International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol.2 No.2; Mar-Apr 2021

STUDY, DESIGN, AND SIMULATION FOR MICROSTRIP PATCH ANTENNA

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DOI: http://dx.doi.org/10.52267/IJASER.2021.2201

ABSTRACT

Microstrip antennas are widely used in wireless communication systems because they are lightweight, compact, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology. Concept of microstrip radiators was first proposed in 1953, but it was only in 1970s that practical antennas were fabricated. With features such as low cost, lightweight and Integra table on board containing RF or microwave circuits, they become popular with circuit designers. The main objective of this project is to design and simulate a single element patch microstrip antenna of different shapes using *Agilent's Advanced Design System 2015* A design software\ momentum simulation. These are: rectangular, square, circular, circular ring and non-uniform polygon. The other specifications are displayed with each design. The ADS results give the return loss, radiation pattern, polarization, power, absolute fields calculated parameters and some other interesting outputs that can be analyzed. The theory of microstrip antenna is simply given in this report and the factors affecting the antenna design are explained. The design steps of below types of antenna are given and for the others antenna.

KEYWORDS: Mobile antennas, Multifrequency antennas, Antenna measurements, Antennas and propagation, Frequency, Acoustics, Acoustical engineering, Antenna arrays, Laboratories, Signal processing, DGS: Defected Ground Structure

1. INTRODUCTION

Wireless communications have been one of the highest growing markets over the past two decades. The growth in the market has been continuous both in terms of the number of subscribers and number of telecommunications services offered. By April 2002, the number of world cellular subscribers reached 1 billion. To connect people and improve the overall quality of life, new third generation wireless systems have been developed that offer new multimedia capabilities, better reliability, improved battery life and efficient and more cost-effective solutions. As the wireless communication continues to develop very rapidly, number of base station antennas has also increased. In coming years, the new generation of wireless communication systems will demand new and improved base station antennas. New base station antennas will need to be developed that will replace the current sectored panel antennas and reduce the overall number of antennas on a base station. They will operate in the frequency band (1920 - 2170 MHz) for WCDMA or may even be dual-band or multi-band and be able to cover some or all of GSM (890 - 960 MHz), GSM1800 (1710 to 1885 MHz) and CDMA (824 – 894 MHz and 1850 – 1990 MHz) frequency bands.

Antennas

An antenna is usually defined as the structure associated with region of transition between a guided wave and a free-space wave, or vice versa. On transmission, an antenna accepts electromagnetic energy from a transmission line (coaxial cable or waveguide) and radiates it into space, and on reception, an antenna collects the electromagnetic energy from an incident wave and sends it through the transmission line.

In ideal conditions it is desirable that the energy generated by the source is totally transferred to the antenna. However in practice this total transfer of energy is not possible due to conduction-dielectric losses and lossy nature of the transmission line and the antenna. Also if the transmission line is not properly matched to the antenna there will be reflection losses at their interface. Therefore it is very important that the characteristic impedance of the antenna is matched to the impedance of the antenna.

In wireless communication systems the antenna is one of the most critical components. A good design of antenna can improve overall system performance and reduce system requirements. In order to meet the system requirements of today's mobile and wireless communication systems and the increasing demand on their performances, many advancements in the field of antenna engineering have occurred in the last few decades.

Types of Antennas

Many types of antennas have been developed to date that are used in radio and television broadcast, cellular and wireless phone communications, marine and satellite communications and many other applications. In this section only few common forms and various types of antennas will be briefly described.

• Wire Antennas

Wire antennas are seen in everyday life situations- on cars, buildings, ships, and aircrafts and so on. Wire antennas come in various shapes such as straight wire (dipole), loop, and helix all of which are shown in Figure 1.1. Loop antennas may take the form of a rectangle, square, ellipse or any other configuration.

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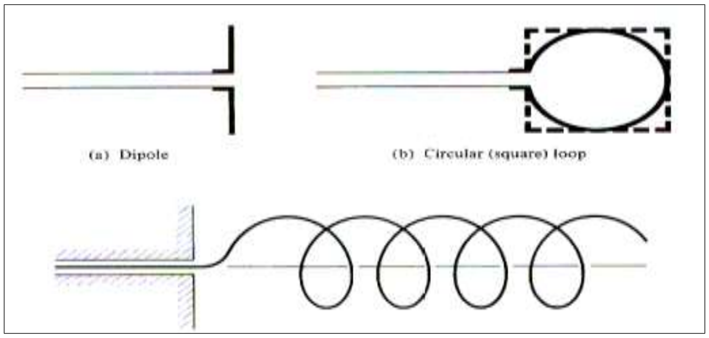

Figure 1.1 Wire antenna configurations

- **Aperture Antennas**

Due to the increasing demand for more sophisticated forms of antennas and utilization of higher frequencies the aperture antenna is more common today. Some forms of aperture antennas are shown in Figure 1.2. They are used for aircraft and spacecraft applications because they can be easily flush-mounted on the skin of the aircraft or spacecraft. Additionally, they can be covered with suitable dielectric materials to protect them from hazardous conditions of the environment in which aircrafts and spacecraft usually operate.

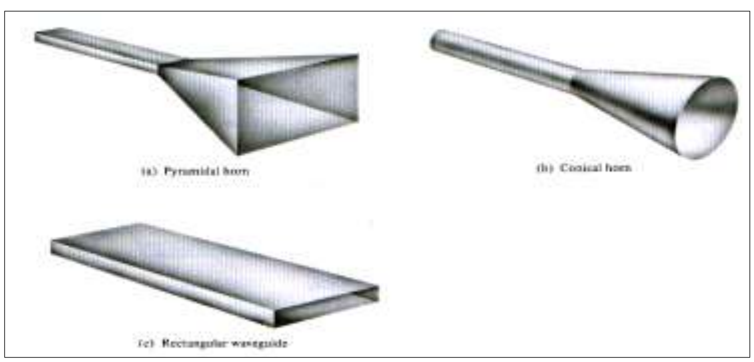

Figure 1.2 Aperture antenna configurations

• Microstrip Antennas

Microstrip antennas became very popular in the 1970s primarily for space borne applications. Today they can be found in many other government and commercial applications. They usually consist of a metallic patch on a grounded substrate and can take many different configurations, as discussed in later chapters.

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Rectangular and circular patches, shown in Figure 1.3, are the most popular because of the ease of analysis and fabrication and attractive radiation characteristics. Microstrip antennas are low-profile, conformable to planar and non-planar surfaces, simple and inexpensive to fabricate using modern printed circuit technology. They can be mounted on surface of high-performance aircraft, spacecraft, satellites, missiles, cars and even mobile phones. Due to these advantageous characteristics of microstrip antennas they will be further discussed and subsequently used and analyzed in this thesis.

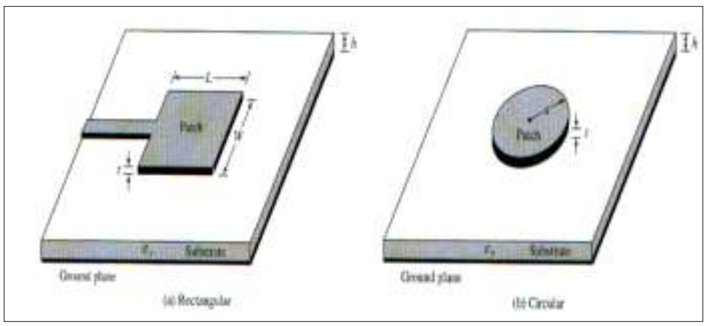

Figure 1.3: Rectangular and circular microstrip patch antennas

• Array Antennas

Many applications require radiation characteristics that can only be achieved if a number of radiating elements are arranged in a geometrical or an electrical manner that will result in the desired radiation pattern. The arrangement of such element is called an array and is used primarily to achieve a radiation pattern in a particular direction or directions. As will be discussed later, antenna arrays are used in cellular base stations to create directional patterns covering only desired area. These antennas, which are usually made up of an array of 4 to 12 elements, are referred to in cellular systems as sectored or directional antennas and take form of a panel array. Typical examples of arrays are shown in Figure 1.4.

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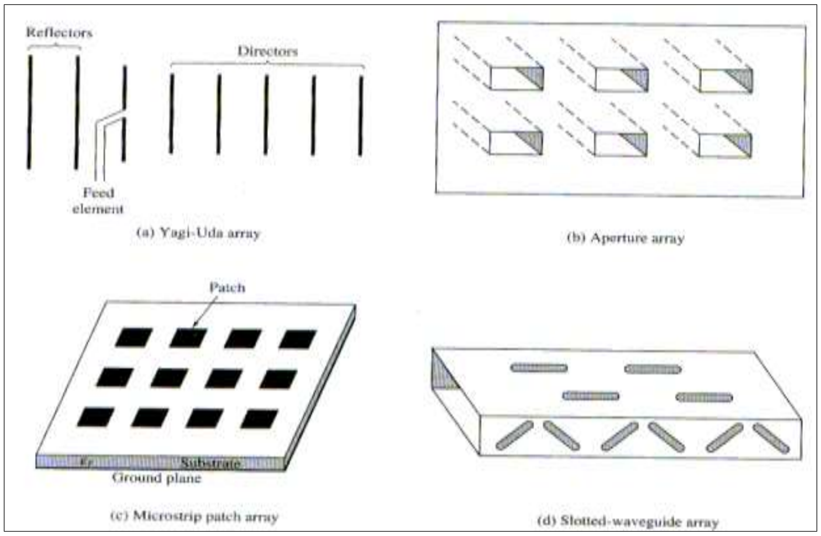

Figure 1.4 Typical wire, aperture and microstrip array configurations

Radiation Pattern

The antenna radiation pattern is simply a mathematical function or a graphical representation of the radiation properties of the antenna. The radiation pattern is often determined in far-field region as function of space or directional coordinates. A coordinate system for antenna analysis is shown in Figure 1.5.

