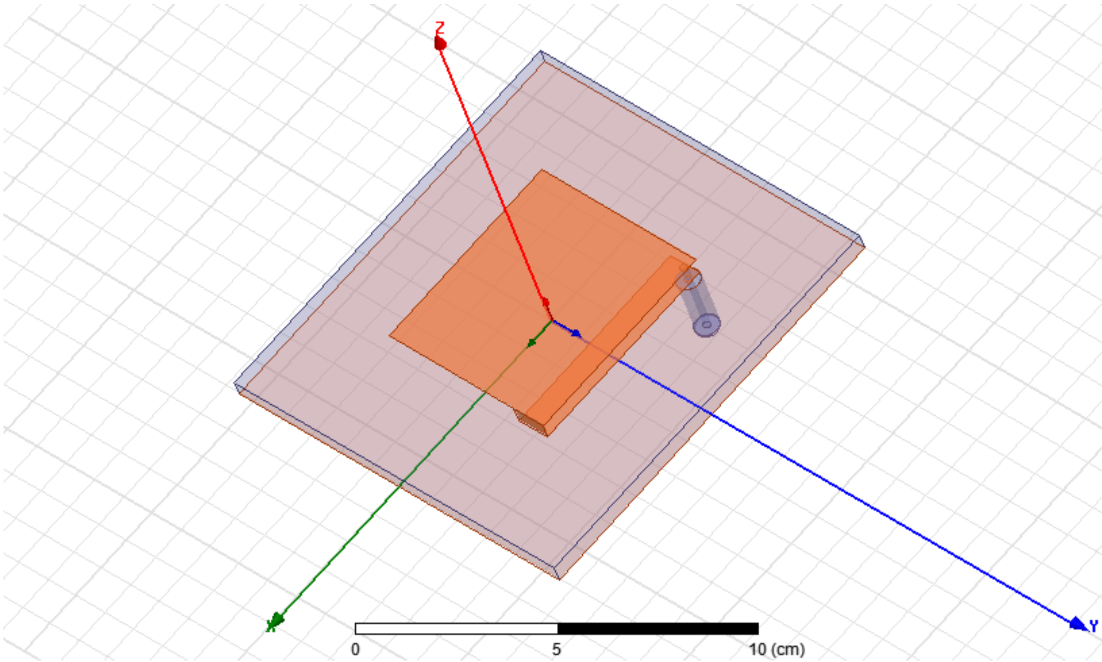

Figure 3. 54: MSP antenna with IPF with the same length of the patch.

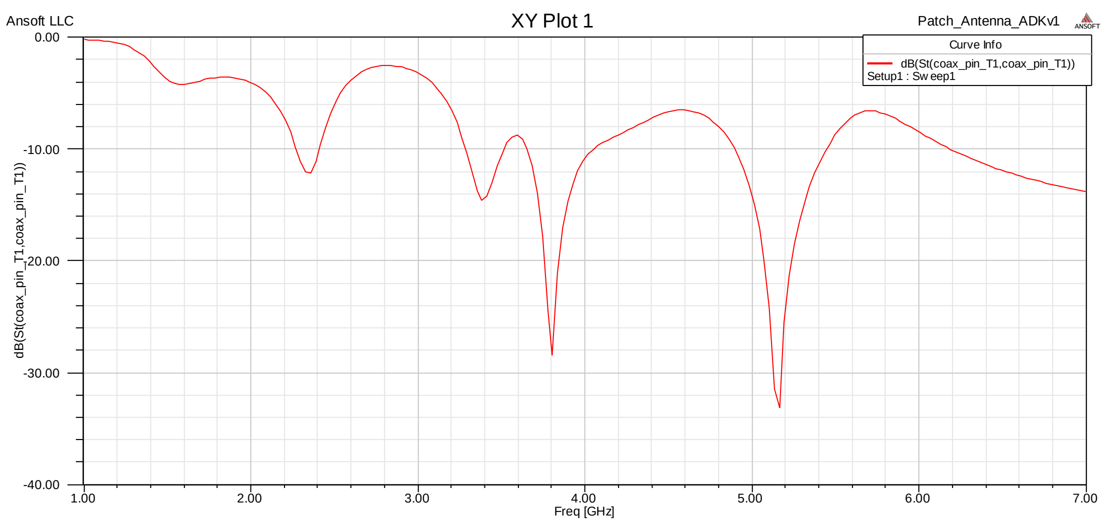

Figure 3. 55: Return loss of MSP antenna with the length of IPF on x axis the same length of the patch.

