

BACK RADIATION SUPPRESSION IN MICROSTRIP ANTENNAS USING DIFFERENT TECHNIQUES

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for the award of degree of*

Master of Engineering In Electronics and Communication

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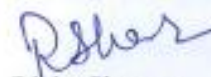
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DECLARATION

I, **Richa Sharma**, hereby certify that the work which is being presented in this thesis entitled "**Back Radiation Suppression in Microstrip Antennas Using Different Techniques**" by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Ms. Amanpreet Kaur and Dr. Rajesh Khanna.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of any other degree.

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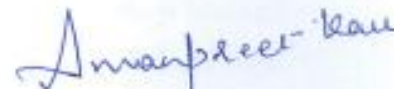


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ABSTRACT

This work covers two aspects of microwave communication technology. The first is the analysis and design of microstrip slot antenna with better front radiation and the second aspect is the design of high gain antenna with improved radiation characteristics. The effect of different dielectric materials on the radiation pattern is compared in the report. Another method to reduce the back radiation has been developed in the work which incorporates the compact aperture feed technique in a slot antenna. It also includes the patches which are at the bottom of the substrate and they help in carrying out the more field pattern into the front direction. Such approach is very useful in mobile communication where the cellular phone directly comes in contact with the human skin and such a design can avoid the leaky radiation into the human body and may radiate only unidirectional. Another concept has also been developed where the same approach is advanced for improving front back ratio and the gain. This work includes the array of patches under the slot which are displaced and positioned such that they give maximum gain of 8.4 dB and also give the front to back ratio of 25 dB approximately. This fabrication of this design is also done as well as the testing is done using VNA model no: E5071C. The testing results along with the comparison between testing results and simulated results are also shown. The operating frequency of single band at 3.6 GHz is obtained at 3.61 GHz.

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Richa Sharma

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ABBREVIATIONS

WLAN	Wireless Local Area Network
CST	Computer Simulation Technology
VNA	Vector Network Analyzer
SAR	Specific Absorption Rate
VSWR	Voltage Standing Wave Ratio
PMC	Perfect Magnetic Conductor
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility

CHAPTER 1

INTRODUCTION

1.1 ANTENNAS

An antenna serves as the transition between the RF front-end circuitry and the radiation and propagation of electromagnetic waves in free space. Antennas play a critical role in microwave and other wireless applications systems. Planar oriented antennas, such as microstrip patch and printed dipole have attracted significant attention among antenna engineers due to the tremendous benefits they bring to modern wireless systems in comparison to more conventional designs. The microstrip antenna is probably the simplest yet most popular planar antenna. In its simplest form, the patch antenna can be realized by etching a rectangular metal pattern on a dielectric substrate [1]. These antennas are:

- Low profile;
- Lightweight antennas;
- Most suitable for aerospace and mobile applications;
- Easily integrated with electronic components;
- Easily integrated into arrays.

The results of the research have contributed to overcome many of their limitations and to the success of these antennas not only in military applications such as aircraft, missiles, and rockets but also in commercial areas. Most of these commercial systems must be low-cost, easy to use, small in size, and rugged to achieve wide acceptance. Low cost demands easily produced components [2]. Two parameters usually come first in relation with the design and analysis of any antenna structure. The first is its radiation patterns, which essentially determine how the radiated Electromagnetic fields can be controlled by antenna. Other important parameters to describe the antenna radiation properties include directivity, gain, radiation efficiency, front-to-back ratio, cross polarization level, axial ratio (for circularly polarized antenna), as well as side lobes for the case of an array antenna. The other important parameter in antenna analysis is the input impedance, or equivalently the input return loss, which describes how well the antenna, is matched with its feeding network. The narrow impedance bandwidth is ultimately a consequence of its electrically thin ground- plane

backed dielectric substrate, which leads to a high-resonance behavior. Bandwidth improves as the substrate thickness is increased. A thick substrate will support surface waves, which will deteriorate the radiation patterns as well as reduce the radiation efficiency [3].

1.2 BACK RADIATION IN ANTENNAS

At microwave and millimeter wave frequency microstrip slot antenna becomes very small and light weight. In spite of these advantages, it has main disadvantage of back radiation, which limits its use in mobile communication. This back lobe is undesired because it shows power loss. It increases SAR (Specific absorption rate) for the mobile users. Additional undesired radiation occurs due to the side lobes [4]. As the length of the slot increases number of side lobes increases and the main lobe moves towards the slot axis. The radiation pattern of most antennas shows a pattern of lobes at various angles, directions where the radiated signal strength reaches a maximum, separated by nulls, angles at which the radiated signal strength falls to zero. In a directional antenna in which the objective is to emit the radio waves in one direction, the lobe in that direction has larger field strength than the others; this is the main lobe. The other lobes are called side lobes, and usually represent unwanted radiation in undesired directions. The side lobe in the opposite direction (180°) from the main lobe is called the back lobe. In transmitting antennas, excessive back lobe radiation wastes energy and may cause interference to other equipment. In receiving antennas, back lobes may pick up interfering signals, and increase the noise level in the receiver [5].

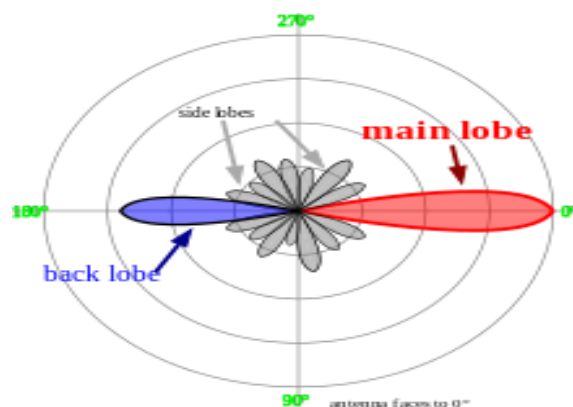
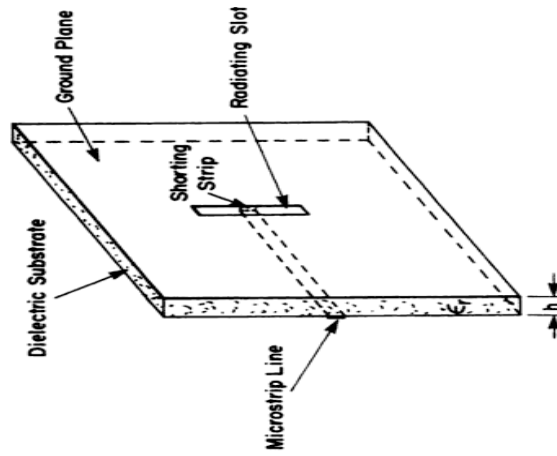


Fig. 1.1 Radiation pattern of an antenna [6]

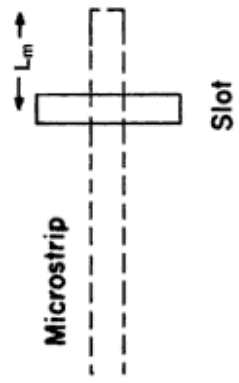
The power density in the back lobes is generally much less than that in the main beam. The main lobe and side lobes occur for both conditions of transmit, and for receive. Several methods have been proposed to suppress the back lobe, such as by using array topology [7], a taper-loaded antenna [8] and a 2 wave-length Microwave Leaky Wave Antenna with coaxial probe coupled patch antenna arrays [9], which has a back lobe suppression less than -8dB. However, all proposals mentioned above require complicated circuit feeding. To reduce the back radiation, a metallic reflector or cavity is often used in slot-coupled antennas. For this purpose, a metallic reflector usually requires a supporting substrate with a minimum thickness approaching a quarter wavelengths, which increases the volume and leads to difficult fabrication processes. In addition, metal reflectors can support parallel plate modes, which are propagating electromagnetic waves bounded by the region between the metal plate and the ground plane, and diffracted at the edge of the finite ground plane. As a result, a metal reflector easily produces other undesired radiation [10]. Although an enclosed cavity can eliminate back radiation, it may excite high-order modes, which can degrade the antenna performance. Additionally, similar to a backed metallic reflector, a cavity also takes a large volume. As is well known, the space for each circuit component is limited and low profile and compact size components are very important for avoiding the interactions among different devices in the design issues. In this work, the slot antennas are designed for solving the problem of back radiation due to the reason that they incorporate relatively compact structures and ensure the large coverage of radiation in space.

1.3 MICROSTRIP SLOT ANTENNA

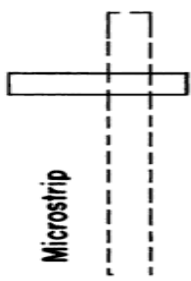
Microstrip slot antennas have the advantage of being able to produce bidirectional and unidirectional radiation patterns with larger bandwidth [11]. Strip and slot combinations offer an additional degree of freedom in the design of microstrip antennas. Such antennas are less sensitive to manufacturing tolerances than are microstrip patch antennas.



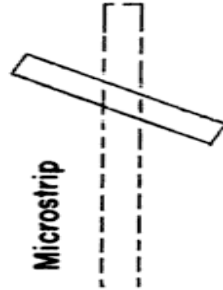
(a) Microstrip terminated in a short circuited stub



(b) Microstrip terminated in an open circuited stub



(c) Offset Microstrip feed



(d) Center fed but inclined Microstrip feed

Fig. 1.2 (a), (b), (c) and (d) Different configurations of the microstrip feed [12]

A microstrip slot antenna comprises a slot cut in the ground plane of the microstrip line. The field of the microstrip line excites the slot. For efficient excitation of the slot, the strip conductor is either short circuited through the dielectric substrate to the edge of the slot as shown in Fig. 1.2 (a) or the strip conductor is terminated in an open circuited stub beyond the edge of the slot as shown in Fig. 1.2 (b). In addition, the resistance seen by the feed line can be reduced by off center feeding or by centre fed inclined feeding as shown in Fig. 1.2 (c) and Fig. 1.2 (d). The stub tuning introduces reactive loading of the antenna, thereby changing the resonant frequency. The stub is designed so that the input resistance compares with the feed line impedance at the new resonant frequency.

In the designs further, two of these feeds have been used for designing antennas, one is centered and the other is offset feed. Further, the aperture coupling feed has been considered in all the designs, due to its numerous advantages that have been discussed in next section.

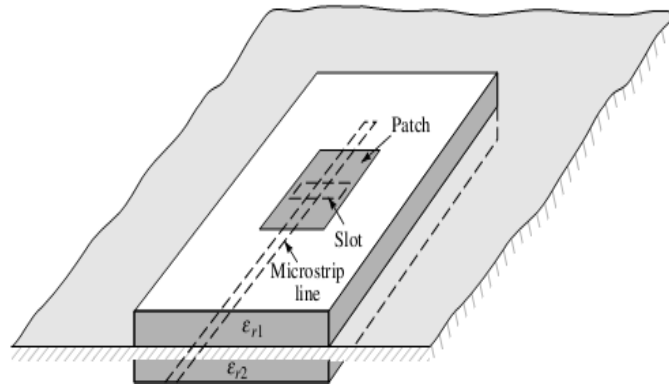
1.4 APERTURE COUPLED FEED

The aperture coupling method of providing energy to the radiating patch of a microstrip antenna element [13] allows the use of different substrates for the patch and the active circuitry, and leads to be increasingly popular means of producing patch arrays with enhanced performance. The feed and any other circuitry are placed on the bottom of the lower substrate. Therefore no spurious radiation is produced to disturb the side lobes or polarization of the antenna. The substrates are separated by a ground plane which has an aperture for coupling to the patch on the top of the upper substrate as shown in Fig. 1.6. The substrate electrical parameters, feed line width, and slot size and position are used to

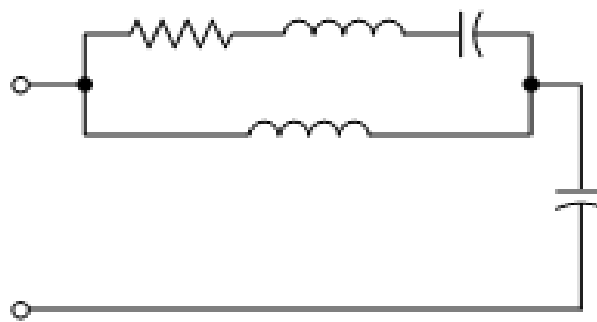
optimize the design. Besides this, the aperture coupled feed method have many advantages over other feeding techniques:

- No radiation from the feed network can interfere with the main radiation pattern.
- No direct connection is made to the antenna elements.
- The input impedance is easily controlled by the size and position of the aperture.
- Any excess reactance caused by the coupling aperture can be removed through the use of a tuning stub.
- Very low cross-polarization levels.
- It eliminates the soldering process.