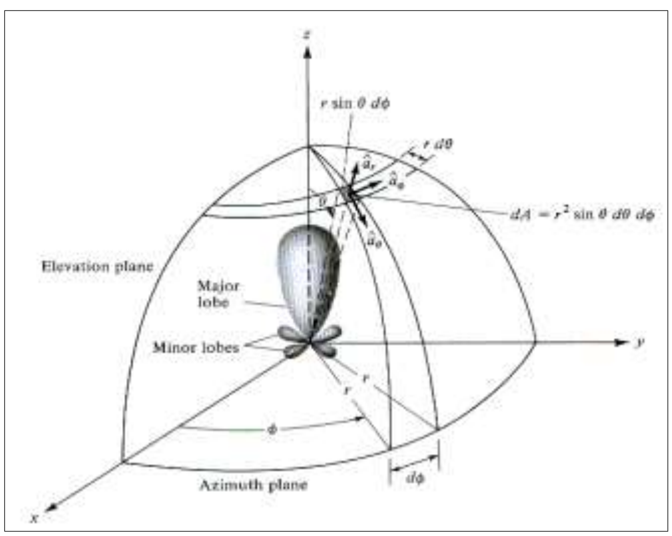

Figure 1.5 Coordinate system for antenna analysis

Radiation properties include power flux density, radiation intensity, field strength and polarization. Two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path of constant radius is of the main interest.

Radiation Pattern Lobes

Radiation pattern of an antenna consists of various parts referred to as lobes, which can be classified as major, minor, side and back lobes. Figure 1.6 shows a three-dimensional polar pattern with various radiation lobes. Some have greater radiation intensity then the others, which is sometimes desirable and undesirable. Figure 1.6 (b) shows the same pattern characteristics in a linear two-dimensional pattern.

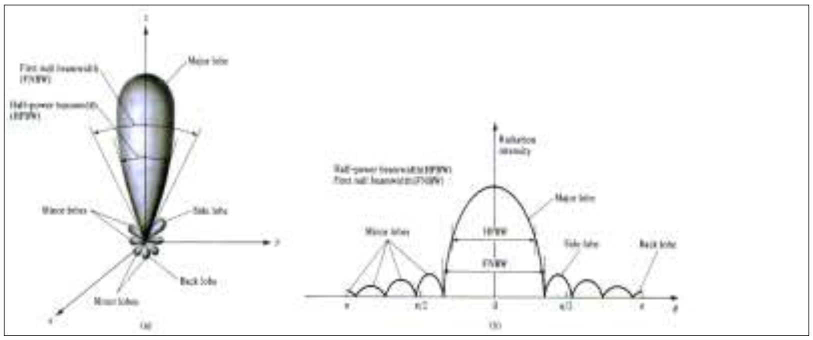

Figure 1.6 (a) Radiation lobes and beam widths of an antenna pattern. (b) Linear plot of power pattern and its associated lobes and beam widths

The main beam (or major lobe) contains the direction of maximum radiation. Some antennas may produce split-beams where there are several main beams. A minor lobe is any lobe other than the major lobe. A side lobe is a radiation lobe that is in direction different to the direction of the major lobe and is usually adjacent to the main beam. A back lobe is referred to as the radiation lobe that is 180o away from the main beam. In another words, it is the minor lobe in direction opposite to that of the major lobe.

Minor lobes usually represent radiation in undesired directions. The level of side lobes is usually expressed as a ratio of the power density in the minor lobe to that of the major lobe. Side lobe ratios of –20 dB or higher are desirable in most mobile communication and cellular systems application.

Gain

Because most antennas are passive devices, they can achieve gain in one direction only at the expense of gain in another direction. These gain antennas cause the signal to be relatively stronger in one direction than another. For most mobile applications upward and downward radiations are not desirable, so minimizing radiation in these directions while concentrating it in the forward direction is advantageous.

VSWR

Antenna with a voltage standing-wave-ratio (VSWR) of 1.0 will transmit all of the power presented to it. As VSWR rises, an increasing amount of power will be reflected. It is generally accepted that a VSWR

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of 1.5 - 1.7 is the highest acceptable values for a cellular antenna. So an antenna with a VSWR of 1.5 will reflect 4 percent of the total power.

Bandwidth

The bandwidth of an antenna is the range of frequencies over which the VSWR remains below 1.5 - 1.7 or some other defined VSWR usually less than 2. The VSWR will vary as a function of frequency. Occasionally the bandwidth will be specified for a VSWR of 2.0 and such an antenna will not be as good a match as one specified to a VSWR of 1.5.

Beam width

Because the gain of an antenna is a result of pattern compression, there will generally be a direction in which there is maximum gain, as seen in Figure 2.6. The beam width is defined by the two points that define the half-power levels (down 3dB).

Front-to-Back Ratio

The front to back ratio is ordinarily measured as the ratio of the gain of the maximum lobe compared to the gain at 180 degrees to that direction. As can be seen in Figure 1.6, that number may not give a true impression of the actual power levels that are scattered in the backward direction.

Antenna Construction

The earliest cellular antennas were simple dipoles and sector antennas derived from dipoles (dipoles surrounded by reflector). These devices served the industry well and are still the mainstay of small and rural networks. Later came the antennas with mechanical down tilt. These antennas, while simple in concept were the source of many network problems. The mechanical down tilt distorted the azimuth beam pattern and often gave unpredictable results. A further improvement in the early 1990s was electrical down tilt, which relied on phasing of the antennas and produced an undistorted down tilted pattern.

Experiments showed and theory predicts that the polarization of a signal that had travelled extensively in a mobile environment was no longer vertical. Further studies showed that two cross-polarized antennas received signal that were sufficiently uncorrelated and that they provided diversity similar to that of two spatially separated vertically polarized antennas. These cross-polarized antennas could be mounted into a single radome, thus giving diversity with half the number of antennas.

The quarter-wave transformer shown in Figure 1.7 is a simple power divider. Because the power divider is fed inside the antenna, the internal wiring harness is quite complex. A cellular omni-directional antenna is usually of this kind and it has a good wide-band performance.

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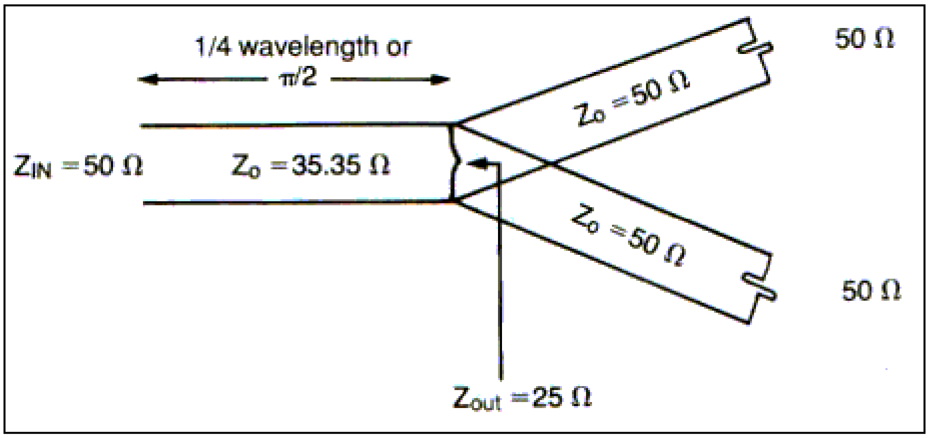

Figure: 1.7 A 50-ohm power divider

Diversity

Panel antennas are usually either 9dB omni-directional or 14 dB to 18 dB, 60-degree to 120-degree sector antennas. Diversity reception is frequently used and antennas should be mounted as shown in Figure 1.8. Diversity results in an effective 6 dB improvement in the receive path where diversity combiners are used. Due to multipath fading two receive antennas are usually used for diversity combining and this configuration ensures acceptable isolation and diversity reception. The separation for effective diversity performance depends on the height of the base station; usually 1/10 of the antenna height.

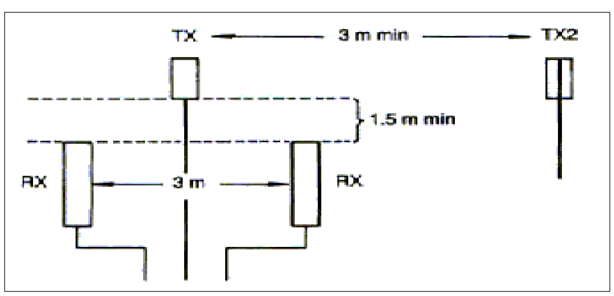

Figure 1.8 Antenna mounting for a 30-meter tower

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Diversity works best at right angles to the plane of the antennas. There is virtually no diversity effect in the plane of the antennas because when the antennas are in line they receive signal for the same path and so the multipath effect advantage cannot be taken.

If switching diversity is used for two antennas in the plane of the received signal the second antenna will contribute virtually zero gain whereas for combining diversity the gain will be 3 dB (the power in two antennas will be added).
Vertical diversity can also be used but it generally requires greater physical separation to achieve the same results. For diversity to work well it is necessary that two antennas have the same gain and thus contribute equally to the received signal. It is also important that the base station height is large compared to the antenna separation otherwise the diversity will not work well.

There are two types of diversity receivers; the diversity-combining receiver which aligns the phases of the incoming signals and then adds them and the switched-diversity receiver which chooses the best of the two signal paths and switches to that path. A gain of 6 dB can be obtained using the first method and a gain of 3 dB of the second method.

Materials
The most sensitive parameter in the estimation of antenna performance is the dielectric constant of the substrate material. Propagation constant of an electromagnetic wave travelling in the microstrip substrate must be accurately known as well.

Small variations in the substrate dielectric constant or dimensional changes due to temperature fluctuations can result in frequency shift. Therefore, substrates used in the design of microstrip antennas need to be of a high quality in terms of stability in their mechanical and electrical properties. From chapter 8 we have seen that materials with lower dielectric constant will provide greater bandwidth, more directive and more efficient antennas however with thinner substrates, as is the case in this design, the bandwidth will be small.