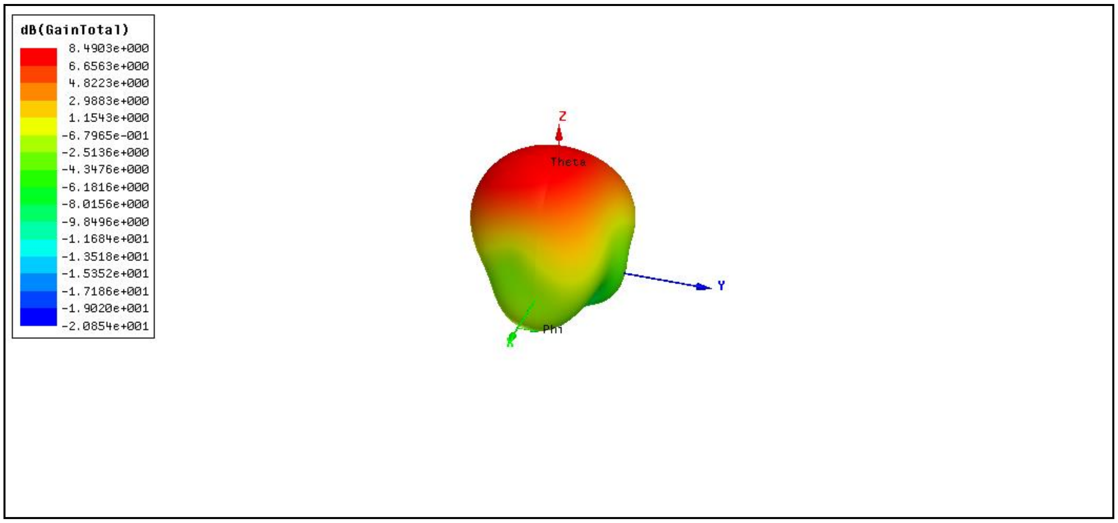

Figure 3. 56: Gain of MSP antenna with the length of IPF on x axis the same length of the patch.