In this feeding method, the slot is represented by an equivalent normal electric dipole to account for the normal component (to the slot) of the electric field, and an equivalent horizontal magnetic dipole to account for the tangential component (to the slot) magnetic field [14]. If the slot is centered below the patch, where ideally for the dominant mode the electric field is zero while the magnetic field is maximum, the magnetic coupling will dominate. Doing this also leads to good polarization purity and no cross-polarized radiation in the principal planes. The equivalent circuit in Fig. 1.3 (b) appears as a series RLC network, with a shunt inductance representing the coupling slot. . The key factor of this feeding technique is that the aperture is usually smaller than resonant size, so the back lobe radiated by the slot is 15-20dB below the forward main beam. Aperture coupled antennas are advantageous in arrays because they electrically isolate the feed and phase shifting circuitry from the patch antennas. The disadvantage is the required multilayer structure which increases fabrication complexity and cost. Hence, in the further work this disadvantage of aperture coupling feed is overcome by using a modified aperture coupled feed in which a single dielectric layer is used in the design. Hence, a less complicated and compact structure is designed.



(a)



(b)

Fig. 1.3 (a) Geometry and (b) Equivalent circuit of Aperture Coupled Microstrip Antenna [15]

1.5 OBJECTIVE OF THE THESIS

- Design and simulation of a modified aperture coupled antenna with improved front radiation.
- Design and simulation of a single band microstrip slot antenna operating at C band with suppressed back radiation by using patches under the substrate layer.
- Design, simulation and fabrication of a slot antenna array with parasitic patches with improved front radiation and gain for WLAN application.
- Testing of the antenna to validate the results.
- Analysis of the results for application in the current scenario.

1.6 ORGANIZATION OF THE THESIS

Chapter 1 gives an introduction of microstrip antenna and describes its associated problem of back radiation. It presents a general review for the previous work and states the objective of the thesis.

Chapter 2 includes the literature survey on the aperture coupled feeding technique, slot antennas and ways of back radiation suppression in such antennas. The brief idea about the researches done to improve the front to back ratio and the gain for the microstrip antennas is given.

Chapter 3 includes the comparison of radiation pattern for two different dielectric materials in the lower substrate of an aperture coupled antenna and concludes with the best one suited in the current scenario.

In Chapter 4, a single band aperture coupled microstrip antenna with reduced back radiation is designed, simulated and measured in the C-band. The back radiation is suppressed by the displacement of the patch position along the slot axis at such a position where the voltage null occurs and the patch radiation takes 180 phase shift and radiates in the front. The design is achieved by systematic application of the CST Software.

Chapter 5 concentrates on further improvements in the result parameters like directivity, gain and return loss with a design having patch array along the slot axis. This design is simulated, designed and measured in S band.

In Chapter 6, the antenna studied in Chapter 4 is fabricated and tested for validation of results.

In Chapter 7, summary and suggestions for future work related to the designed antennas are presented.

CHAPTER 2

LITERATURE SURVEY

This chapter gives us an idea about the evolution of Aperture Coupled Microstrip Antenna, various techniques used so far to reduce the back radiation in microstrip antennas and various related developments in the past and the research gaps.

2.1 LITERATURE SURVEY

In 1981 Keith R. Carve And James W. Mink [16] proposed that the choice of material is a very important task in antenna design. PTFE (Polytetrafluoroethylene) being electrically and mechanically robust and available in wide range of thicknesses and sheet sizes became the most used material type. Basically, by the proper selection of the material, it becomes easy to eliminate the temperature effects on the resonant frequency of a microstrip patch antenna.

In 1986 Peter L. Sullivan and Daniel H. Schaubert [17] proposed that how the antenna can be designed to have a specified input impedance. On variations of the aperture length of aperture coupled antennas, it was found that reduction in length decreases the coupling factor between the feed line and the patch antenna and increasing the length however improves coupling but larger apertures radiate more power on the feed line side of the ground plane. He found that the aperture length can be adjusted to obtain the desired resistive part of the impedance and the open circuited stub length can be adjusted to obtain the desired reactance.

The alignment of patch above the slot is analyzed with different positions of the patch; primarily by shifting the patch in the direction of resonance and secondly by moving it orthogonal to the resonance and it was found that the maximum coupling is obtained when the patch is centered over the aperture.

In year 1987 C. H. Tsao. Y. M. Hwang: F. Kilburg and F. Dietrich [18] introduced the wide band patch radiating element using aperture coupled feed method. First of all, he designed linear polarized aperture coupled antenna and achieved 19.2%. Then the design of dual linear polarized antenna by using two input port feed network earned bandwidth up to 23%.

In year 1989 Daniel H. Schaubert, David M. Pozar And Andrew Adrian [19] analyzed the antenna performance with eight different dimensions and three different feeding methods;

one is the microstrip line along a radiating edge, second along the non radiating edge and third is the coax probe. Out of three, the radiating edge shows highest resonance resistance. It has also shown that feedings methods have some little effect on resonant frequency of around 2 percent or less. The conclusion that was made out of it was that the erratic results may be obtained for substrates thicker than about $0.02\lambda_0$.

In year 1989 Hugo F. Pues and Antoine R. Van De Capelle [20] proposed the broad-band impedance matching as a method for bandwidth enhancement of microstrip antennas. A reactive matching network has been added to compensate for the rapid frequency variations of the input impedance. This impedance matched antenna was found to have low mismatch loss when compared with a reference antenna.

In year 1992 Clarke and M. Cuha [21] discussed that a slot-fed stacked microstrip patch antenna is suitable for monolithic phased array structures and possesses an operating bandwidth of 18%. The analysis was done on two different designs, with a foam spacer between two rectangular patches in both designs. The conclusion was made that the best bandwidth was obtained when the dimensions of the top patch are approximately equal to that of the bottom patch.

In year 1992 new antenna configurations have been proposed by David M. Pozar [22] for improved electrical performance and manufacturability. The discussion includes mainly the microstrip antennas with mechanical and fabricated features like low cost, lightweight, easy integration etc. He has proposed the bandwidth enhancement methods primarily by using a thick, low dielectric constant substrate (although it leads to spurious feed radiation as well), secondly by designing a planar impedance matching network. He introduced the method of stacked antennas as well for increasing bandwidth.

In year 1994 Richard Q. Lee and Rainee N. Simons [23] made use of a series gap in the centre-strip conductor and provided good return loss, better coupling efficiency but a slight change in resonant frequency. By varying the series gap improved results were obtained with the increase in gap.

In year 1995 Pamela R Haddad & David M. Pozar [24] worked on increasing the thickness of ground plane of the aperture coupled patch antenna so as to provide heat sink for active

MMIC circuitry and to provide mechanical support for thin substrates. On experimenting with different thicknesses, it was found that resonant frequency increases and resonant resistance decreases with the increase in thickness.

In year 1995 T.M. Au, K.F. Tong, K.M. Luk and K.F. Lee [25] worked on an aperture coupled microstrip antenna with an air gap operating at the C-band carries the resonant frequency to be tuned from 4.21GHz to 4.80GHz, giving a tuning range of 14% of the resonant frequency. There was no significant change in the far field radiation pattern.

In year 1995 Xian Hua Yang and Lotfollah Shafai [26] proposed that by changing the position of aperture, the asymmetric excitation carries out to increase the cross polarization current on the patch. Also, the coupling efficiency and the transverse electric surface also increase for the variations in the aperture position. So the transverse part should not be made too long to keep the cross polarization level low in directions away from broadside.

In year 1996 Vivek Rathi, Girish Kumar, and K. P. Ray [27] proposed various aperture shapes for optimum antenna performance. Shapes included dog bone, bowtie, "H", "U", "L" and hour glass. On comparison, the hour glass shape was found to have highest resonant impedance and the largest loop size i.e. the maximum coupling

In 1997, S. Maci and G. Bifji Gentili [28] discussed an overview about the dual-frequency techniques for patch antennas, Orthogonal-mode dual-frequency patch antennas, Multi-patch dual-frequency antennas, reactively loaded patch antennas, geometries for single and dual linear polarization, slotted rectangular patch antenna, slotted cross-patch antenna, Cross-sub-array dual-frequency patch antenna.

In year 1998 S.D Targonski and D. M. Pozar [29] discussed that for many wireless applications, bandwidths of 10-15% are required and can be easily achieved by using large aperture with fairly thick antenna substrate. By using stacked antenna bandwidth in excess of 50% has been realized.

In year 1999 Tayeb A Denidni & Martin Hotton [30] carried out the enhancement of bandwidth by introducing a foam layer between the two substrates of an aperture coupled patch antenna. The thicker foam provides wider bandwidth, but less coupling for a given aperture size. By adjusting the other parameters of this design, a broadband microstrip patch

antenna was developed at 1.92GHz with 10% bandwidth to cover the PCS band(1.85GHz to 1.99GHz).

In 2002, H.S. Shin and N. Kim [31] proposed a coupled antenna with an H-shaped aperture. The presented antenna has a wide bandwidth, high gain, and low cross-polarization levels with only one-patch. The measured bandwidth of this antenna is 56.2%. The maximum gain at 2.05 GHz is 10.4 dBi and the 3 dB gain bandwidth with a center frequency at 2.17 GHz is 24%. Thus bandwidth can be enhanced by using H-shaped.

In year 2002 R.C Hall and J.R. Sanford [32] made use of asymmetric stripline to increase the coupling. Bandwidth was increased by the use of a wide bandwidth aperture such as bowtie, by the integration of a matching network in the stripline circuit and by the use of specially tuned slotted patch.

In year 2002 Shi-Chang Gao, Le-Wei Li, Mook-Seng Leong and Tat-Soon Yeo [33] proposed that to achieve a wide bandwidth, stacked patches with an air layer between two layers substrates are used. The position of patches is such that the upper patch is beneath the upper substrate and the lower patch is above the lower substrate. Lower patch is excited by a H shaped aperture. When the offset position of aperture is varied in two orthogonal directions, the upper and lower resonance also varies accordingly which is a key characteristic while tuning the wide band antennas. By making the too large distance between the two patches, double resonance disappears.

In year 2003 S. Gao, L. W. Li, M. S. Leong, and T. S. Yeo [34] applied the corner feeding of a square patch to realize dual orthogonal polarizations along the diagonals in order to enhance bandwidth. The antenna uses H shaped aperture in order to reduce the backward radiation levels.

In 2004, Qinjiang Rao and Ronald H. Johnston [35] proposed a structure in which the radiating patch and the microstrip feed line are both fabricated on the top of a substrate, a coupling slot is etched on the bottom of the substrate, and a back-cavity is employed to block back radiation from the slot. The proposed antenna structures have potential for the implementation of lower profile and compact antenna size. Simulations and measurements

show that the proposed antennas can operate at multiple frequencies with very good ratio of front back radiation and very low cross polarization radiation.

In year 2005 Rashid. A Saeed, S.Khatun, Borhauddin, M.A. Khazani, Raina A Mokhtar[36] proposed that for maximum coupling, the patch should be centred over the slot, moving the patch relative to the slot in H-plane direction has low effect, while moving it in the direction of E-plane decreases the coupling level, so for maximum coupling, the feed line should be at right angle to centre of the slot.

In year 2005 Qinjiang Rao & Ronald H. Johnston [37] has proposed the idea of reducing the strongly coupled surface wave modes by moving the feed line of a conventional aperture coupled microstrip patch antenna to the top surface and adding a reflecting plate at the bottom, forming a cavity backed antenna. The size and position of the microstrip feed line and the coupling slot affect the impedance matching and the operating frequency of the improved low profile aperture coupled antenna.

In year 2005 John Huang [38] analyzed the new feed designs one with a two layer and the other with a single layer thin membrane. The single layer consists of only a microstrip line, the thin membrane and the slot in the ground plane omitting the patch radiator. The E and H plane patterns show that the slot radiates equally on both sides of the ground plane. This structure acts as a paper thin antenna and provided bandwidth up to 12%.

In the year 2006, Qinjiang Rao, Tayeb A. Denidni and Ronald H. Johnston [39] proposed a new design using a dielectric reflector to block the back radiation using aperture-coupled structures. Compared to the current backed techniques using a metal plate or a cavity, the proposed design using a thin dielectric substrate as a reflector. The proposed structure can offer a high radiation efficiency, a high front to back radiation ratio, and a high co-cross polarization ratio. With these features, the proposed design is significant in the electromagnetic interference and electromagnetic compatibility (EMI/EMC) designs for reduced undesirable radiation.

In year 2009 M.S.R. Mohd Shah, M.K.Suaidi, M.Z.A.Abdul Aziz, M.F.Abd Kadir, M.K.A. Rahim [40] Due to the current trend, one way of improving and making maximum use of

wireless communication is by using array antennas. As the number of arrays in the antenna increases, there is an increase in gain, return loss, bandwidth.

In year 2010 Christopher J. Meagher and Satish Kumar Sharma [41] in 2010 made use of a dielectric cover, spaced some distance from an aperture-coupled microstrip patch antenna that yielded a high gain antenna with matching and half-power gain bandwidths. The cover is spaced off of the patch antenna by air and is found to significantly increase antenna broadside directivity in some configurations.

In the year 2011, Nan-Chang and Jyun-Ming Lin [42] made use of the long microstrip line that effectively couples the energy first from the aperture cut from the ground plane and then to the patch. Also larger the ground plane, lesser will be the back radiation. As the ground plane size at low frequency is relatively smaller in terms of wavelength than at higher frequency, larger back radiations are expected at low frequency band.