This design will use substrate parameters from a very common substrate known as RT/ Duroid 5880. Antennas for WCDMA applications will need to have substantially large bandwidth. From Pozar, the requirements to increase the impedance bandwidth are thick and low permittivity substrates. This also has the desirable qualities of high radiation efficiency and low surface radiation. However this design will only concern single layer microstrip design as the focus of the thesis primarily lies in effects of curvature on conformal antenna arrays.

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Patch Size Calculation

This process provides a reasonably accurate starting point although it does not provide the final patch dimensions. The equations have been obtained from Balanis and the values calculated refer to the dimensions illustrated in Figure 1.9

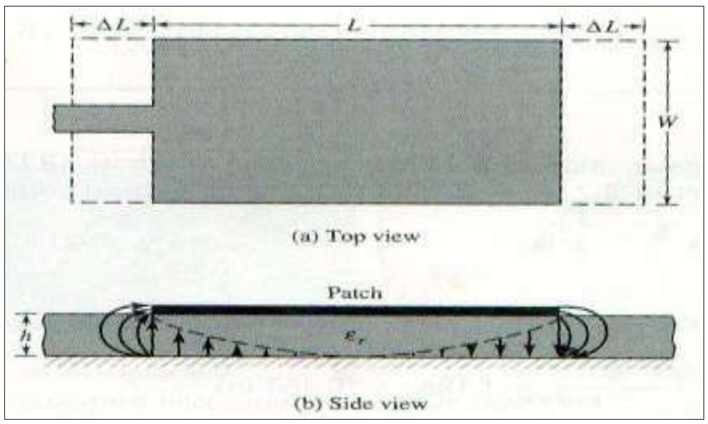

Figure: 1. 9 Dimensions of a single layer element

2. What is a Microstrip Patch Antenna (MPA)?

A Microstrip Patch Antenna uses the "microstrip" structure to construct an antenna. Microwave engineers first used "strip lines" to fabricate circuits from circuit board. The strip line requires two ground planes, and a flat strip (circuit board trace) in between, to guide radio frequency or signals. As the art progresses, many circuits are found to be easily made with "microstrip" structure, which is similar to the strip line, but with one ground plane removed. One of the big problems with certain circuits implemented in microstrip is radiation. Fortunately, antenna engineers picked up on this undesirable effect and started to take advantage of it. Many antennas have since been designed and implemented with the microstrip technique, ever since the groundbreaking paper by Professor Deschamps in 1953 at the 3rd USAF Symposium on Antennas, although it is a resonant device with relatively narrow operation bandwidth.

Historical Development of Microstrip Patch Antenna

The microstrip patch antenna is dated back to as late as 1950s where famous figures like Professor Deschamp and Gutton invented the first microstrip patch antenna. The first prototype can be imagined as

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a thin radiating metal piece of arbitrary shape, separated from a ground plane by a dielectric substrate, as referred by Figure 2.1.

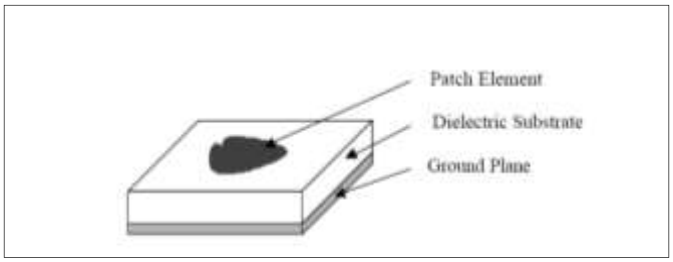

Figure 2.1: Physical structure of a microstrip patch antenna

Rapid development later begins in the late1970s whereby by the early 1980s, the microstrip patch antenna technology was well established in terms of design and modeling techniques. This is credited to several of its inherent characteristics like being low profile, lightweight and inexpensive. It must be pointe d out that, besides the microstrip patch antennas, the other two categories of microstrip antennas are the microstrip traveling wave antenna and the microstrip slot antenna.

Basic Characteristics of Microstrip Patch Antenna

The basic microstrip patch antenna is made up of a thin sheet of low-loss insulating material called the dielectric substrate Figure 2.1. It is considered the mechanical backbone of the microstrip circuit as it provides a stable support for the conductor strips and patches that make up connecting lines, resonators and antennas. Furthermore, it fulfills an electrical function by concentrating the electromagnetic fields and preventing unwanted radiation in circuits. The electrical characteristics of the antenna are also largely determined by its permittivity and thickness. The bottom layer of the dielectric is completely covered with metal and this is known as the ground plane. The topside of the dielectric is partly metalized or patched whereby antenna or circuit pattern can be printed. Figure 2.2 depicts the different shapes, which the radiating patch element may take the form of. The attractive radiation characteristics especially low cross polarization radiation makes the square, rectangular, dipole (strip) and circular shapes the simplest and common in terms of analysis and fabrication, Low profile antennas may be required in high performance aircraft, spacecraft, satellite, and missile applications where size, weight, cost performance, ease of installation and aerodynamic profile is constraints. To meet all these requirements, these microstrip antennas are manipulated because of their inherent characteristics:

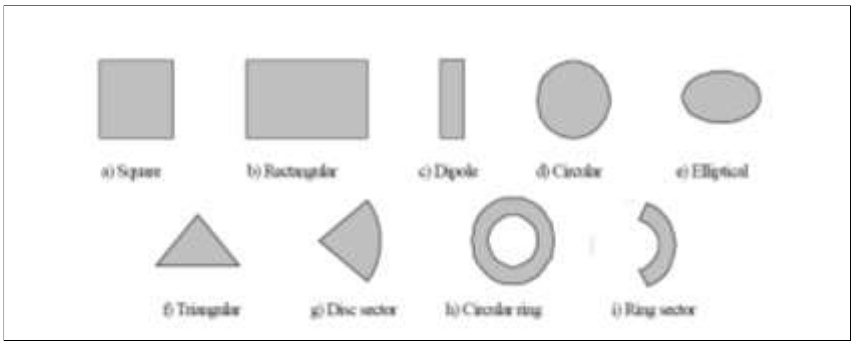

Figure 2.2: Various shapes for radiating microstrip patch elements.

• Capability of adopting modern printed-circuit technology

The microstrip antenna approach has become rather popular and widely used because of the fact that they can be easily fabricated by photolithographic processes. This idea is similar to printed circuits operating at high microwave frequency in terms of Giga hertz as compared to a simple printed circuit board for electronics at low frequency. Microstrip feed lines and radiating patch elements can thus be photoetched with ease on the dielectric substrate.

• Compatible with modular design

Research and development over the years have led to many variations for ease of integration with solid-state devices like amplifiers, oscillators, modulators, attenuators, switches, mixer etc.

These elements can be added to the substrate board without any difficulties. The microstrip antennas are also conformable to planar and non-planar surfaces.

• Attractive features

They are smaller in size and volume having lower weight and low profile. Furthermore, manufacturing cost is low, as their construction does not require machining. Therefore, fabrication is relatively simple and inexpensive. This is part of the reason for the replacement of bulky and cumbersome wave-guide components and related assemblies.

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Feeding Techniques for a Microstrip Antenna

The increased interest in the monolithic integration of microstrip antennas with matching networks, amplifiers, phase shifters etc. has led to many new configurations used to feed microstrip antennas. Among them are four most popular types, namely, the microstrip line, coaxial probe, proximity coupling and aperture coupling. The microstrip line and the coaxial probe feed are classified under the group of direct contact feeding method while the proximity coupling and the aperture coupling are grouped under the non-contact feeding method. The non-contact type of feeding method is introduced to counteract some disadvantages, like bandwidth limitation, of the direct contact feeding method.

• The Microstrip Line Feed

This method is easy to fabricate, simple to model and match by controlling the inset cut position in the patch in Figure 2.3. The most obvious setback while attempting to improve its operating bandwidth by increasing the substrate thickness is an increase in surface waves and spurious feed radiation.

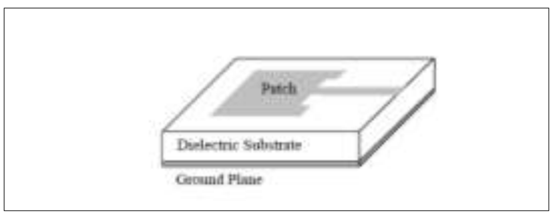

Figure 2.3: Microstrip line feed

This brings about an increase in the side lobe level and cross polarization, thereby degrading the antenna performance. On the other hand, considerable reactive power is accumulated below the patch (cavity effect), degrading the radiation characteristics, and bringing about a reduction in bandwidth. As a result, the practical design limits the bandwidth to about 2 – 5%.

3. Defected Ground Structure (DGS)

Microstrip antennas inherently have a high input impedance at resonant frequency. This may not be convenient for some applications. For active integrated antennas, moreover, the radiated power of microstrip antennas needs to be very low at harmonic frequencies. The main goals of this study are impedance matching and harmonic suppression of microstrip antennas. In order to meet these requirements, two one-dimensional (1-D) photonic bandgap (PBG) structures, namely, the defected ground structure (DGS) and the compact microstrip resonant cell (CMRC), are applied to the feed line of microstrip antennas. The characteristic impedance of the microstrip line is controlled by the additional effective inductance of the PBG structure. Without any matching circuits, microstrip antennas can be easily fed by a simple 50 Ω microstrip line with a PBG structure at the operating frequency. Additionally,

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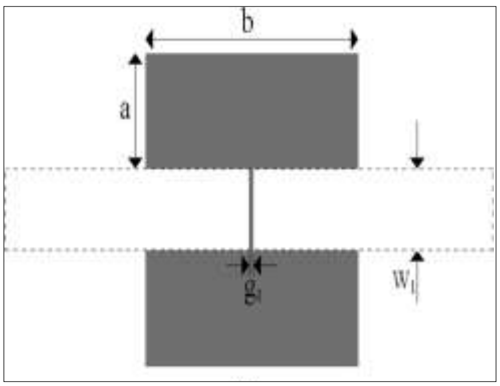
the second harmonic of the proposed antennas is properly suppressed compared to a conventional antenna. Measured results indicate that the two PBG structures are quite effective for harmonic suppression. Therefore, the proposed antennas are suitable for active integrated antennas.