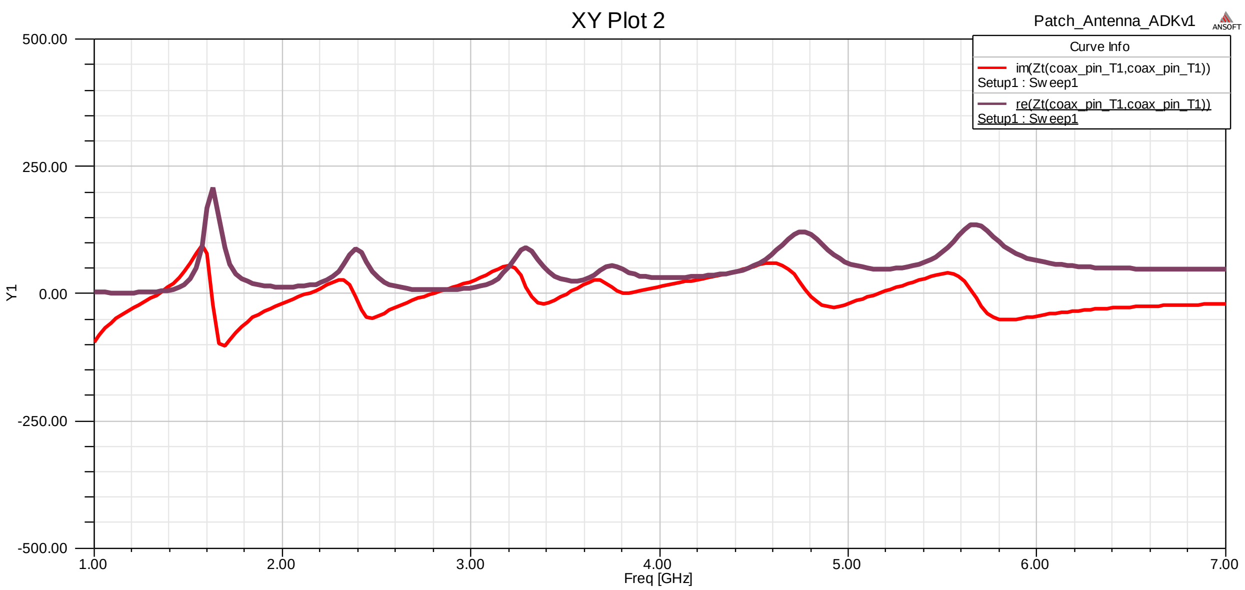

Figure 3. 57: Input impedance of MSP antenna with the length of IPF on x axis the same length of the patch.

3.8: Hexagonal MSP antenna with probe feed patch

Where an additional case is considered to enhance the bandwidth, hexagonal patch technique has been applied over the antenna design using probe feed which dimension of each length is 3cm calculated by using design equations in chapter 2, the feed location is center of hexagon antenna as shown in the figure 3.58. Hence, resonance frequency is generated bandwidth up to 5.49% (2.69 to 2.81) GHz as shown in figure 3.59.however, maximum gain 8.89 dB was attained at the frequency of 2.5 GHz as shown in the figure 3.60.

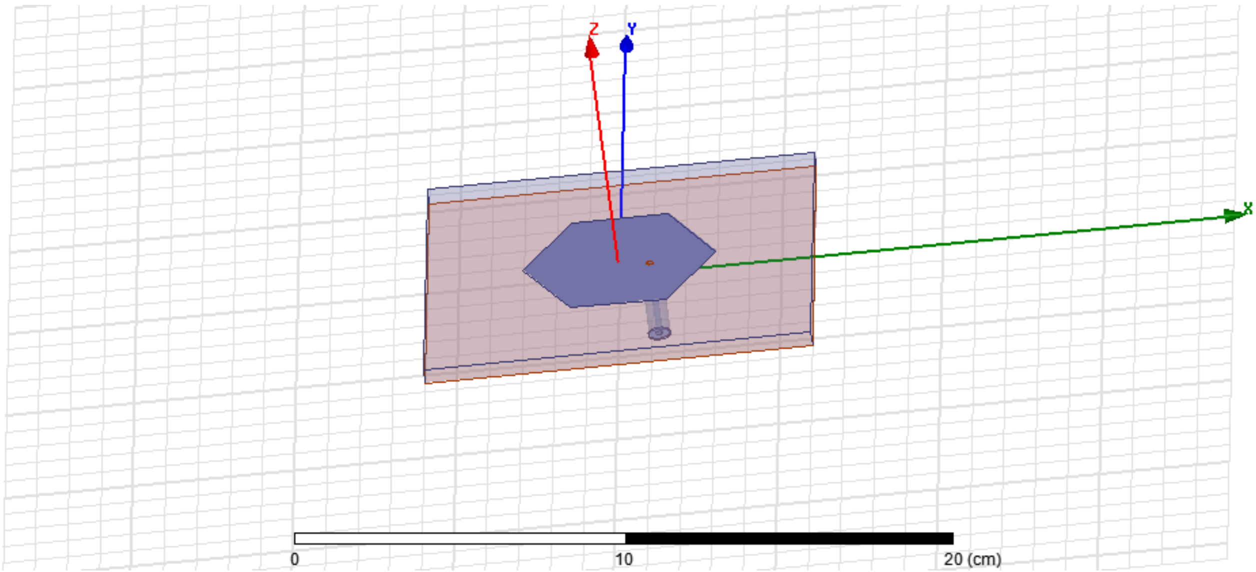

Figure 3. 58: Hexagonal MSP antenna with probe feed patch.