2.2 RESEARCH GAPS

- As the variations in antenna thickness yield improved results in terms of return loss, the dielectric substrates with different permittivity can be used. Since the upper substrate in aperture coupled antenna prefers low permittivity and lower substrate prefers high permittivity for appropriate functionality, the asymmetric variations in dielectric constant of the whole antenna body need to be worked up on to bring out more distinctive and improved results.
- Different shaped slots on ground can help in achieving multiband applications. As different parameters of the slots are varied to get single, dual and quad band antennas.
- Higher dielectric constant substrate materials can be used to improve the front radiation in an antenna and to improve the front to back radiation ratio.
- To improve the radiation in the slot antenna it can be backed by patches for improving the front radiation.
- The use of parasitic elements, stacked patches, using thick substrates of low permittivity etc have proved to improve the bandwidth of the antenna. However, the broad banding design in microstrip antenna results in high volume in spite of its efficient results. The work regarding the reduction of the profile can be done.

- Two different slot configurations proposed are transverse slot and longitudinal slot. Although the first configuration is simpler and does not need impedance matching as compared to the second one, the longitudinal slot antenna provides wider bandwidth. The defected ground structures can be used in the longitudinal slot configurations to improve the bandwidth and increase the gain.

PROBLEM DEFINITION

- The aperture coupled feeding technique is modified for compact structure along with the study of different dielectric materials for back radiation suppression. The modification incorporates the use of single substrate in the design.
- Further, slot antenna is designed for C Band where the back radiation is suppressed by employing patches under the substrate. These patches are placed at the $\lambda/2$ distance from the centre of the slot so as to create the voltage null at the negative peak of the voltage.
- Another study considers the improved front to back radiation ratio of 25 dB along with improved gain of 8.9 dB for WLAN application.
- Further, an antenna is fabricated for WLAN application and tested using VNA for validation of results.

CHAPTER 3

BACK RADIATION SUPPRESSION USING DIELECTRIC REFLECTOR

A new design using a dielectric reflector to reduce the back radiation of aperture coupled antennas is proposed and developed in this chapter. To validate the proposed design, a concise theory analysis is first conducted and then the proposed design is analyzed in a modified aperture coupled microstrip antenna. The measured radiation patterns show that the proposed structure can offer high radiation efficiency, a high front to back radiation ratio, and a high co-cross polarization ratio.

3.1 INTRODUCTION

Compared to the backed techniques like using a metal plate or a cavity [43], the proposed design using a thin dielectric substrate as a reflector offers advantages the production of the parallel modes and high-order resonant modes from a metal reflector or cavity, respectively, can be avoided. Second, there is no inherent conductor loss. Third, it can effectively suppress the excitation of surface waves by using a thin substrate with very high dielectric constant. One may concern about dielectric loss in the high dielectric substrate is that the major energy is reflected into the region A by the first interface AB, and only a very small part is transmitted into region B as shown in Fig. 3.1.

In this design, a radiating patch and a microstrip feed line are both etched on the same side of a top substrate and a coupled slot is etched on the opposite side of this substrate. It includes a dielectric substrate to reduce radiation of slot coupled antenna. The proposed design is mainly based on the following considerations: First, a dielectric reflector can effectively avoid the production of parallel plate modes or high order resonant modes. Second, the structure has no inherent conductor loss of a metal reflector. Third, a dielectric reflector usually uses an electrically thin dielectric substrate with a very high dielectric constant; it can effectively reduce the possibility exciting surface waves. If the dielectric substrate rather than an additional metal plate is used as a reflector to reduce back radiation, the structure of the antenna can be simplified and its volume can also be reduced.

3.2 ANTENNA STRUCTURE AND OPERATION MECHANISM

Fig. 3.1 shows layered substrates used in an aperture-coupled structure, where a slot is cut into interface AB. Region A over the interface AB is assumed to be an antenna substrate. To reduce the back radiation from the slot, a dielectric substrate called region B is placed under the slot. Interface BC is designed as the boundary layer between the backed dielectric substrate B and an air layer C. If the dielectric substrate B can effectively reduce back radiation from the slot, the energy leaking into region C should be very small compared to that in region A. As shown in Fig. 3.1, regions A and B are the top dielectric substrate and the bottom substrate of a slot aperture, respectively. The dielectric constant in region A is ϵ_a whereas it is ϵ_b in region B. Since the thickness of region B is usually very small compared to the operating wavelength, it can be assumed that the propagation direction of the plane wave is normal to the two interfaces when it propagates from region A to region C. With different substrate layers, then part of the energy of the incident wave is reflected back from the interface along the opposition direction of the incidence wave [44]. As shown in Fig. 3.1, the reflected fields in the two different substrate layers are \mathcal{E}_{ra} and \mathcal{E}_{rb} and their propagation constants are k_{ra} and k_{rb} , where

$$k_a = k_{ra} = \omega \sqrt{\mu_0 \epsilon_0 \epsilon_a} \quad (3.1)$$

$$k_b = k_{rb} = \omega \sqrt{\mu_0 \epsilon_0 \epsilon_b} \quad (3.2)$$

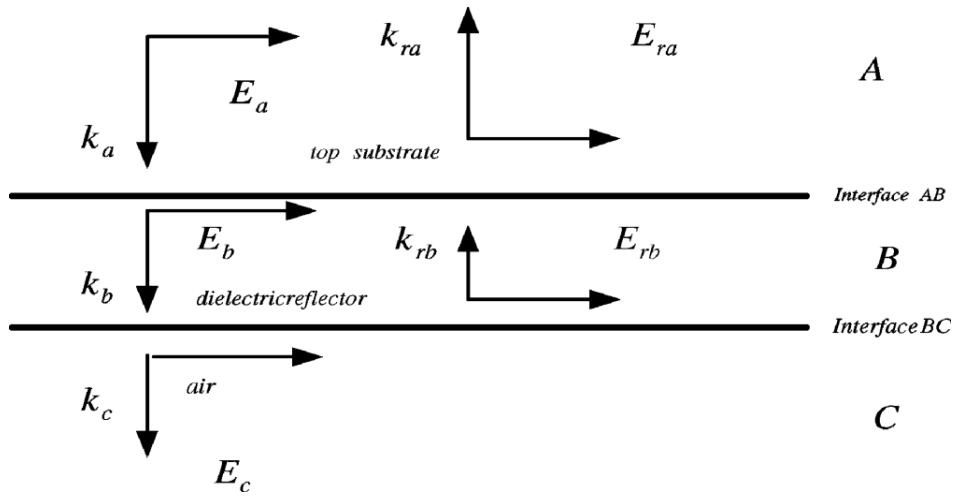


Fig 3.1 Plane waves incident to various interfaces in a backed dielectric layer structure

[45]

The ratio of reflected to the incident wave amplitude is given by:

$$\frac{E_{ra}}{E_a} = \frac{\sqrt{\frac{\epsilon_a}{\epsilon_b}} + 1}{\sqrt{\frac{\epsilon_a}{\epsilon_b}} - 1} \quad (3.3)$$

Similarly,

$$\frac{E_{rb}}{E_b} = \frac{\sqrt{\frac{\epsilon_b}{\epsilon_c}} + 1}{\sqrt{\frac{\epsilon_b}{\epsilon_c}} - 1} \quad (3.4)$$

The first reflection surface or interface AB is considered. It can be observed from equation (3.5) that most of the wave is reflected back into region A and only a small portion of the energy is transmitted into region B when $\epsilon_a \gg \epsilon_b$. When the dielectric constant in region B grows to infinity, the reflection coefficient tends toward -1 . All energy is completely reflected into region A, this case is known as a short-circuit situation. Therefore, the larger the dielectric constant in region B, the more the reflected power into region A. This result indicates that the higher is the dielectric constant, the lesser is the dielectric loss in the dielectric reflector. When a small portion of the energy is transmitted into region B, it propagates toward the second reflection surface or interface BC. With the equation (3.6), if $\epsilon_b \gg \epsilon_c$, most of a small amount of the energy propagating toward the interface BC will be reflected by interface BC, and only a further small part of the power can escape into region C.

The ratio of the transferred to incident wave amplitude can be approximately written as

$$\frac{E_b}{E_a} = \frac{2}{\sqrt{\frac{\epsilon_a}{\epsilon_b}} + 1} \quad (3.5)$$

Similarly, if the transferred energy in region B propagates continuously to region C through interface BC,

$$\frac{E_c}{E_b} = \frac{2}{\sqrt{\frac{\epsilon_b}{\epsilon_c}} + 1} \quad (3.6)$$

When $\epsilon_b \rightarrow \infty$, interface BC acts as “dielectric open.” In this case, all power will completely be reflected and the interface BC acts like a perfect magnetic conductor (PMC). This result indicates that the higher is the dielectric constant, the lesser is the escaped energy into region C. Therefore, the back radiation is reduced. a thin backed dielectric reflector with a high dielectric constant can not only effectively reduce the back radiation but also avoid the production of the dielectric loss in the reflect dielectric substrate. Fig. 3.2 shows the configuration of the proposed antenna.

In this structure, a microstrip feed line has been used on the same side as the radiating element but the coupled slot was still located on the opposite side. This modified antenna uses thinner substrate layers compared to conventional aperture-coupled microstrip antennas; it also allows an easy adjustment for impedance matching through a microstrip feed line. Since a coupled slot radiates bidirectionally, the back radiation from the slot directly feeds the radiating patch while the forward radiation first propagates into region B.

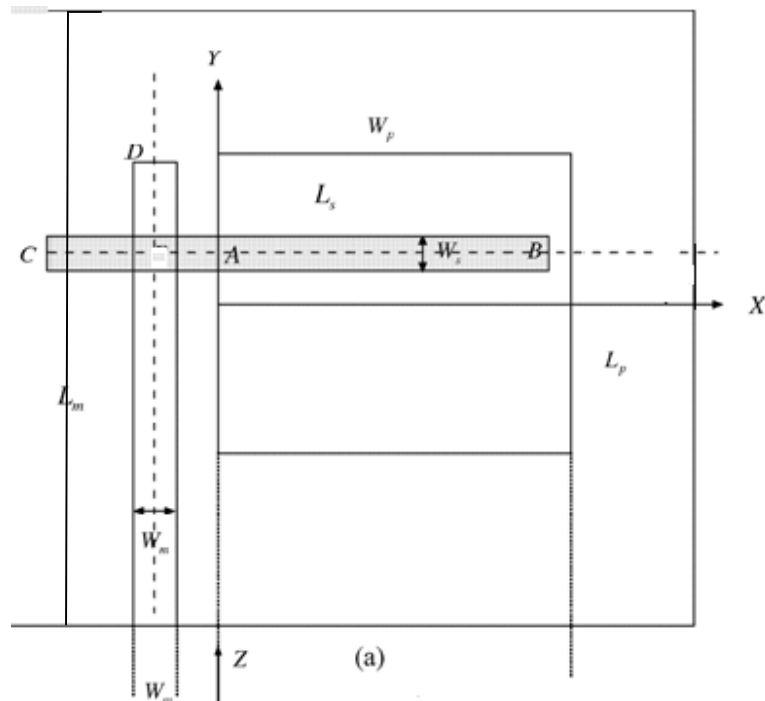


Fig 3.2 Top view of the proposed antenna

If the dielectric constant in region B is the largest among the different dielectric substrates, then the energy propagating into region B should be mostly reflected to region A and feeds the radiating patch over interface AB. Very little energy should propagate into region C. Therefore, the objective to reduce the back-radiation can be achieved by using this technique.

3.3 DESIGN SPECIFICATIONS AND SIMULATION

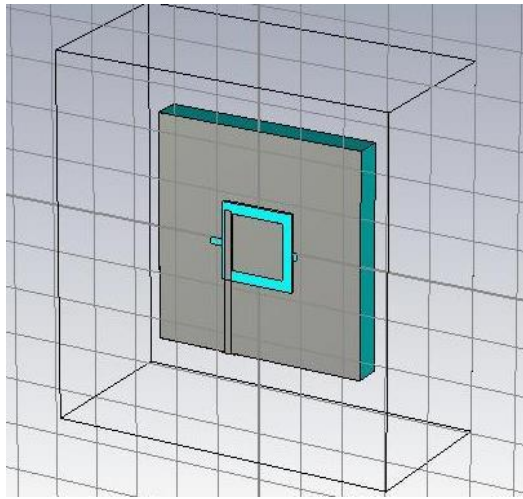
The proposed antenna is aperture fed with a modified technique. The square radiating patch and the microstrip feed line both are fabricated on a same dielectric substrate. A single element of rectangular patch antenna has been designed for 3.6 GHz resonant frequency. To study the effect of dielectric substrate on the antenna performance, especially on back-radiation, the dielectric constant ϵ_r in region B is set as a variable. In this design two cases are considered: one with a high dielectric constant dielectric reflector and the second without any reflector, or the bottom side of the slot is in free space. For the former, the dielectric constant ϵ_r in region B is 10.2 whereas for the latter ϵ_r is 1.06. The main dimensions of design are given in below Table 3.1.