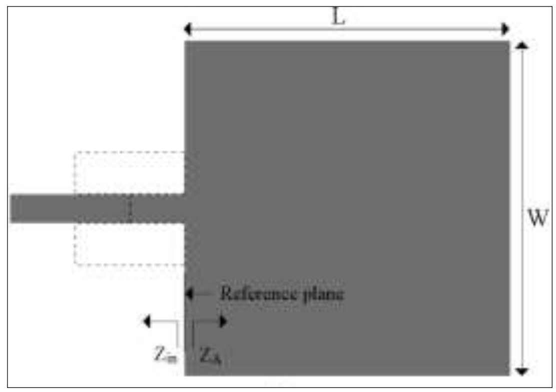


Fig. 3.1 -D PBG structures: DGS section **Fig. 3.2. Proposed antennas with DGS section**

Fig. 3.1 shows the DGS pattern as etched on the ground plane, where a, b, and g are the horizontal and vertical length of the aperture and the etched gap distance, respectively. The length of the narrow gap is the same as the width, of the microstrip line on the other plane. DGS section can provide a cutoff frequency in some frequency. It means that DGS section increases the effective permittivity, so that the effective inductance of a microstrip line is increased. The cutoff frequency depends on the etched square area in the ground plane. Therefore, the square area gives rise to increase the effective inductance of a microstrip line. There is also an attenuation pole location in some frequency. It is related with the etched gap distance. It is well known that an attenuation pole can be generated by combination of the inductance and capacitance elements. The etched gap, which is placed under a microstrip line, provides the parallel capacitance with the effective inductance. The narrow connecting lines lead to series inductance. Two configurations of the PBG microstrip antenna are illustrated in Fig. 3.2. For the input impedances of a microstrip antenna and the PBG microstrip line, the patch's bottom edge is set to the reference plane. We can represent the PBG antenna by an equivalent circuit shown in Fig. 3.3.

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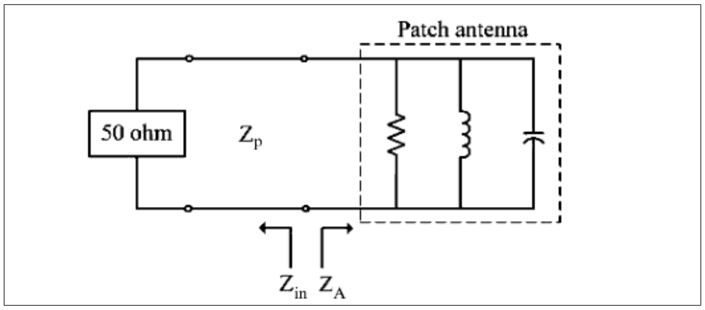


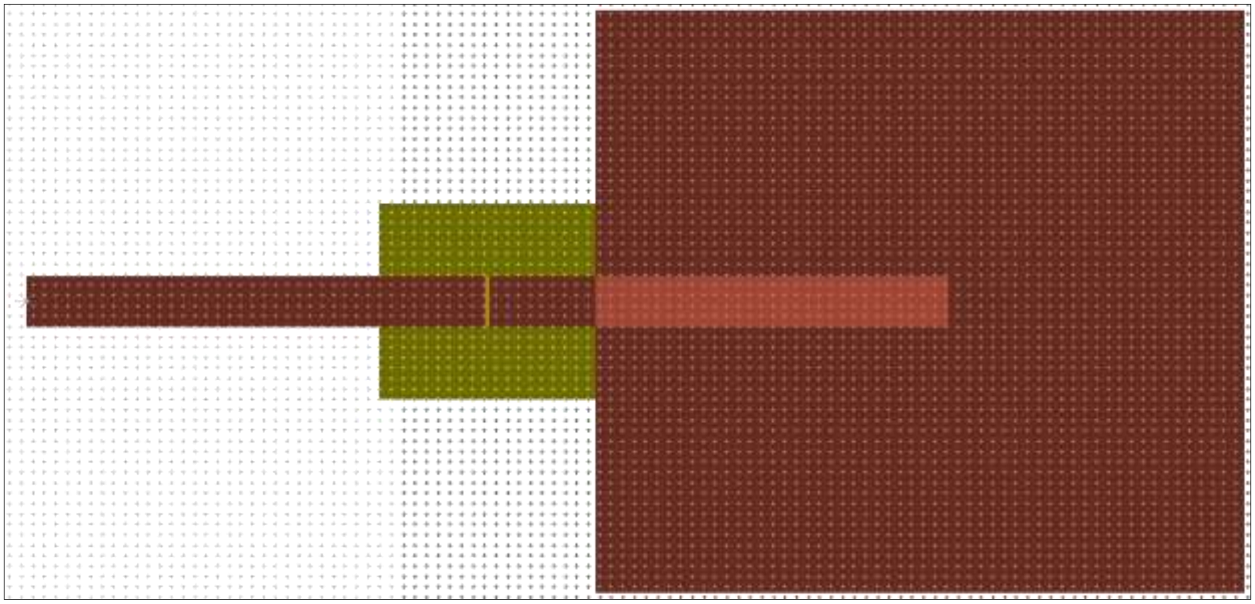
Fig. 3.3. Equivalent circuit of the antenna shown in Fig.3. 2.

It is well suited to compact and low-cost active circuit applications at microwave frequencies.

Different Design for DGS:

• original Rectangular Design

Lay out



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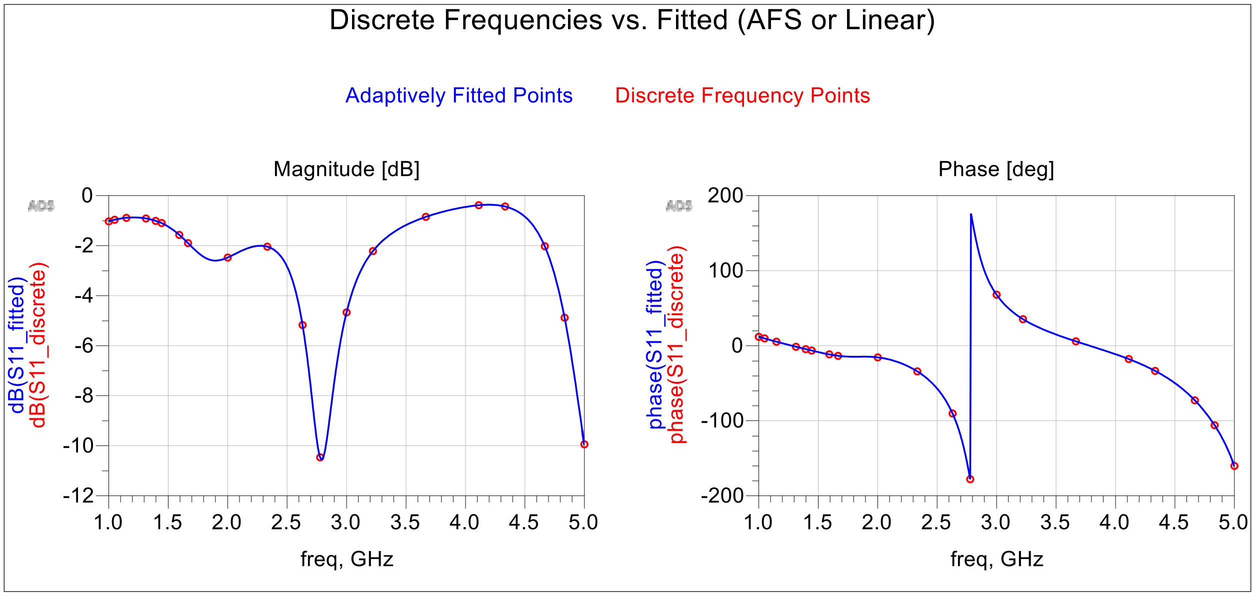