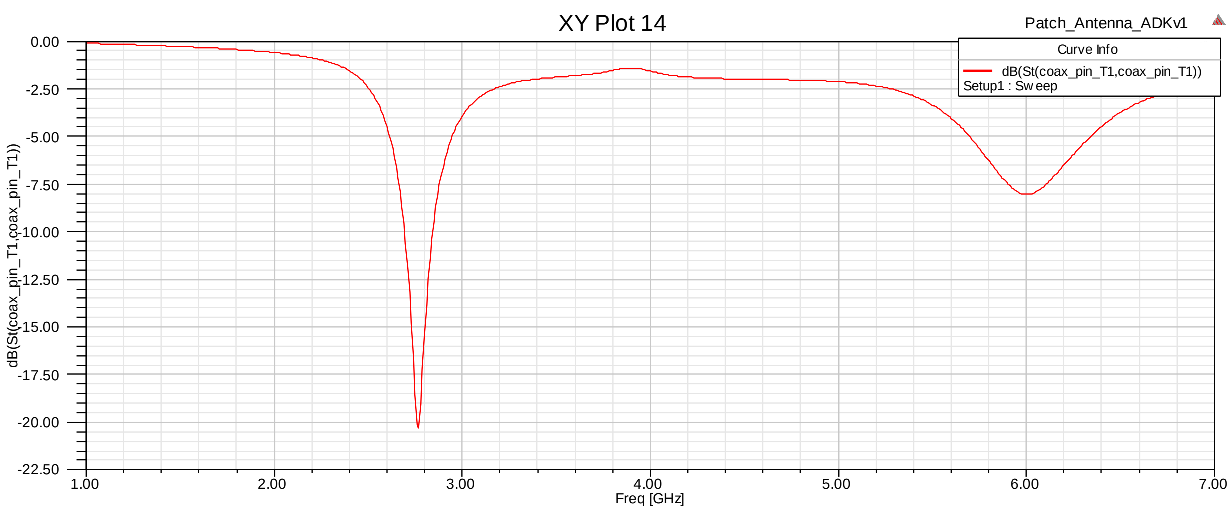

Figure 3. 59: Return loss hexagonal MSP antenna with probe feed.

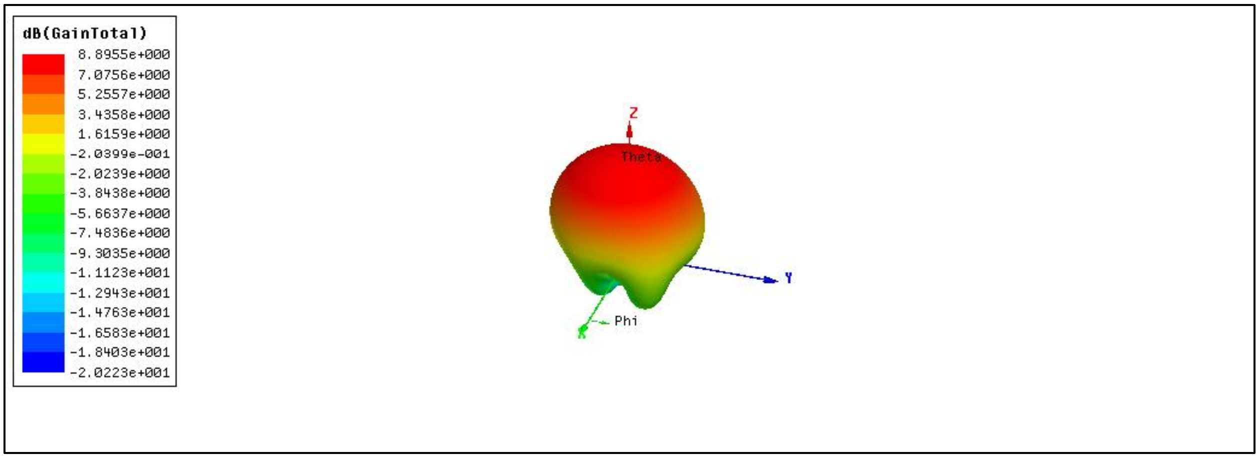

Figure 3. 60: Gain hexagonal MSP antenna with probe feed.

3.9: Hexagonal MSP antenna with indirect probe feed patch

By using an indirect probe feed for hexagonal patch antenna as shown in the figure 3.61, while, three resonant modes are produced. The first resonant mode increases with return losses of -28.50dB that is generated bandwidth up to 12.45%, the second resonance mode decreases with return loss of -14.34dB that is generated bandwidth up to 9.69%, and the third resonance mode decreases with return loss of -13.50dB that is generated bandwidth up to 9.9%,. The indirect probe feed for hexagonal patch antenna enhance bandwidth as shown in the figure 3.62. It has a band range of 2 GHz to 5 GHz with total gain approximately of 9.41 dBi as shown in the figure 3.63.