Table 3.1 Design Specifications

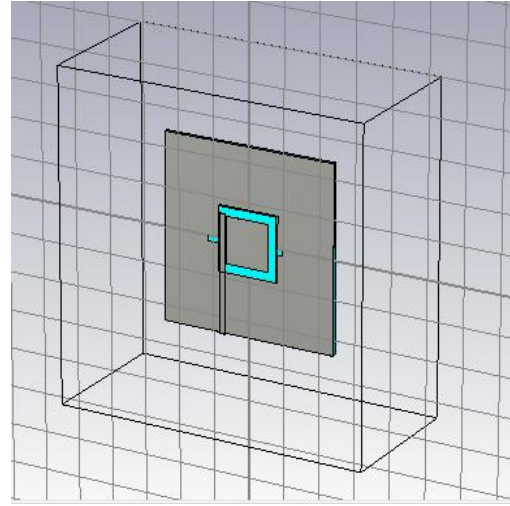
Frequency (f_r)	3.6 GHz
Square Patch dimensions (L_p and W_p)	12mm
Dielectric Constant of patch substrate (ϵ_r)	2.2
Upper Substrate Thickness (h_1)	1.50mm
Lower Substrate Thickness(h_2)	12mm

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 10. It analyzes 3D and multilayer structures of general shapes. It can be used to calculate return loss, VSWR, current distributions, radiation patterns, gain and directivity etc.

Both cases are considered simultaneously here to analyze the difference between their responses. The geometry of two antennas with two different bottom dielectric substrates is as follows:



(a)

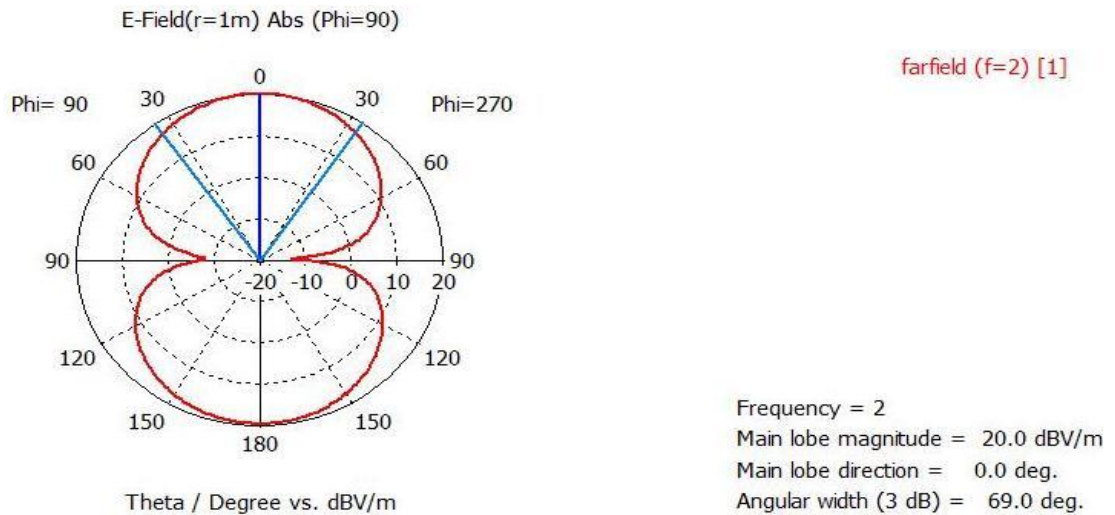


(b)

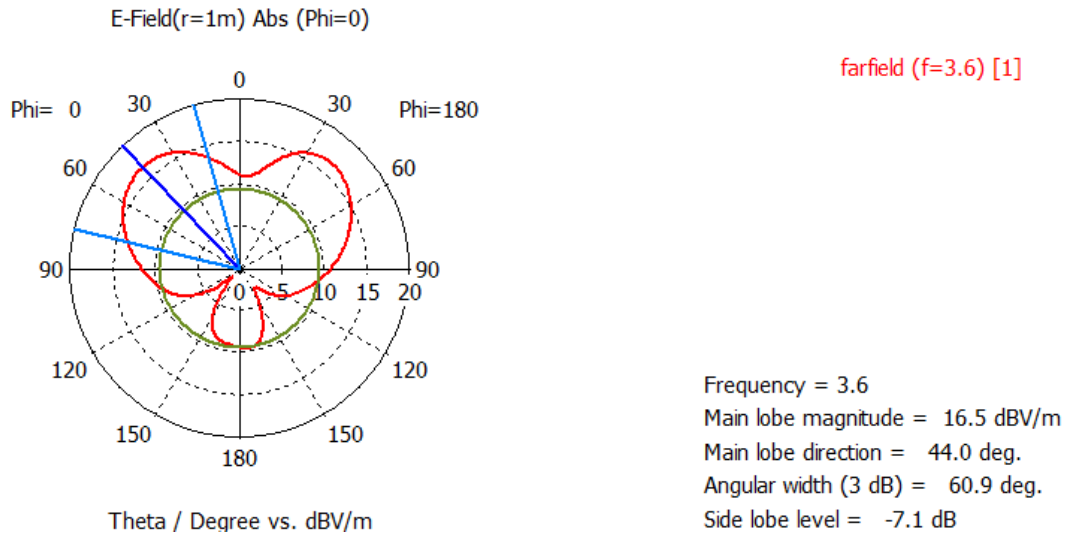
Fig. 3.3 Geometry of antenna (a) without back dielectric resonator (b) with dielectric reflector

3.3.1 Comparison of Radiation Patterns

Figure 3.4 (a) and (b) shows the polar-plot of E field pattern for the discussed antenna with two different dielectric materials on the bottom layer.



(a)



(b)

Fig. 3.4 (a) & (b) E plane radiation pattern (without and with dielectric reflector)

Fig. 3.4 (a) shows the bidirectional E field pattern of the proposed antenna. This is the case of a lower dielectric material used at the bottom substrate. The main lobe magnitude is 20.0dBV/m towards 0 degree with 3 dB angular width of 69.0 degree. Fig 3.4 (b) is the E field pattern of the concerned case, which is the case of using high dielectric material of 10.2 in the bottom substrate. In this case the front radiation is improved with main lobe magnitude of 16.5dBV/m at 44.0 degrees.

Thus, the proposed design using a thin dielectric substrate as a reflector offers advantages: First, the production of the parallel modes and high-order resonant modes from a metal reflector or cavity, respectively, can be avoided. Second, there is no inherent conductor loss. Third, it can effectively suppress the excitation of surface waves by using a thin substrate with very high dielectric constant.

CHAPTER 4

DESIGN AND PARAMETRIC STUDY OF MICROSTRIP SLOT ANTENNA WITH REDUCED BACK RADIATION

This chapter covers a microstrip slot antenna for C Band with compact structure and suppressed back radiation. C band radars are affordable for TV stations. The feeding technique used is aperture coupling with a modification that patches and the feed line are positioned below the substrate and the slot is etched above the substrate. The position of the patches along the slot axis is kept at the negative peak of the standing wave distributions to generate the voltage null on the slot line so as to have a 180° phase shift in the centre of the patch hence achieving better front to back ratio. Also the gain of 6.774dB is achieved in this design. The results are validated by simulation measurements.

4.1 ANTENNA DESIGN AND OPERATION MECHANISM

4.1.1 Antenna structure without patches under the substrate

The Fig. 4.1 (a) (top view) and Fig. 4.1 (b) (bottom view) below shows the view of the cell structure of a simple aperture coupled microstrip slot antenna. The design is a simple slot antenna with $125 \times 130 \text{ mm}^2$ substrate layer with of Rogers RO4232 substrate material with dielectric constant 4.2 and a slot is cut into the ground of this design which rests on the substrate layer. The microstrip feed line is on the opposite side of the slot and its width is set for 50Ω characteristic impedance.

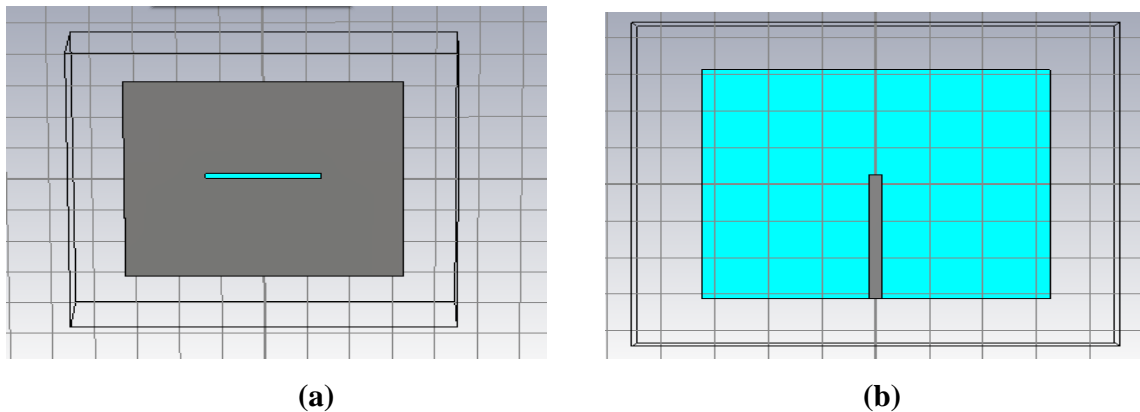


Fig. 4.1 (a) Top view (b) bottom view geometry of the slot antenna

The slot in the above design is incorporated to radiate bidirectionally. The S11 parameter and the E field pattern are shown in Fig. 4.2 and Fig. 4.3 below.

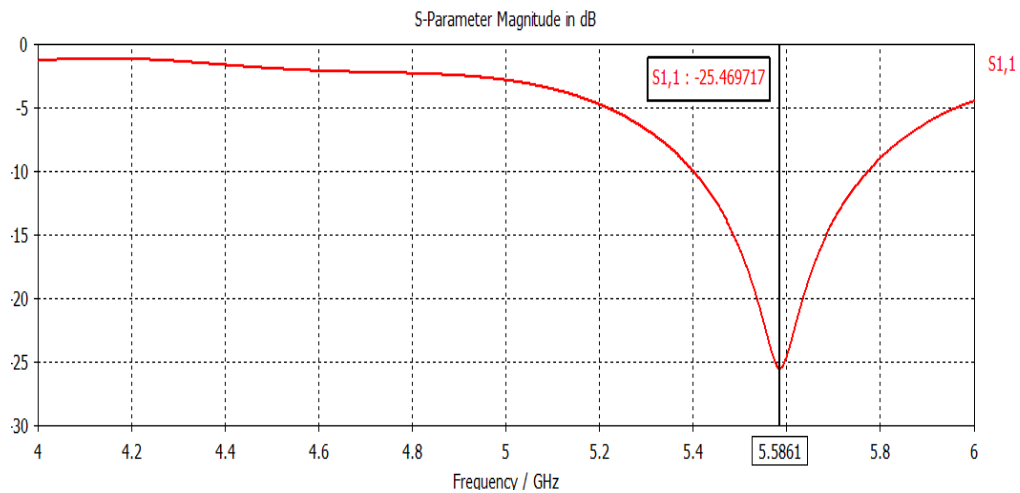


Fig. 4.2 S11 parameter of the slot antenna

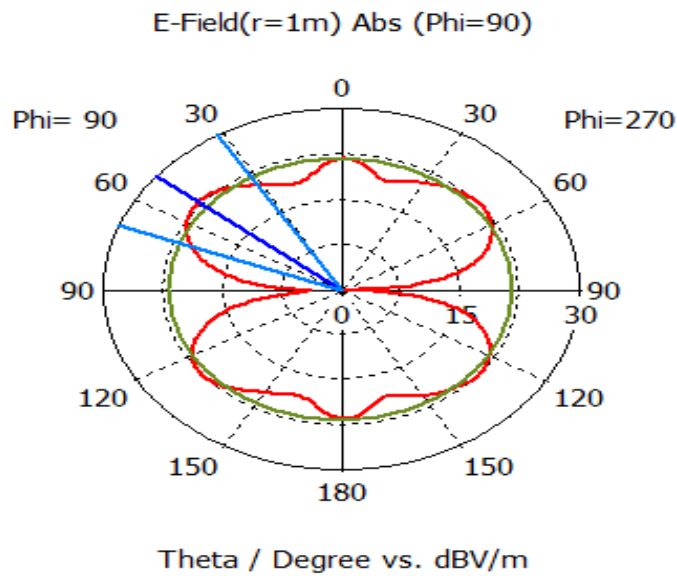


Fig. 4.3 E Field pattern

The S11 parameter is -25.469dB and the antenna resonates at 5.57GHz. The E field pattern shows the bidirectional radiation distribution which is due to the alternating standing wave distribution along the slot axis which reverses over a half wavelength. Since the field is distributed towards both sides, the power density of the antenna hence becomes low.

4.1.2 Antenna with patches under the substrate to reduce back radiation

This is the proposed slot antenna in which there are two slots above the substrate and the patches are under the substrate. The idea of placing patches under the substrate is that the slot electric field perpendicular to the slot length appears to have a standing wave distribution with positive and negative nodes along its axis. The direction of this electric field is reversed after propagating over a half wavelength. Hence, by sliding the patch toward or away from the center of the slot, we can adjust the phase of the patch 180° by coupling it to the negative voltage node or the positive voltage node on the slot line [46]. The proposed antenna is simulated for different displacements of the patch position and their corresponding field patterns are also studied for better front to back ratio. The geometry of the proposed structure is shown in Fig. 4.4.