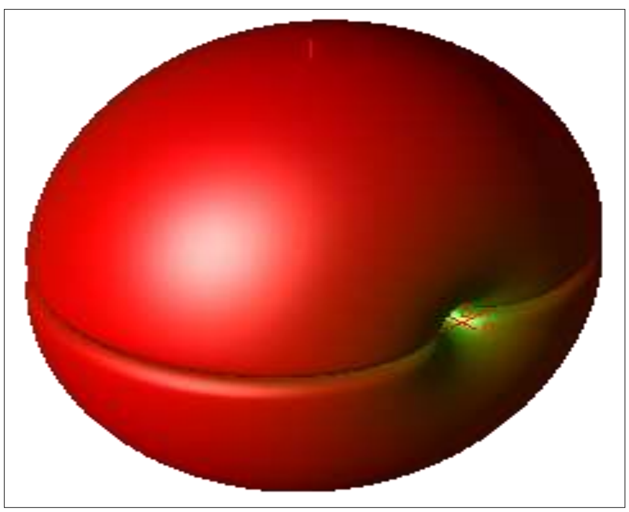

Radiation Pattern

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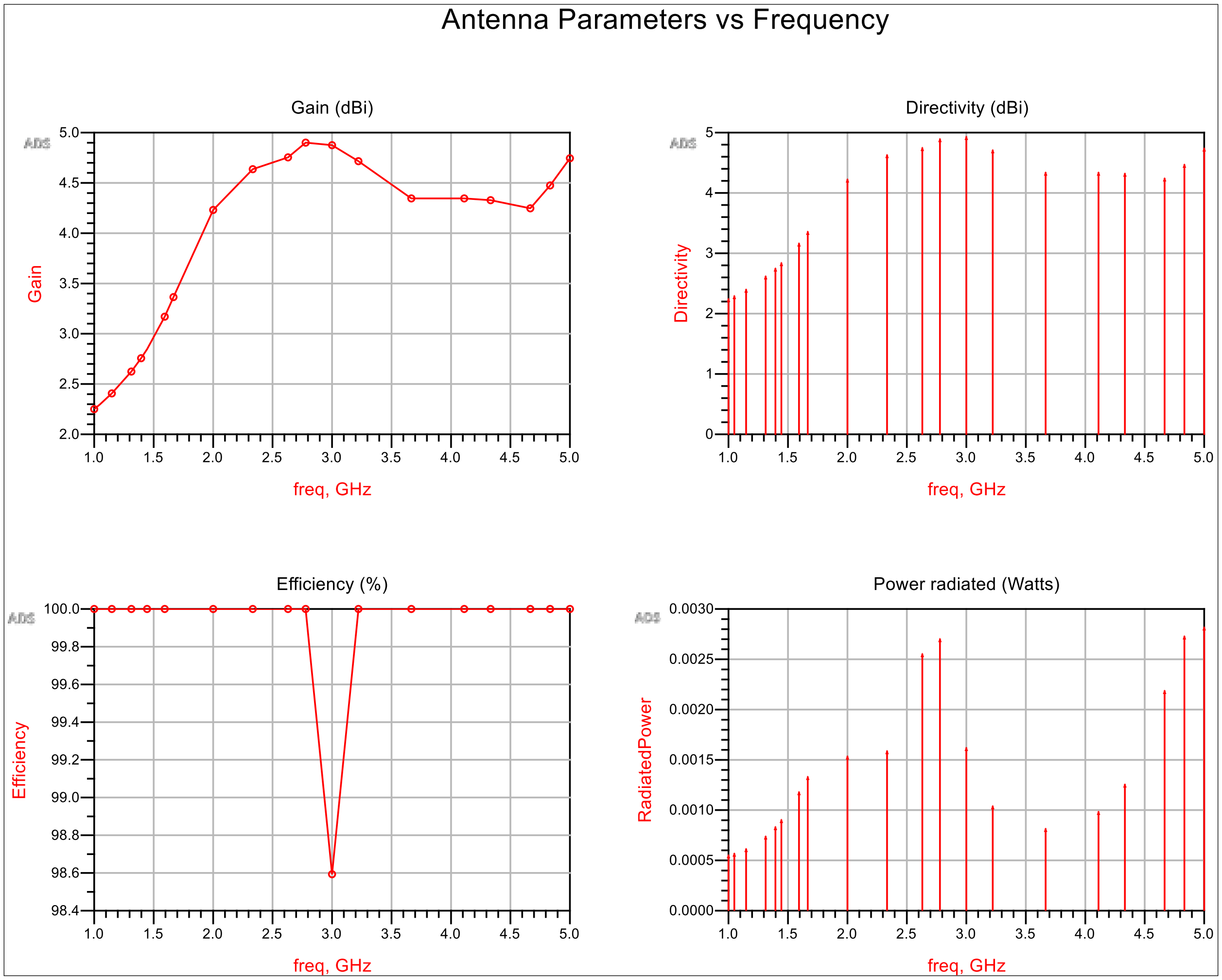

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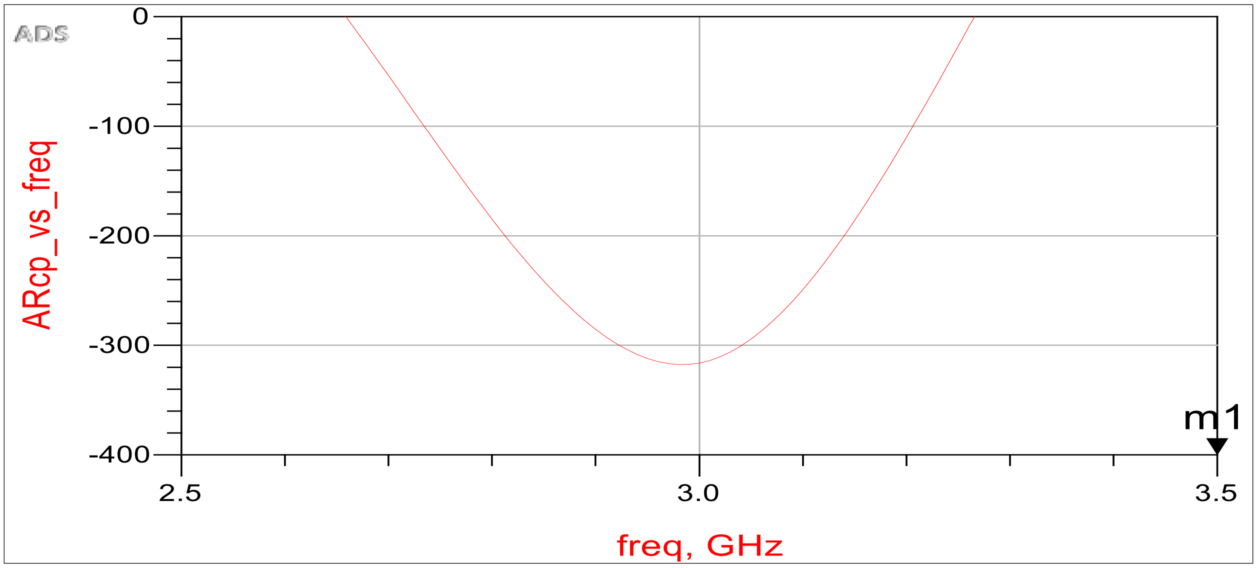
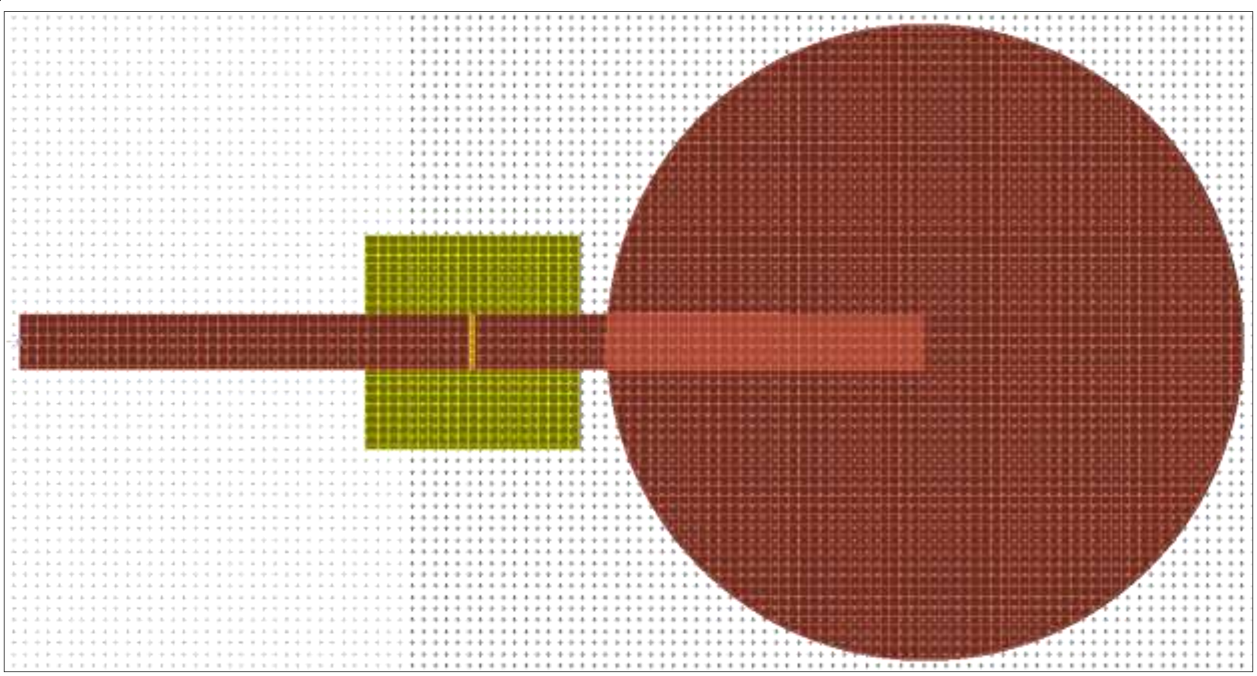
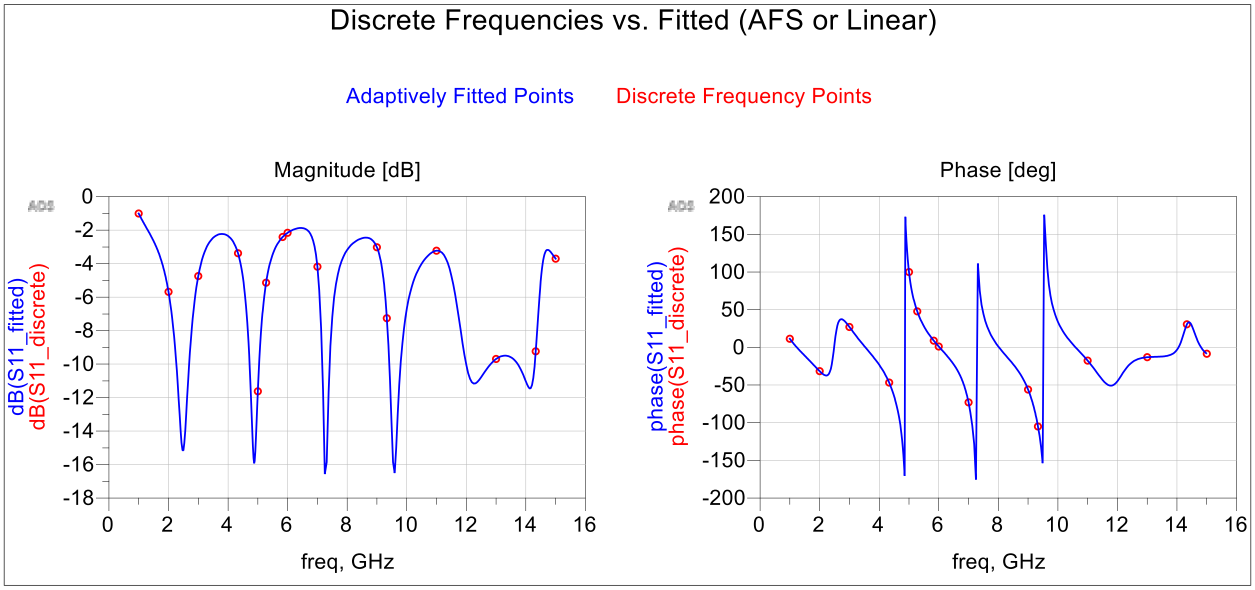