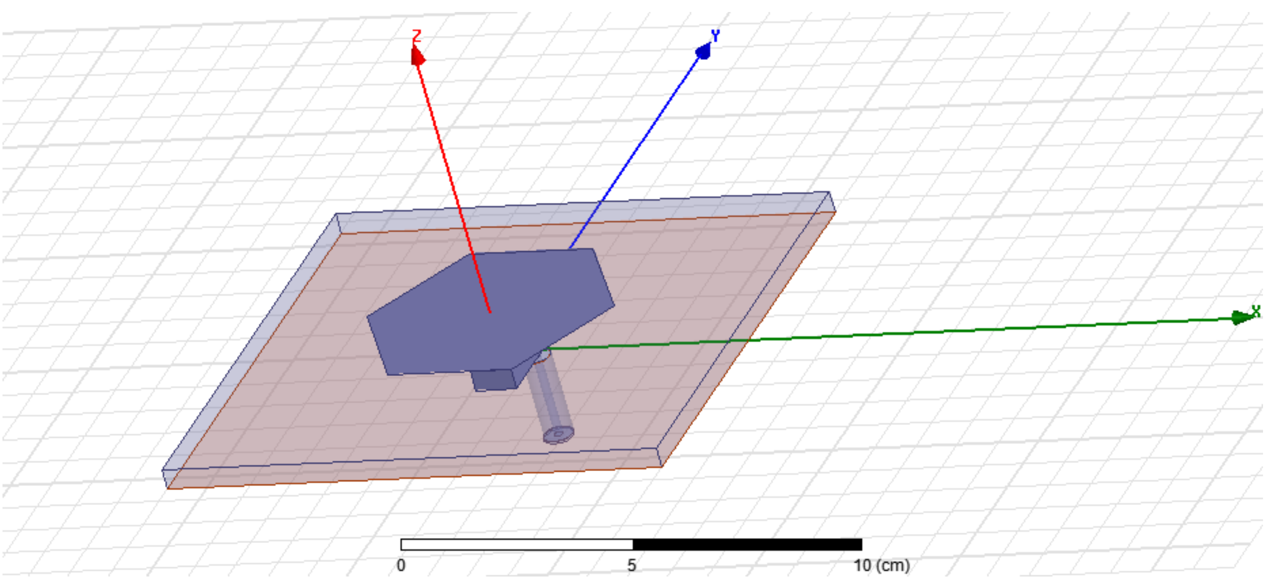

Figure 3. 61: Hexagonal MSP antenna with indirect probe feed patch.

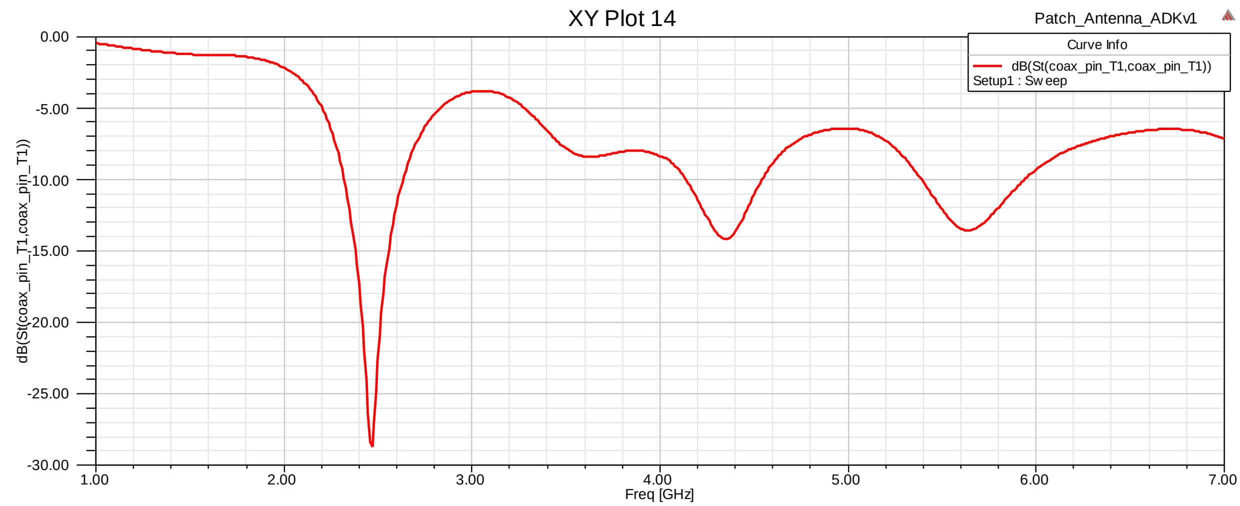

Figure 3. 62: Return loss Hexagonal MSP antenna with indirect probe feed patch.