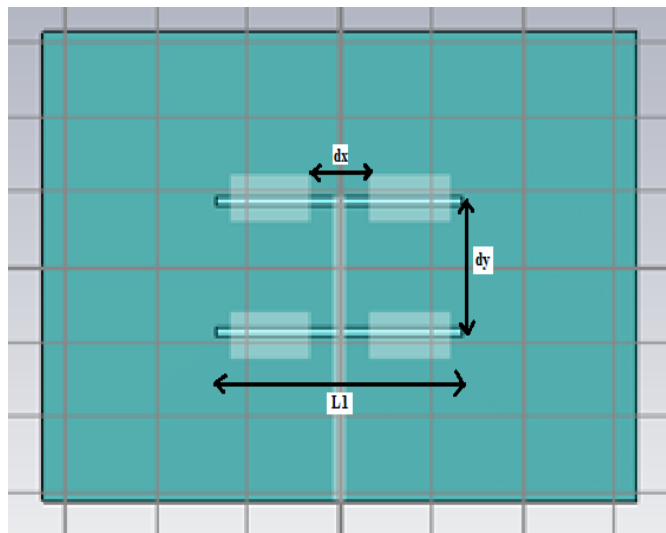


Fig. 4.4 Geometry of the proposed antenna

4.1.3 Design and Simulation Results

The configuration of the antenna top view and bottom view are shown in the Fig. 4.5 and Fig. 4.6 below. In this paper the antenna is expected to operate in 4.0 GHz to 5.0 GHz frequency band. The slots are cut on the ground plane of $125 \times 130 \text{ mm}^2$. The effective dielectric constant of the substrate is calculated by using equation (4.1). After calculating effective dielectric constant, the guided wavelength (λ_g) is calculated by using equation (4.2) and the length and width of slot is given by L_1 and W_1 in the Table. The effective length of the slot is kept 1.5 wavelengths (λ_g) so that the peak voltage will be located at the center of the slot. The

thickness of substrate layer is given by 'h' mm in the Table 4.1. The distance dy is the distance between the centers of two slots. The effective length of the patch is calculated by using equation (4.3). The remaining dimensions of the antenna are calculated and are given in the Table 4.1.

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2} \quad (4.1)$$

$$\lambda_g = \lambda / \sqrt{\epsilon_{\text{reff}}} \quad (4.2)$$

$$L_1 = \frac{c}{2f\sqrt{\epsilon_{\text{reff}}}} \quad (4.3)$$

where $c = 3 \times 10^8$ m/sec

Table 4.1 Dimensions of antenna:

Dimensions	Value
Substrate height (h)	1 mm
Dielectric constant of substrate ϵ_r	3.2
Length of slot (L_1)	54mm
Width of slot (W_1)	2mm
Length of patch (L)	17.5mm
Width of patch (W)	17.5mm

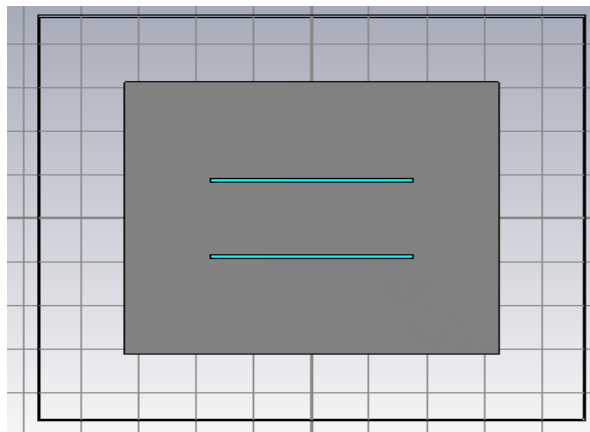


Fig.4.5 Top View of the proposed antenna

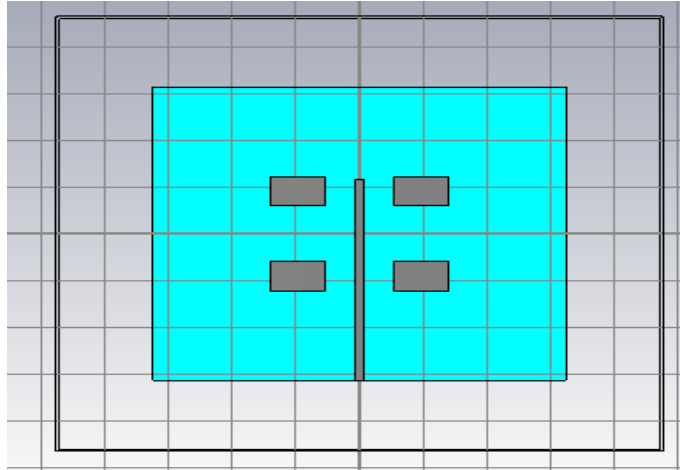


Fig. 4.6 Bottom view of the proposed antenna

According to the operating mechanism described above, the spacing ‘dx’ between the two patches is very significant in affecting the antenna performance. Therefore, the antenna structure is simulated for different values of dx and at those values of dx the return loss, gain, E field pattern and directivity are compared.

4.2 ANALYSIS THEORY

By using full wave spectral-domain approach all components of the electric and equivalence magnetic surface current can be considered using the equivalence principle and integration equation approach. According to the equivalence principle, the coupled slot aperture on the ground plane can be replaced by the equivalent magnetic current. Then the problem can be evaluated separately in the two regions (1 and 2), with appropriate boundary conditions. As shown in Fig. 4.7, there are three sources in region 1; they are the equivalent magnetic current M_1 and the electric surface current J_f and J_p , where the sub-f and sub-p are used for quantities related to the feed line and the patches, respectively.

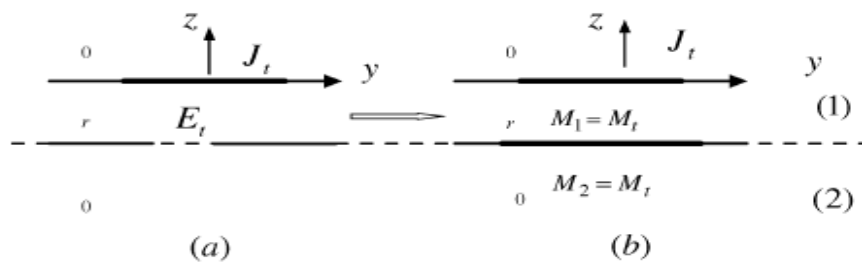


Fig. 4.7 (a) Geometry and (b) Equivalence Principle of the proposed antenna [47]

In region 2, there is only the equivalent magnetic current M_2 [48]. Assuming the field in region 1 is E_1 and that in region 2 is E_2 , these fields satisfy the following boundary conditions.

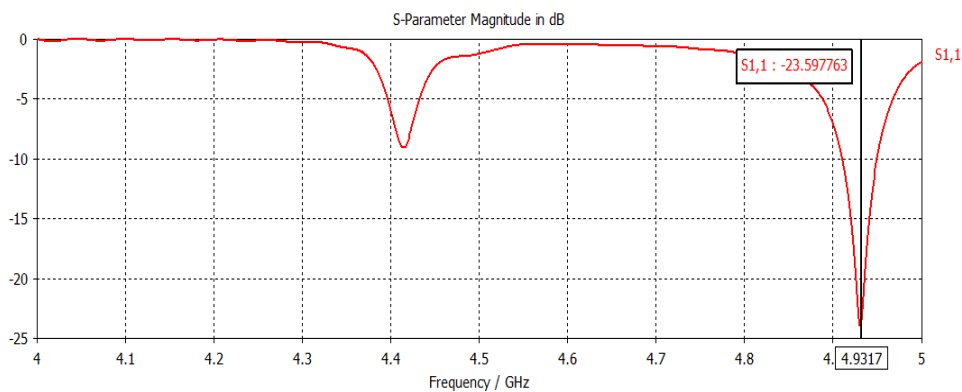
- 1) The tangential electric fields on the feed line and patches should vanish.
- 2) The tangential magnetic electric fields through the aperture are continuous.

For obtaining the directed radiation pattern the dimensions of the slot (L_1 and W_1) are to be kept below one wavelength because the number of lobes increases as the dimensions increase.

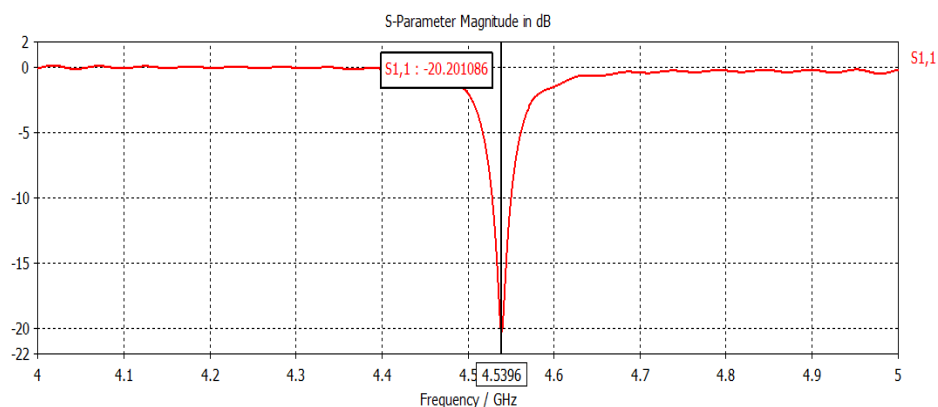
4.3 EFFECT OF SPACING (dx)

Since the effective length of the slot with the partly covered patches will be different from that without patches, the distance of the patches from the center of the slot is chosen to be $1/8$ to $1/2$ wavelengths in the substrate. This range allows the patches to cover the positive or the negative standing wave nodes when they move toward or away from the center of the slot.

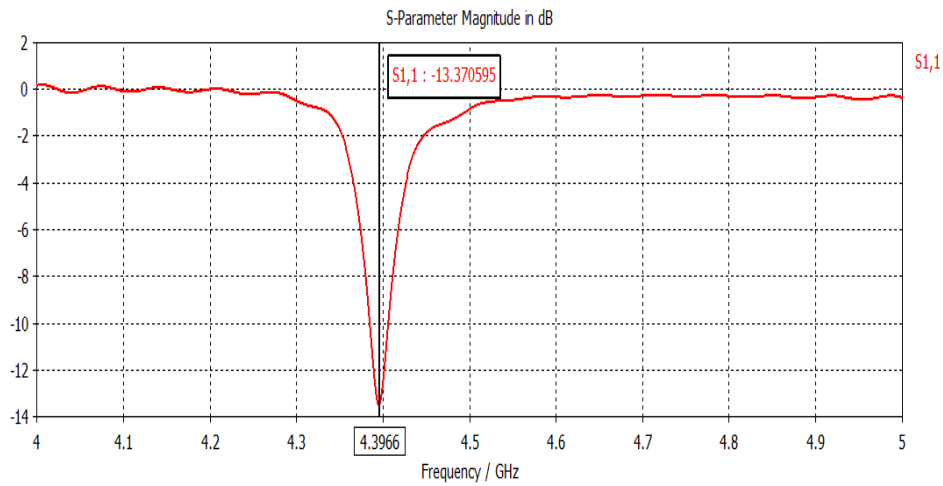
The antenna is simulated for four values of the dx spacings: 9, 13, 17 and 21mm.