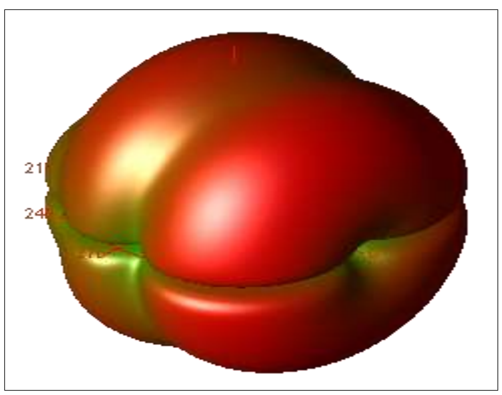
Axial ration versus Frequency

- **Design with circle**

Layout







Radiation Pattern

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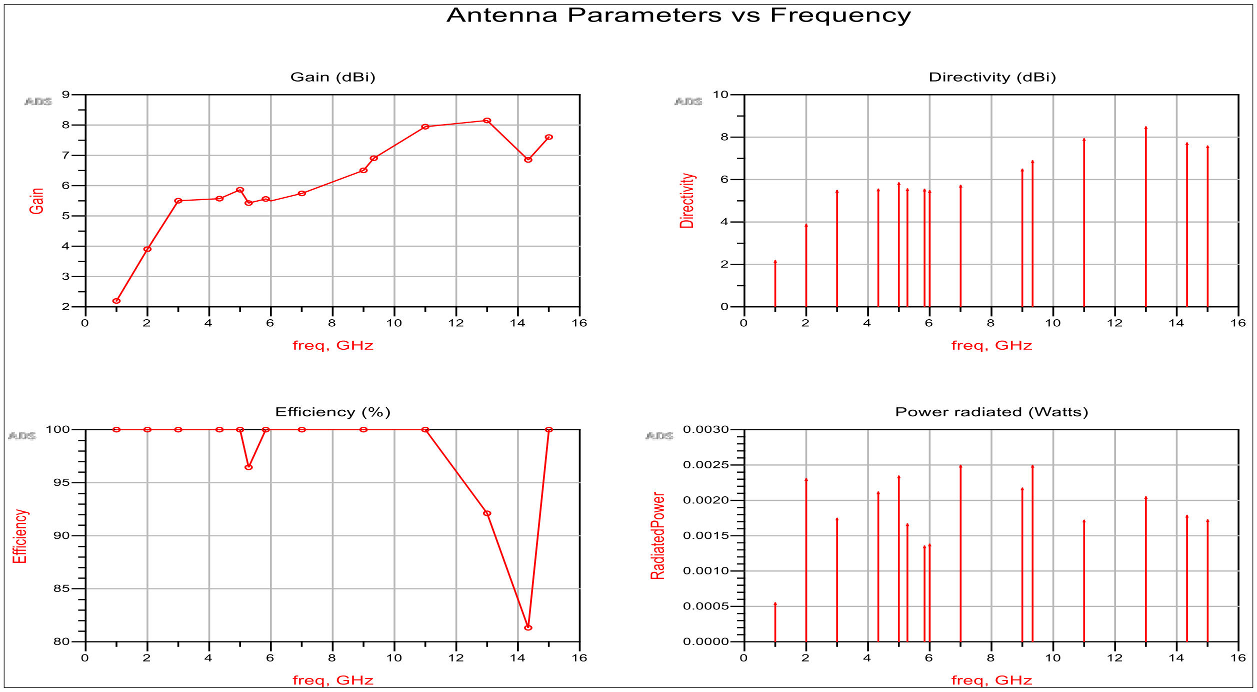

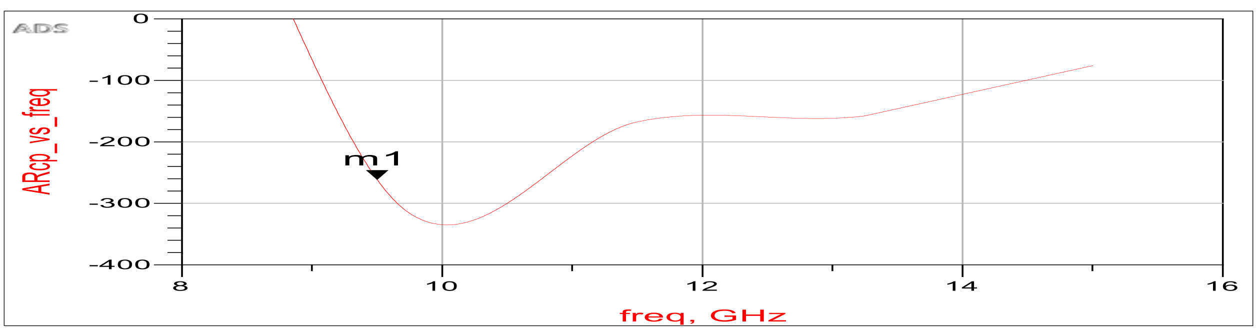

Axial ration versus Frequency

• Design with Parasitic (Enhancement)

Layout

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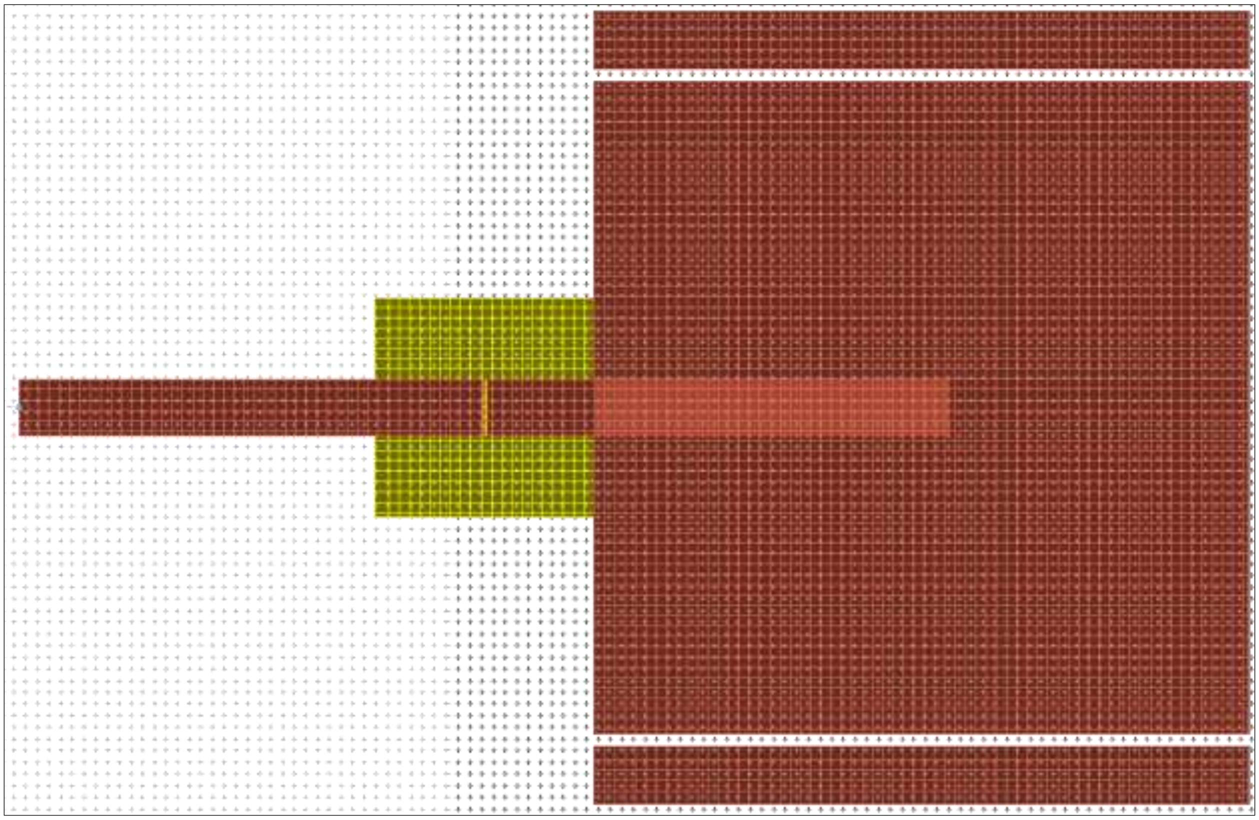