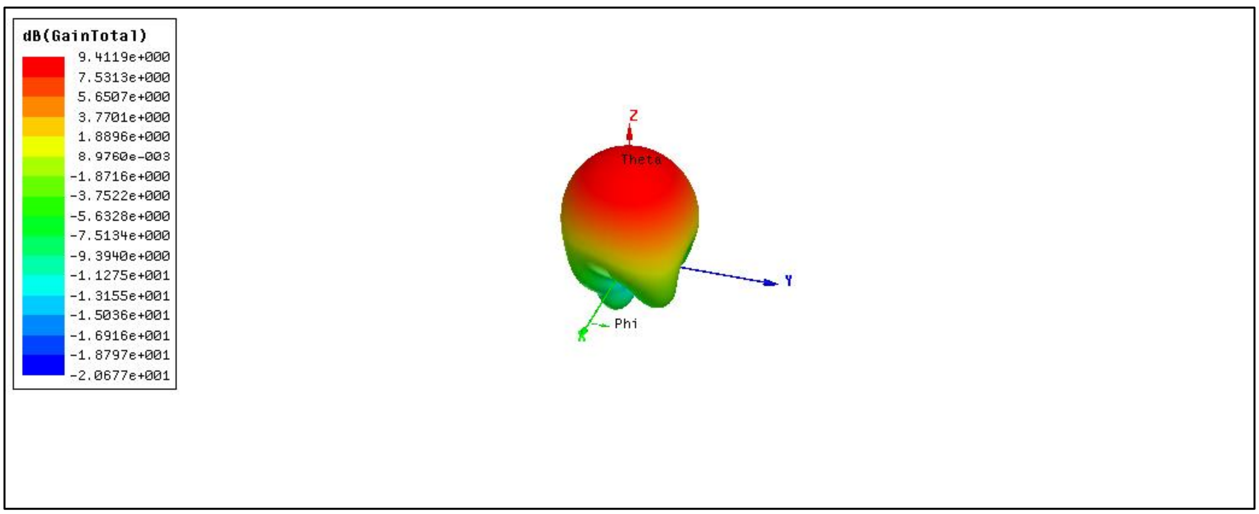

Figure 3. 63: Gain of Hexagonal MSP antenna with indirect probe feed patch.

Finally, I had design MSP antenna with different indirect probe feed positions for wideband applications. We chose the optimum results of indirect probe feed positions. We use a substrate (air) have relative permittivity (1), thickness of (h=5mm) and dimensions L × W (12cm × 11cm). All microstrip patch simulated by software name HFSS which basis on finite element method. A series of parameters of the MSP should be carefully selected. In this section, the effects of several key parameters on the proposed antennas were discussed and simulated using the Ansoft HFSS. In the process of analysis, it is also found that in comparison with the probe feed and indirect probe feed effects on the bandwidth and resonant frequency. The resonant frequency slightly decreases and bandwidth increase with changing indirect probe feed. To meet these improvements, an extensive-simulation study has been carried out to determine the optimal dimensions of the rectangular patch shapes, by maximizing the bandwidth and results are shown.

The improvement of bandwidth, resonance frequency, returns loss, and gain are illustrated. The largest improvement is provided by indirect probe feed position. It is clear that the antenna design with indirect probe feed displays the best performance compared with the others. It is noted that a bandwidth of probe feed position at -0.45cm is achieved the percentage bandwidth is 10.12% at minimum return loss –18.37dB is obtained while the percentage bandwidth of 10% with return loss of -15.17dB is obtained for antenna with probe feed position at 0cm. we observe that for the proposed antenna, when the position of the probe feed is changed along stripline length, we obtain a greater bandwidth at -0.45cm and 0cm in comparison with the bandwidth obtained when the probe feed position is changed.