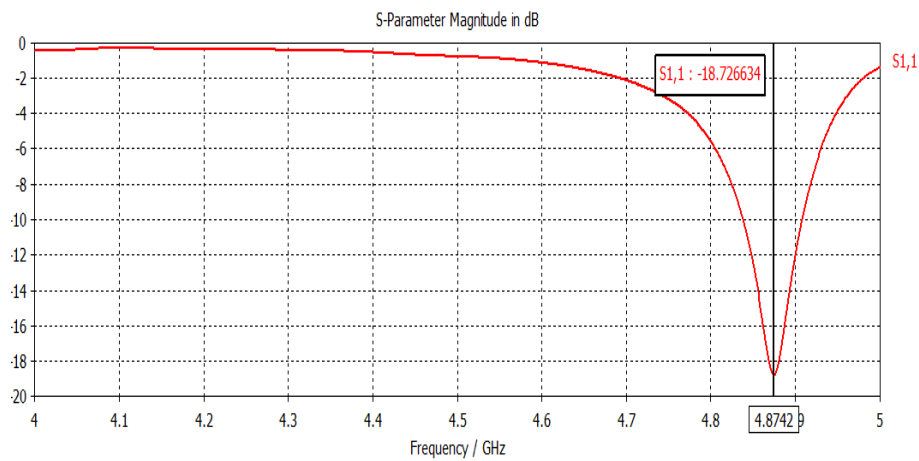
(a)



(b)



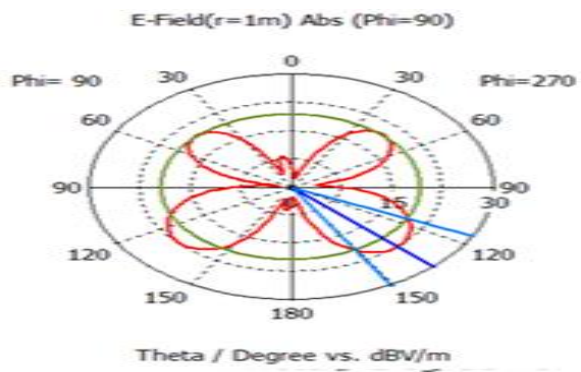
(c)



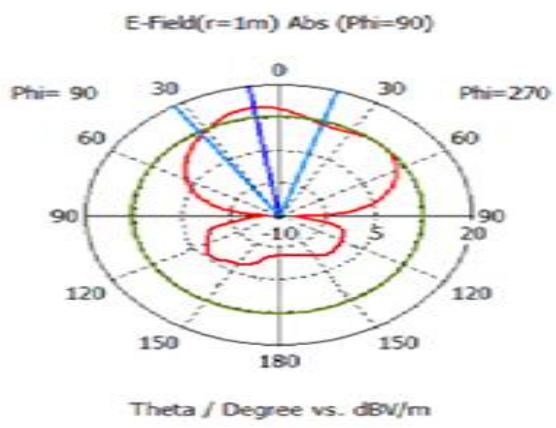
(d)

Fig. 4.8 S11 parameter for dx =9,13,17 and 21mm in (a),(b),(c),(d) respectively

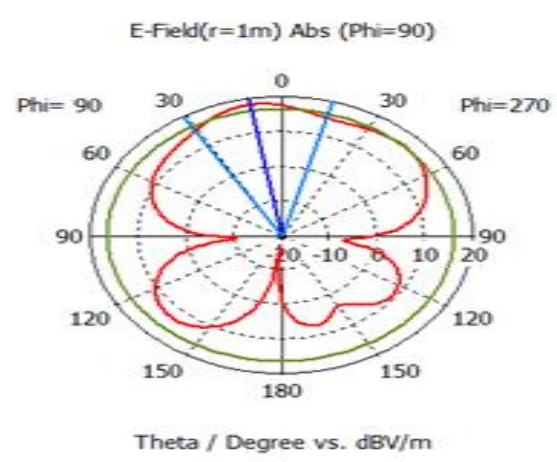
The S11 parameter for the different spacing between the patch has been simulated. The resonant frequency for dx =9mm is 4.93GHz, for dx = 13mm is 4.53GHz , for dx = 17mm is 4.39GHz and for dx = 21mm is 4.87GHz The resonant frequency is shifted to the left as the distance between the patches increases except for dx=19mm where the frequency starts shifting to the right. Thus, the resonant frequency decreases with increase in the distance between the patches up to a particular displacement of the patch. Beyond that displacement, it again increases. The E field patterns for different patch spacing are shown in Fig. 4.9.



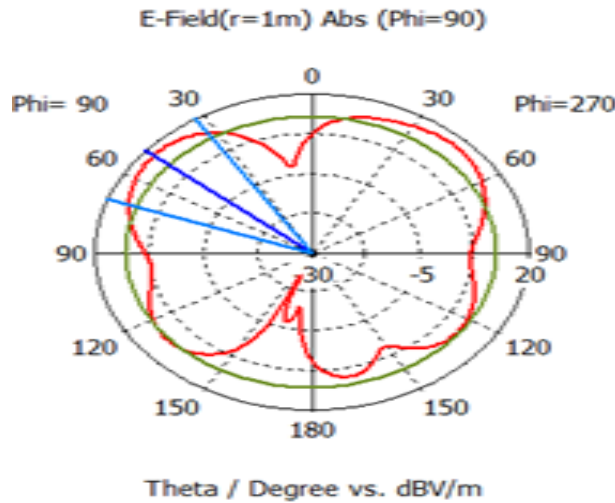
(a)



(b)



(c)



(d)

Fig. 4.9 E field pattern for $dx = 9,13,17$ and 21mm in (a),(b),(c),(d) respectively

The electric field pattern for the different displacements of the patch shows a better front radiation at $dx = 13\text{mm}$ as shown in (b) in Fig. 4.9. The front-back radiation ratio achieved is better than 20dB. The distortions of the measured radiation patterns are due to finite ground plane. The back radiation is suppressed due to the reason that the effective length of the patch is about half wavelength, it causes voltage null movement in the slot as it moves along the axis of the slot as compared to (a), (c) and (d) in Fig. 4.10 where there are significant side lobes and the back lobe.

4.4 CURRENT DISTRIBUTION AT RESONANT FREQUENCY OF 4.53 GHZ

For different displacements of the patch along the slot axis, the current distribution is analyzed and according to the maximum current distribution the patches are positioned. The Fig. 4.10 shows the current distribution at frequency 4.53 GHz and the patches are positioned at 13mm apart. The surface current of 83.4 A/m flows along the patch edges as well as surrounding the slot shown by red arrows in Figure below. Since, this is the position for the better front radiation as well; hence it is chosen to be the appropriate displacement of the patch along the slot axis.

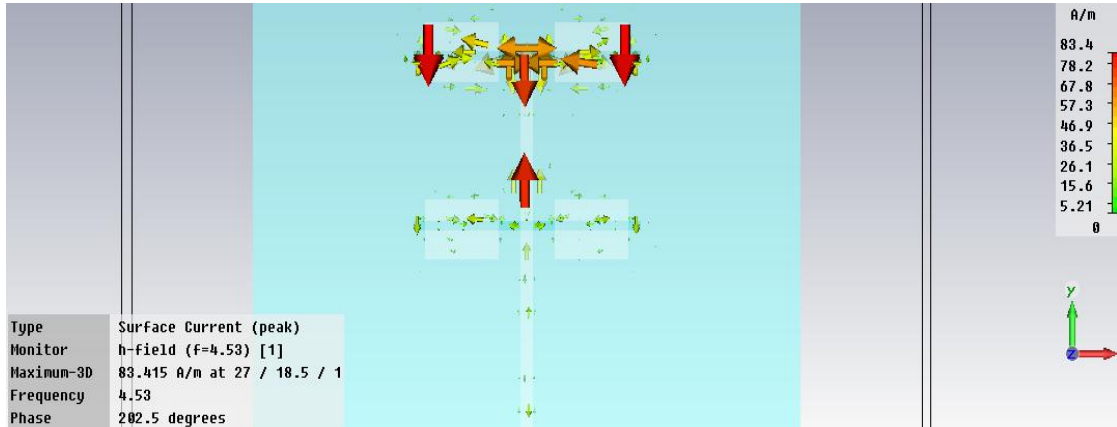


Fig. 4.10 Current distribution at frequency 4.53 GHz

4.5 COMPARISON OF VARIOUS SIMULATED RESULTS

The gain is 6.774 dB and the directivity is 6.255 dBi for $dx = 13\text{mm}$ whereas it is less for the other three cases. Also, the coupling is also better at $dx = 13\text{mm}$ as compared to $dx = 17$ and 21mm . Thus, $dx = 13\text{mm}$ is the point of voltage null in the slot where the back lobe suppresses to a significant point, hence giving good simulation results.

Table 4.2 Comparison of result parameters at different patch displacements

dx →	9mm	13mm	17mm	21mm
Return Loss	-23.59 dB	-20.20 dB	-13.37 dB	-18.72 dB
Gain	5.693dB	6.774dB	6.107dB	6.526dB
Directivity	5.816dBi	6.255dBi	5.568dBi	5.896dBi

It has been found that if the distance of the patches from the center of the slot is chosen to be $1/8$ to $1/2$ wavelengths in the substrate. This range allows the patches to cover the positive or the negative standing wave nodes when they move toward or away from the center of the slot. These results indicate that the coupling between the slot and the patches is significantly varied as the patches move along the slot. It can be found that the patches cover the standing wave nodes when they move within the range studied.

CHAPTER 5

IMPROVED FRONT RADIATION AND GAIN ENHANCEMENT USING PATCH ARRAYS

In chapter 4 the design is presented with suppressed back radiation by using patches underneath the slot of the antenna. In this chapter we introduce a patch array along the long slot to reduce back radiation with an increased bandwidth, return loss and gain. The antenna is designed to resonate at 3.6 GHz.

5.1 MICROSTRIP ANTENNA ARRAYS

Single microstrip patch antenna may not be suitable for application, which needs high gain, beam scanning or enhance bandwidth. In order to enhance gain and to achieve beam steering capability the arrays formation of microstrip patch antenna is used. Antenna arrays may be linear, planar or conformal. In applications related to radar and communication systems narrow beam is desired and hence planar array configuration may be used for such a requirement [49].

5.1.1 Microstrip Planar Arrays

Considering that edge effects are subjected to all the elements, the design of finite arrays necessitates grouping of the patches in a symmetrical pattern so that radiation in the desired direction is obtained. This can be achieved only when fields due to individual patches get combined in phase in the desired direction and cancel each other in all other directions. In other words each patch output is combined to obtain the fields radiated by the array. It is important to note that radiation pattern of individual patch in the array is the same when it is in stand-alone mode. Hence the original pattern of the individual patch gets multiplied by the array factor that takes into consideration the amplitudes and phases of the feed current [50].

However due to closer proximity between patches in the array there is interaction between the elements. Since each patch element induces currents to the other adjacent patches, it leads to coupling among the radiating patches. Inter element location and spacing between the arrays affects the radiation pattern as well as antenna parameters. The system requirement necessitates that spacing between the patch elements in the array, in terms of wavelength in both H and E planes, be specified in order to obtain the desired radiation pattern.

Simple design steps of planar arrays with the schematic shown in Figure 5.1 are

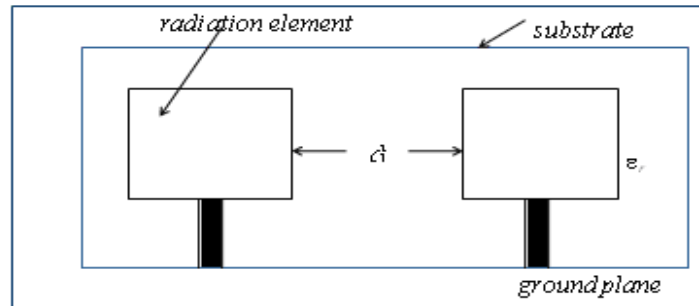


Fig. 5.1 Schematic of Planar Array [51]

1. Proper choice of spacing between patch elements primarily to minimize the grating lobes.
2. Proper selection of substrate material i.e. its thickness, relative permittivity and inter element spacing within the scan volume can eliminate scan blindness.
3. In order to minimize spurious radiation, the feed network should be suitably designed or isolated from the radiating elements [52].

5.2 SLOT ANTENNA USING PATCH ARRAY

Fig. 5.2 shows a cell structure of the proposed design, where the length and the number of slots can be increased along x and y directions, respectively. However, as the slot is made longer, more patches will be needed for each slot. As shown in Fig. 5.2, single slot is etched on a dielectric substrate of thickness h and relative permittivity ϵ_r and they are fed by only one microstrip line that is printed on the other side of the substrate. The slot is coupled to several rectangular parasitic patches, as illustrated. These patches are printed on the same side as the microstrip feed line. The number of patches and the distance between the two patches depend on the length of the slot and the operating frequency. The width of the microstrip feed line is set for 50 characteristic impedance, and the tuning length is chosen to be less than 0.25 for impedance matching. The operation mechanism of the proposed design is based on the following approaches.

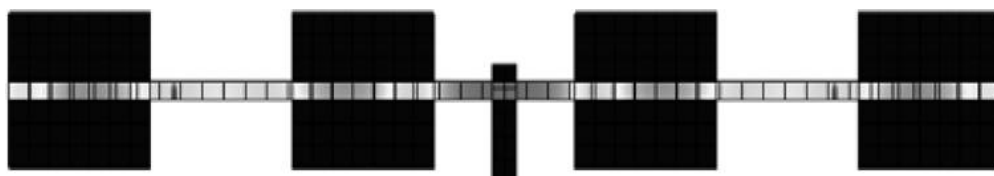


Fig. 5.2 Structure of the patch array antenna [53]

In the present arrangement, the design of chapter four is modified for improving front radiation and gain. This design includes the four patch array arrangement along the slot axis which accounts for better front radiation, gain and return loss as compared to the previous design.

The slot electric field perpendicular to the slot length appears to have a standing wave distribution with positive and negative nodes along its axis. The direction of this electric field is reversed after propagating over a half-wavelength. This appears to give us a mechanism for producing a good front-radiation. More power radiates into the broadside direction; this is due to the fact that the patch array allows a long slot to produce more standing waves along the axis of the slot. In contrast to the H-plane, the beam width in E-plane is broader than in a cell structure. This allows more power to propagate into directions other than the broadside direction.