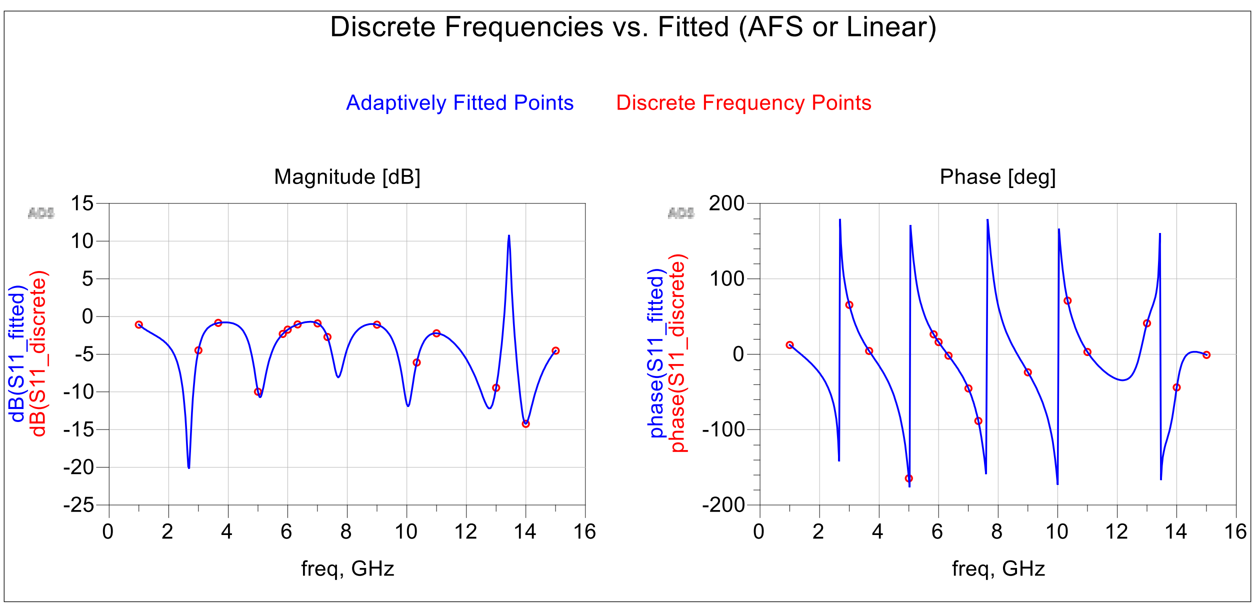

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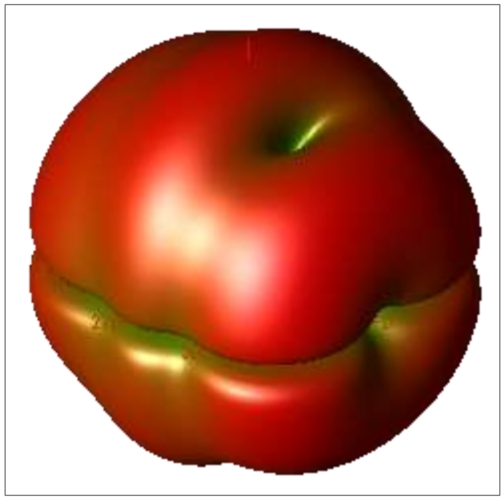

Radiation Pattern

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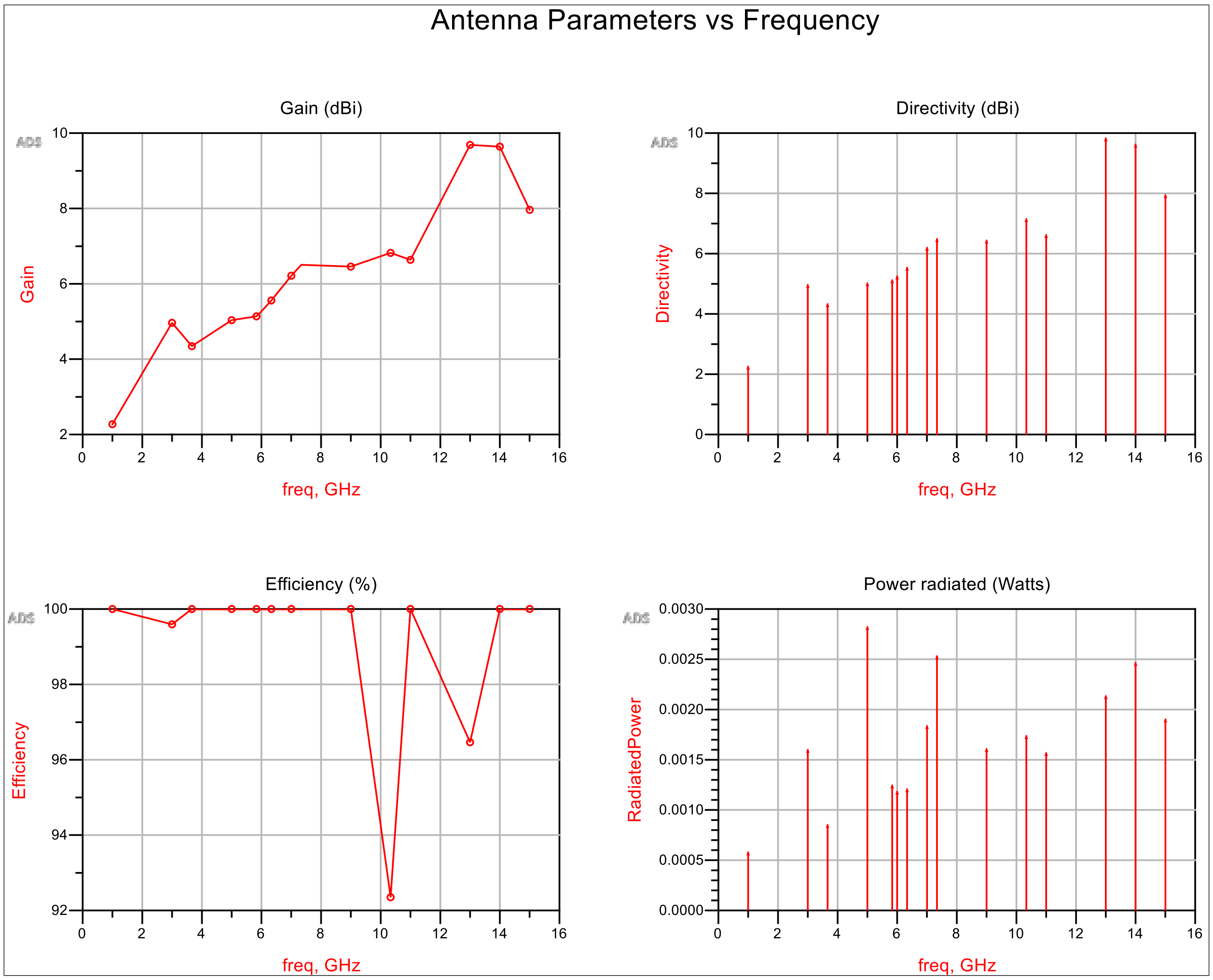
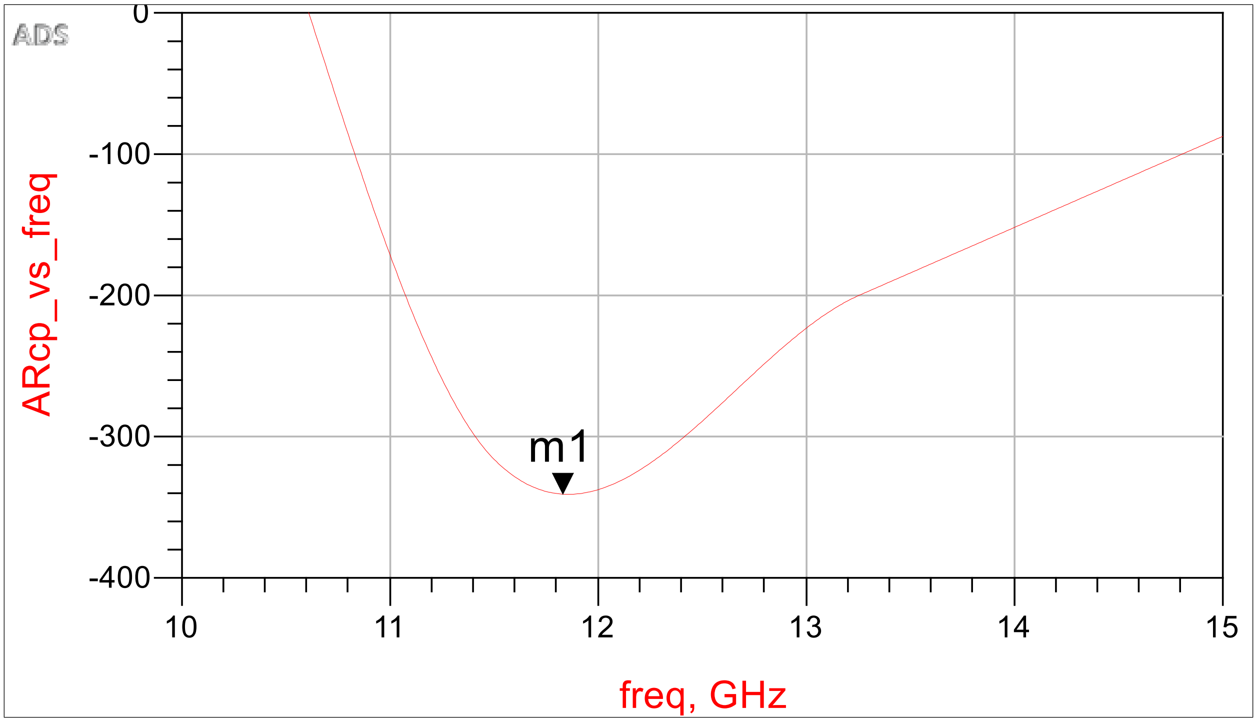
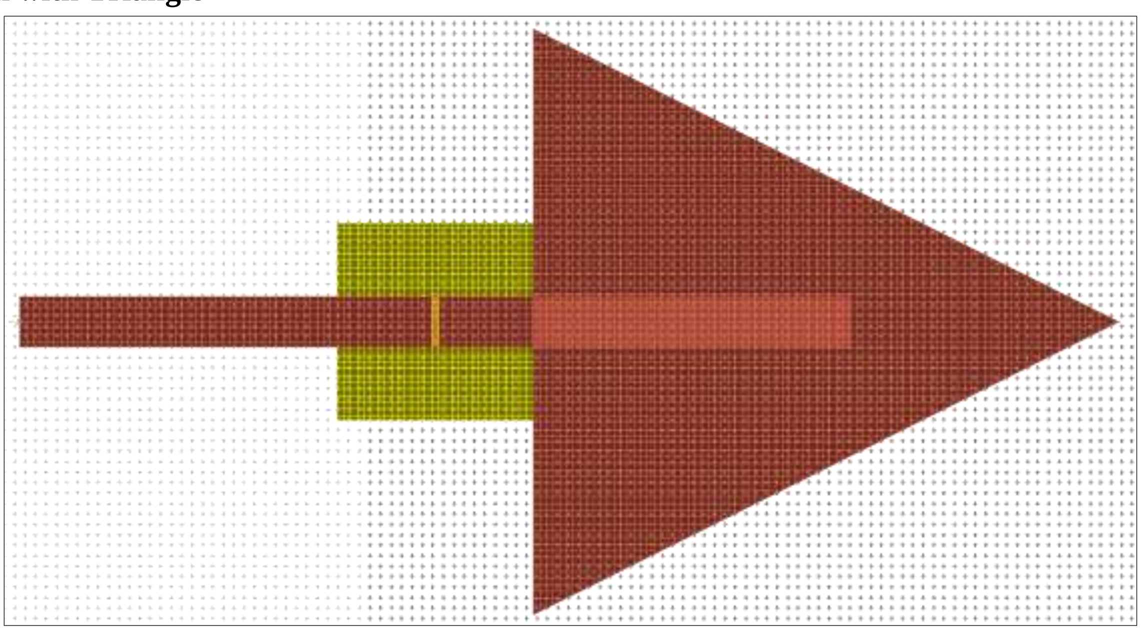