However, note that the inner radius of probe feed is changed to 0.073cm of these MSP antenna, we can improve the bandwidth by up to 26.59% when compared with the probe feed radius is 0.1cm.Thus, a considerable improvement in bandwidth can be obtained for the same indirect probe feed position.

Now, it is clear that the antenna with indirect probe feed gives a good performance of bandwidth compared with bandwidth of the antenna without indirect probe feed.

References

[1] K. L. Wong a nd W. H. Hsu, “Broadband triangular microstrip antenna with U-shaped s lot, ” Electron. *Lett*. 33, 2085–2087, Dec. 4, 1997.

Chapter 4

CONCLUSION AND FUTURE PROSPECTS

During recent years, much effort has gone into bandwidth enhancement techniques for microstrip antennas in general. As such, there is a great amount of information in the open literature and it covers a very broad range of solutions that have been proposed. The entire spectrum of approaches that have been suggested is too comprehensive to discuss here and therefore the discussion in this chapter will be restricted to techniques that have been applied to enhance the bandwidth of probe-fed microstrip patch antennas in particular .In this thesis, a broad overview will be given in terms of the various techniques that are currently available to enhance the bandwidth of microstrip patch antennas.

The performance, advantages and disadvantages of the most practical approaches will also be discussed which there has been a tremendous amount of activity during recent years, is that of computational electromagnetics. These tools are essential for an accurate analysis and design of complex antenna. Although probe-fed microstrip patch antennas are structurally quite simple, an accurate analysis of their various characteristics proves to be rather intricate. A major advantage of the new feeding mechanism is that only a single substrate is required to support the antenna. This implies cost savings when compared to other approaches, as well as simplified manufacturing techniques and light weight.

The principal contributions of this study include the development of a new probe feeding mechanism for probe-fed MSP that is called indirect feed insert between substrate material and patch. The characteristics of proposed antennas have been investigated through different parametric studies using HFSS simulation software. Indirect probe feed microstrip patch antenna has been successfully designed having a center frequency of 2.5 GHz.

One of the problems in this thesis is related with the numerical modelling techniques and theoretical formulation this makes micorstrip patch antenna with indirect probe feed much more efficient to analyze that was implemented for the purposes of this study

The method of changing the indirect probe feed position and dimension W or L, reasonable return loss S11 values will be obtained, however. S11 values are acceptable, but the microstrip antenna still suffers from low gain and small bandwidth, because there is a tradeoff between antenna dimension and bandwidth.

The drawback in such antenna design is that the relative permittivity value of the substrate, if high ε_r material is assigned, the antenna will suffer from poor S11 but will have a nice gain, and just the opposite will happen when you assign low ε_r. Because of this, the FR4 epoxy substrate has low gain. However, there are many steps to solve this issue. This could be done by changing in the shape of the antenna or assigning different material properties like Left-handed meta-material (LHM), which is a material whose permeability and permittivity are simultaneously negative, but in this thesis assigned the air.

Then, in simulation result for return loss S11 of original antenna which the resonant frequency has been 2.5 GHz, the bandwidth is 4.4% and gain is 9.58dBi, after many steps in simulation more than indirect probe feed dimensions, the trouble was solved, being about changing the indirect probe feed positions. Most of these steps have been described in chapter three.

The proposed indirect probe feed microstrip patch antennas have improved bandwidth that is 26.91% and achieved good impedance matching, stable gain, and radiation patterns.

The indirect probe feed antenna can be used for Wireless system application that operate quad and triple (multiband) frequencies. In addition, the proposed antenna is 12 cm by 11 cm.so the designed antenna is suitable for wireless system devices.

In future work, one may modify any antenna shape to a specific application. Future work will concentrate on how to tackle size and performance of this type of antennas. Triple band with high gain will be a good idea to continue studies in this field. As is the case with all research, there are always more aspects that can be investigated than what is practically possible. Here also, there are some aspects of both the new antenna and the numerical formulation that can be extended.

Although the new antenna have been characterized to some extent, it would be useful to have more comprehensive guidelines to design such antenna. This should include geometrical parameters as well as the optimum choice of material properties, especially dielectric constants and substrate thicknesses, fabrication and verification of simulated results can be carried out in future