5.3 DESIGN AND ANALYSIS OF ANTENNA

The figure below shows the Fig. 5.3 (a) (top view) and Fig. 5.3 (b) (bottom view) view of the cell structure of an aperture coupled microstrip slot antenna. The design is a simple slot antenna with 80X50 mm² substrate layer with FR4 lossy dielectric material with dielectric constant 4.4 and a slot with length 78 mm and width 2 mm is cut into the ground of this design which rests on the substrate layer. The microstrip feed line is on the opposite side of the slot and its width is set for 50Ω characteristic impedance. Additionally, the structure consists of an array of patch on the opposite side of the substrate. All the design parameters are calculated using the equations used in chapter four. The design specifications for the proposed antenna are given below:

Table 5.1 Design Specifications of antenna

Dimensions	Value
Substrate height (h)	1.6mm
Dielectric constant of substrate ϵ_r	4.4
Length of slot (L_1)	78mm
Width of slot (W_1)	2mm

Length of patch (L)	12mm
Width of patch (W)	12mm

If the length of a slot line is increased to several wavelengths, more patches can be placed along axis, but the spacing between the patches needs to be adjusted due to different interactions among parameters. As a result, additional similar standing wave distributions will be repeated, and the antenna performance can be further improved. According to the described mechanism, the spacing and

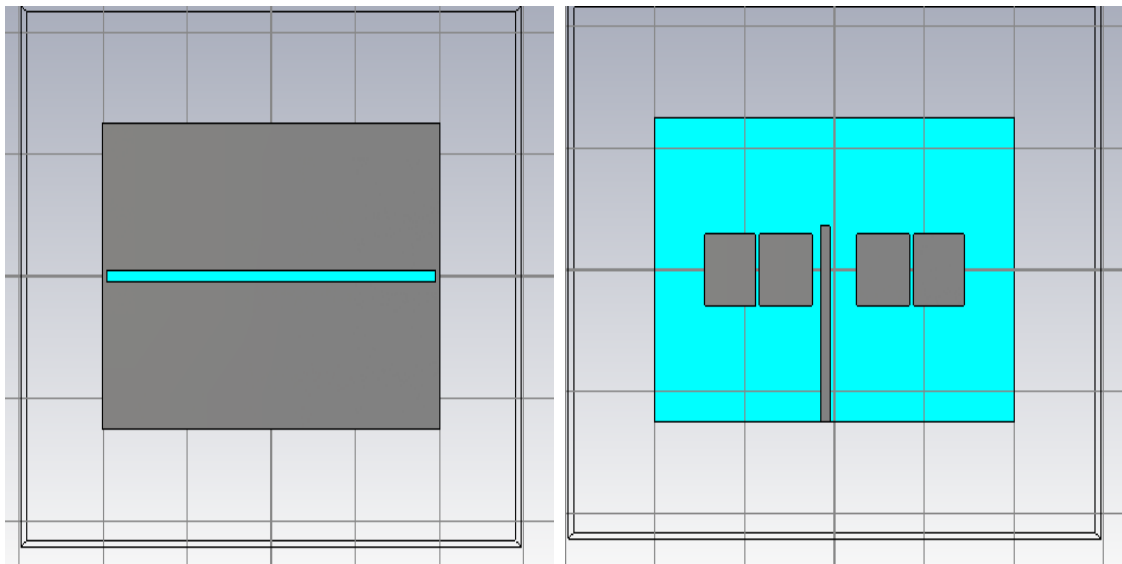


Fig. 5.3 (a) Top view and (b) bottom view of the proposed antenna

thickness are very significant parameters in this design. The effective length of the slot line is approximately 1.5 wavelengths so that the peak voltage will be located at the center of the slot. The width of the slot is kept small relative to the wavelength of operation; therefore, the electric field is primarily in the direction perpendicular to the axis of the slot. The slot can be modeled by a magnetic current.

5.4 SIMULATION SETUP AND RESULT PARAMETERS

The software used to model and simulate the Micro strip patch antenna is CST Micro Wave Studio version 10. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antenna, wire antenna and other

RF/wireless antennas. It can be used to calculate return loss plot, current distributions, radiation patterns, smith chart etc.

5.4.1 Return Loss and Antenna Bandwidth: Figure 5.4 shows the S11 parameters (return loss) for the proposed antenna resonates at 3.6 GHz having value of -29.07dB. The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 62 MHz and resonant frequency is 3.6 GHz. More is the return loss means more of the coupling.

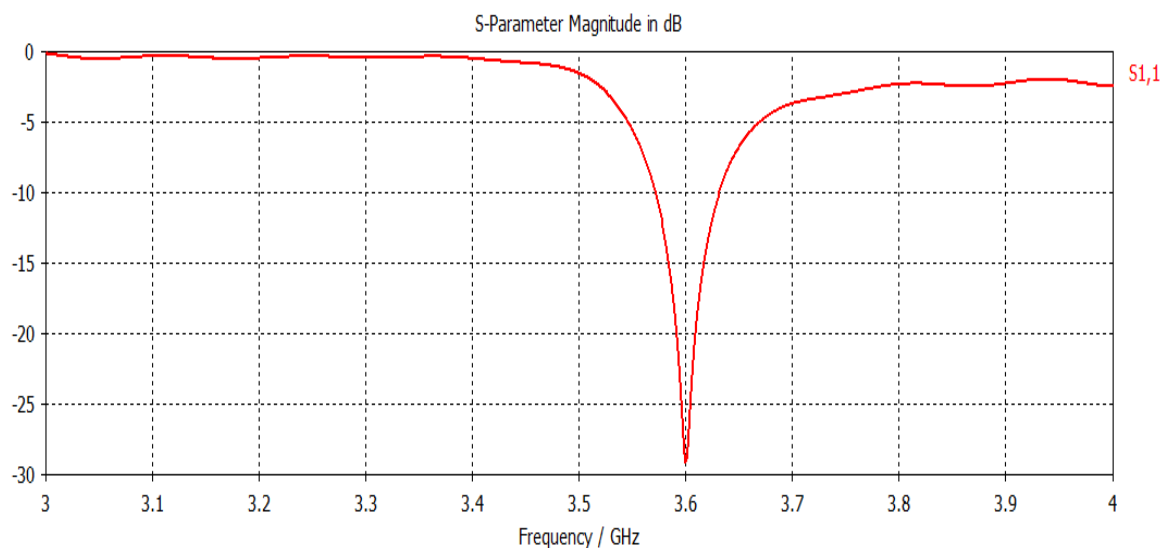


Fig. 5.4 Return loss S11 (in dB) at 3.6GHz

5.4.2 Radiation Pattern

The radiation characteristics of the antenna are measured in the far-zone. Solid lines of Fig. 5.5 show the measured E plane radiation patterns of the antenna at frequency 3.6 GHz respectively. The 3- dB beam width is equal to 126.1° in E-plane.

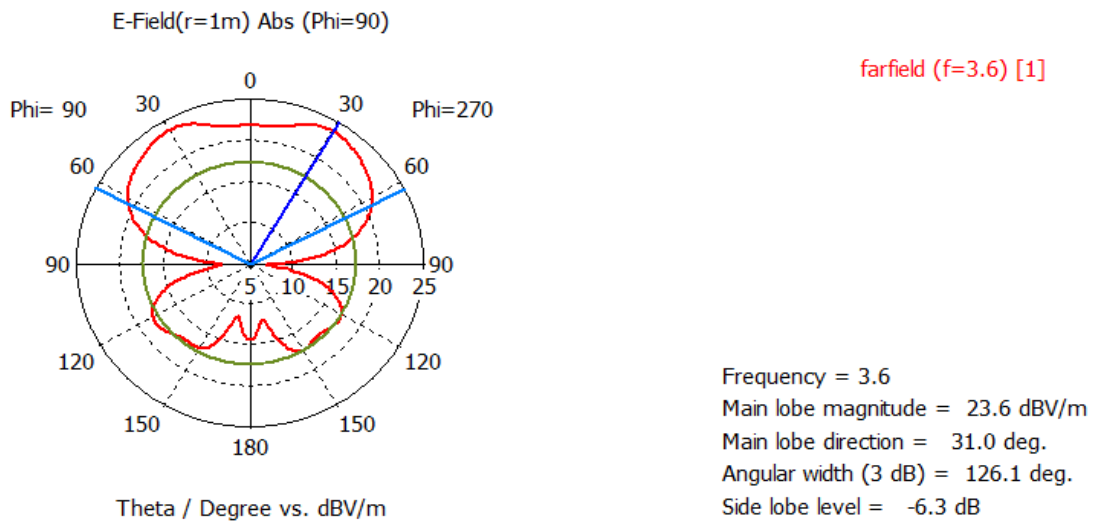


Fig. 5.5 Radiation pattern of a linearly polarized microstrip antenna in E-plane

5.4.3 Gain: The Gain plot (Figure 5.6) gives the gain = 8.9 dB. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications in X-Band providing a better performance. From polar plot view of the gain, it can be seen that at a frequency of 3.6 GHz, gain is 8.9 dB, radiation pattern obtained is directional with main lobe directed at an angle of 31.0 degree, having angular beam width of 126.1 degree. Thus gain is improved by using patch array in the design.

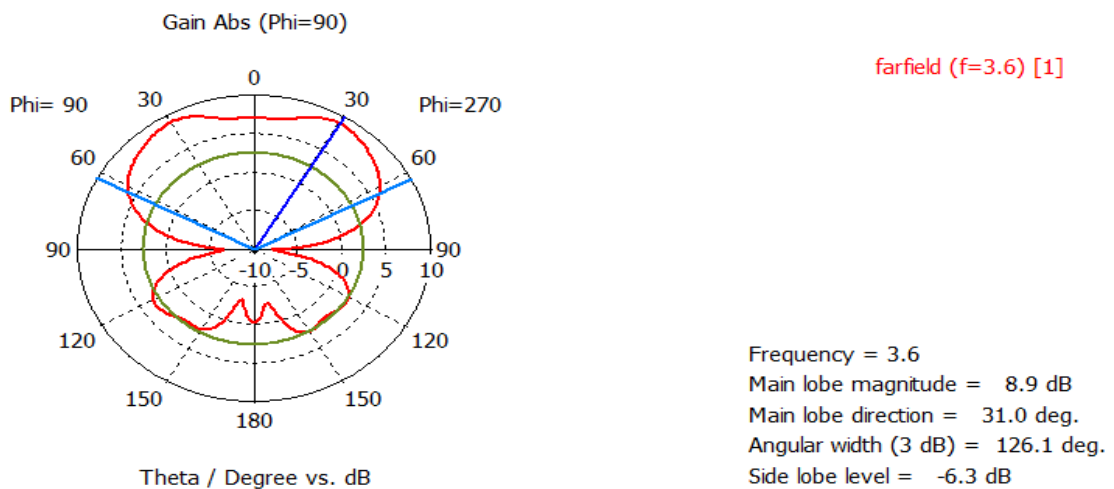


Fig. 5.6 Gain of the designed antenna (polar plot) at 3.6GHz

5.5 CURRENT DISTRIBUTION AT RESONANT FREQUENCY OF 3.6 GHZ

According to the current distribution, the array of patches helps in improving gain and front back radiation ratio. For the patch array along the slot axis, the current distribution is analyzed and according to the maximum current distribution the patches are positioned. The Fig. 5.7 shows the maximum surface current distribution along the slot and the patch edges at frequency 3.6 GHz. The red arrows of 90.9 A/m shows the regions of maximum current flow in the antenna designed.