Axial ration versus Frequency

• **Design with Triangle**



International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

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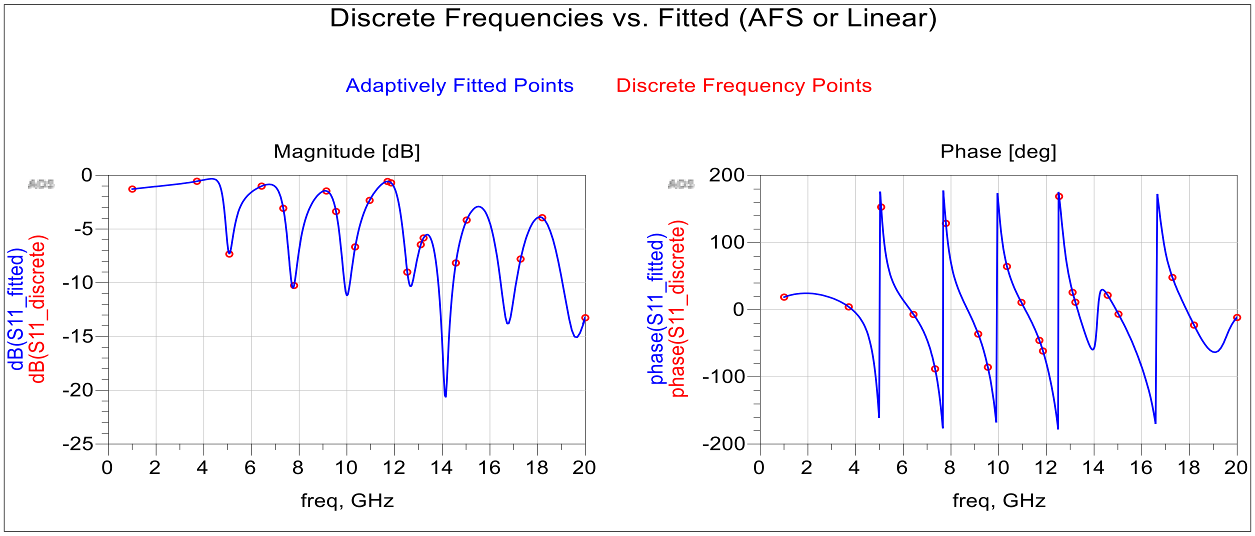
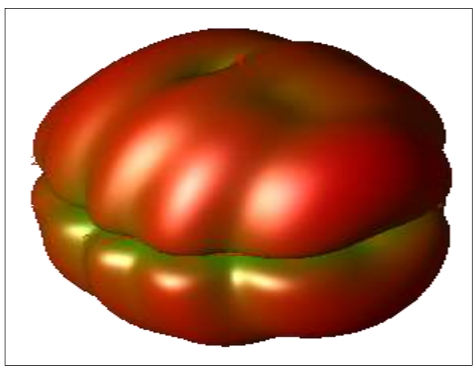
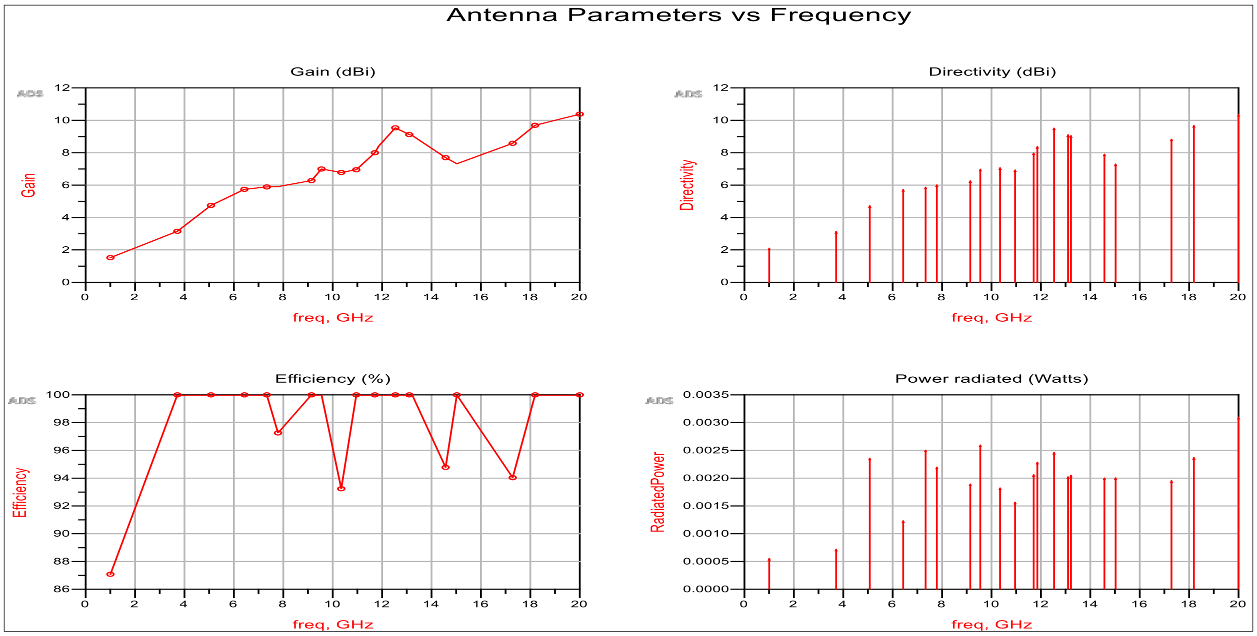
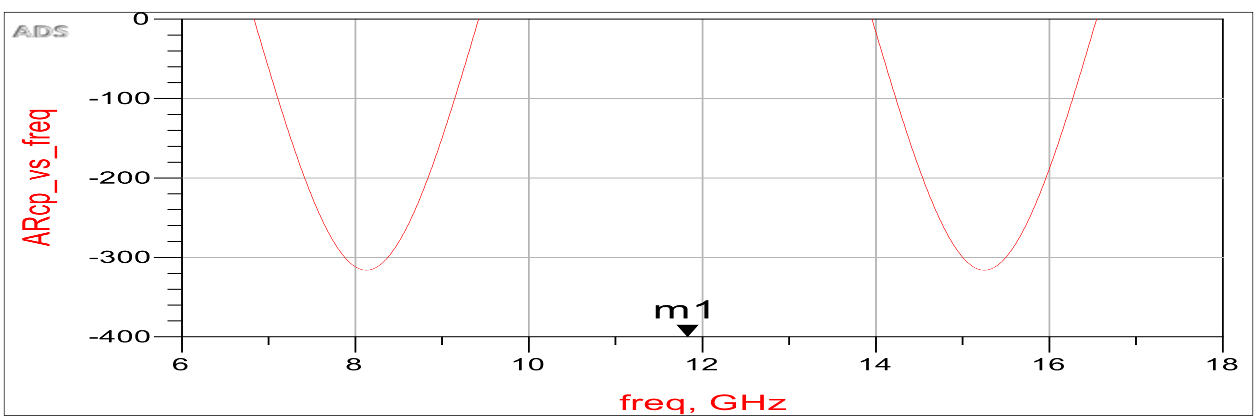




Radiation Pattern





Axial ration versus Frequency

Geometry Design of Microstrip patch Antenna	Parameter						
	Gain (dB)	Bandwidth (GHZ)	Polarization	Directivity (dB)	Efficiency %	Power radiated (W)	Axial ration BW (GHZ)
original Rectangular	4.9	.5	circular	5	100	.00255	1
circle	8	.5	circular	8.5	100	.0025	2
Parasitic (Enhancement)	9.5	.5	circular	10	100	.00259	2
Triangle	10	1	circular	10	100	.0025	4

4. CONCLUSION

The extensive research of microwave and RF field has been carried out over the past decade. Microstrips have been widely used in these fields and their advantages made them play an important role in today's communications. In this paper, the various aspects of microstrips are surveyed and suitable methodologies are applied. Rectangular, square, circular, circular ring, triangle, parasitic, and polygon patch antennas have been designed. The details of design of rectangular patch antenna are given in steps. For the other designed shapes, the design formulas were not given in this report, but anyone can take them from suitable reference.

The simulation is done by Advanced Design System 2015. ADS program is very important software for microwave designer and it is recommended her to learn more and more about this special software. The resulting return loss value (less than -25dB) is very attractive in the X-band but in pay of decreasing the efficiency of the antenna. The limitations and numerical calculations of the program must be not forgotten.

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For future improvement of these designs, one can make trade off the parameters of the antenna to get the desired aim. Arrays of microstrip patch antennas can also be designed and simulated here and this is left to whom he wants to complete this project.

Antennas designed in this project used microstrip line feed and this method takes up certain amount of space in the circuit. More compact antennas can be design using other feeding methods such as probe feed. Beam steering capabilities array antenna could also be designed to enhance the learning knowledge of design microstrip antennas.

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