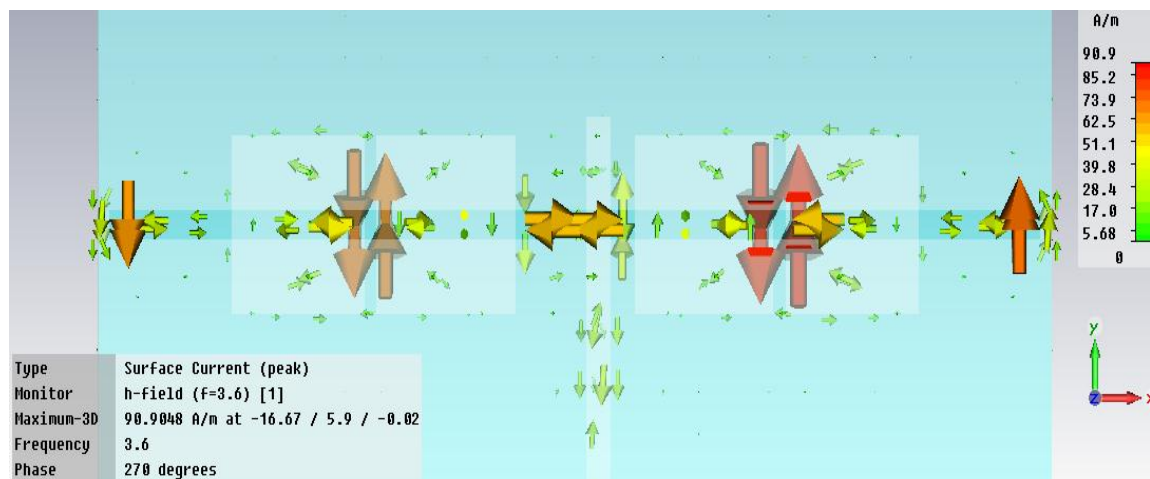
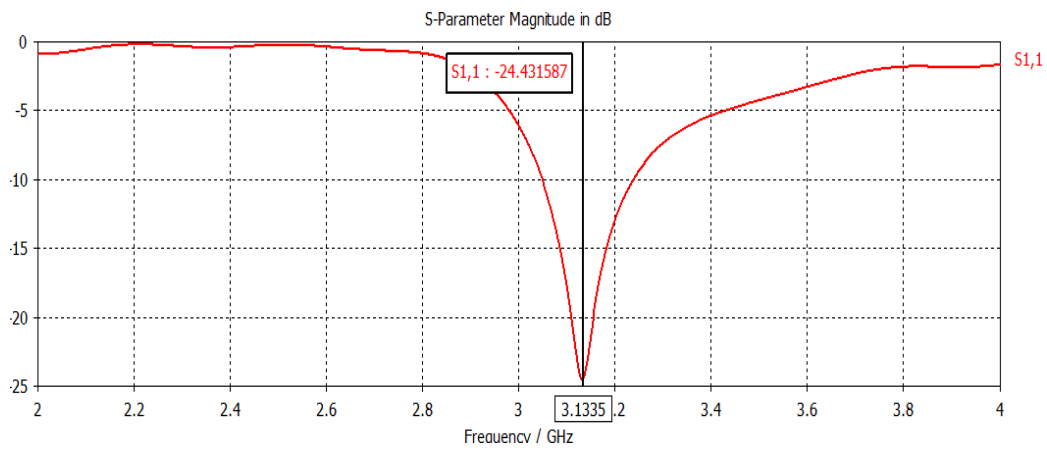


Fig. 5.7 Current Distribution at frequency 3.6 GHz

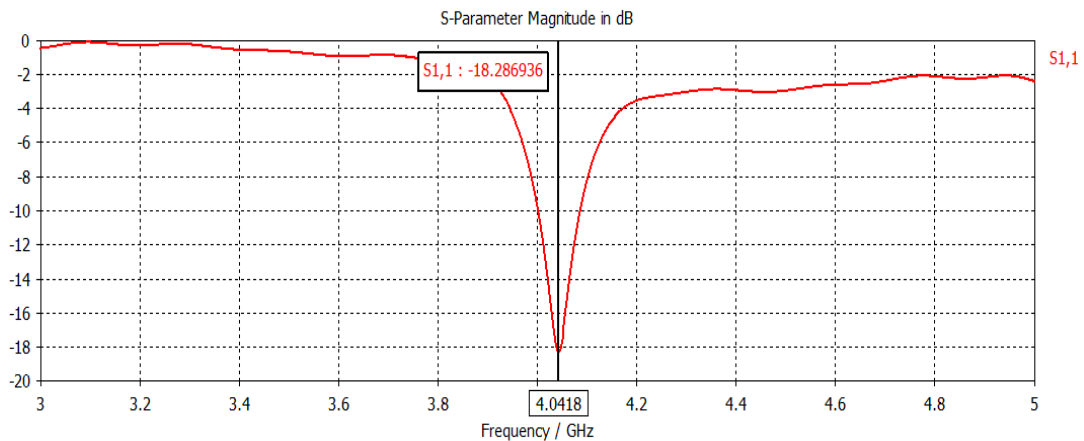
5.6 EFFECT OF DIFFERENT DIELECTRIC MATERIALS ON ANTENNA

Substrate materials play an important role in antenna design, production and finished product performance. A simple method that can be employed to modify the different properties of the antenna is by changing the substrate; as height and dielectric constant of the substrate influence the antenna properties. The substrate in microstrip antenna is primarily required for giving mechanical strength to antenna. The dielectric used is also responsible for degraded electrical properties of antenna as the surface waves produced on the dielectric extract a part of total power available for direct radiation (space waves). As the dielectric constant and thickness are varied in these analysis the feed line width and stub length are modified to maintain a characteristic impedance of 50Ω and a stub length of $\lambda_g/4$. Larger the dielectric constant, smaller is the antenna size and the impedance bandwidth. From the Fig. 5.8, it can be shown that as the dielectric constant of antenna increases, the resonating frequency of the antenna decreases. Dielectric constant with value 4.4, resonating at 3.6 GHz frequency is

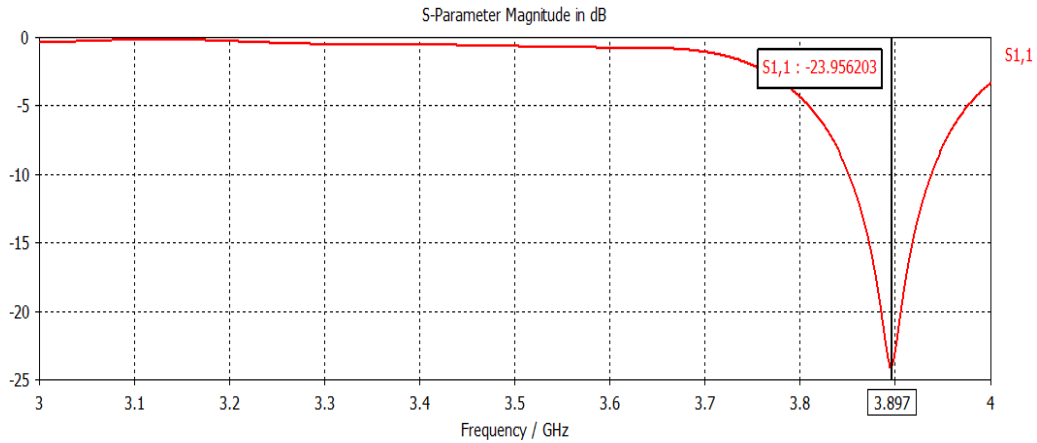
close to the frequency required. Also the return loss observed at this value of dielectric constant is more. So, the antenna having feed and the patch substrate of dielectric constant 4.4 have been chosen. The above design is simulated for different dielectric substrates and the effect is studied through the simulated results. Fig. 5.8 shows the effect on return loss parameter for various dielectric substrates and Fig. 5.9 shows the radiation patterns corresponding to those resonant frequencies.



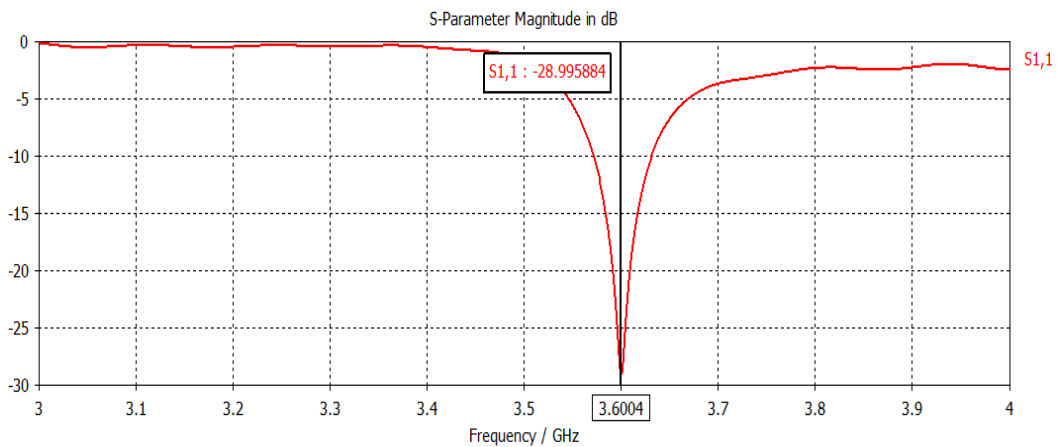
(a)



(b)



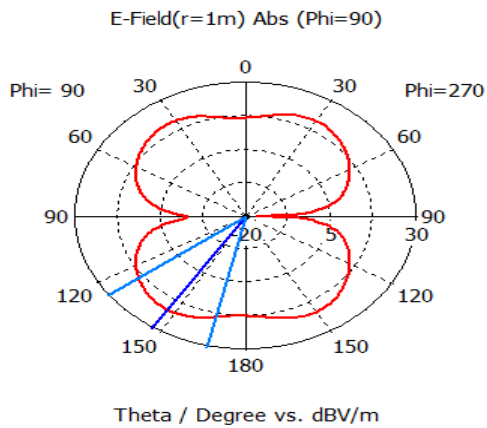
(c)



(d)

Fig. 5.8 S11 parameter for $\epsilon_r = 1.03, 3.2, 3.55$ and 4.4 mm in (a), (b), (c) and (d) respectively

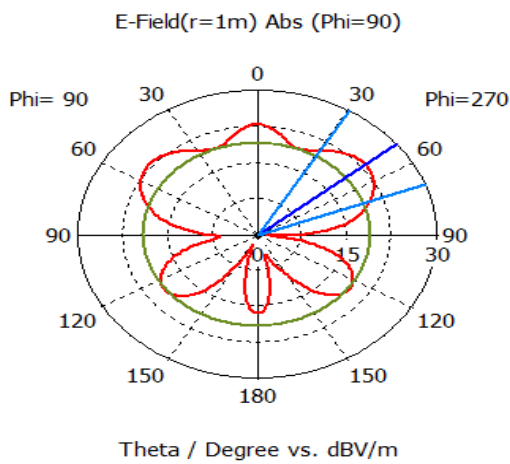
The return loss parameter shifts with the variation in the dielectric substrate. In the above figure, the three different dielectric materials are Air, Rogers RO 4232 and Rogers RO 4003 and FR4 lossy material with dielectric constant 1.03, 3.2, 3.55 and 4.4 respectively. In case (a) the return loss is -24.43 dB and it resonates at 3.127 GHz. In case (b) and (c) the S11 parameter are -18.2967 dB (4.042) and -23.95 dB respectively and the respective resonant frequencies are 4.042 GHz and 3.896 GHz. In case (d), which is our material of interest, the return loss is -28.99 dB and it resonates at 3.6 GHz.



farfield (f=3.127) [1]

Frequency = 3.127
 Main lobe magnitude = 21.6 dBV/m
 Main lobe direction = 147.0 deg.
 Angular width (3 dB) = 40.4 deg.

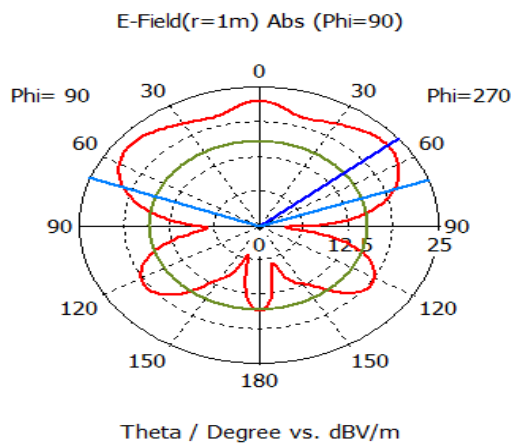
(a)



farfield (f=4.04) [1]

Frequency = 4.04
 Main lobe magnitude = 23.2 dBV/m
 Main lobe direction = 51.0 deg.
 Angular width (3 dB) = 38.7 deg.
 Side lobe level = -4.1 dB

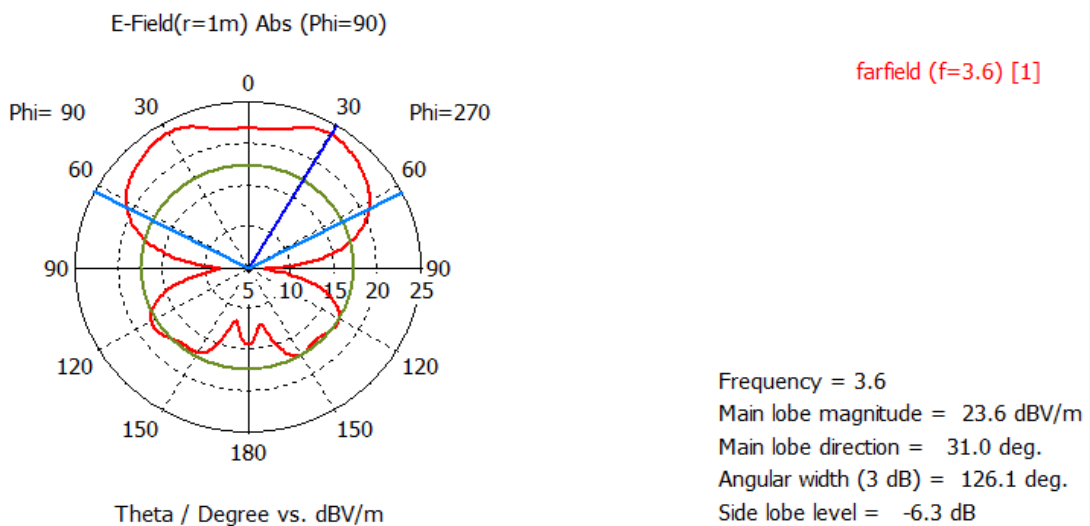
(b)



farfield (f=3.89) [1]

Frequency = 3.89
 Main lobe magnitude = 23.0 dBV/m
 Main lobe direction = 51.0 deg.
 Angular width (3 dB) = 140.4 deg.
 Side lobe level = -7.7 dB

(c)



(d)

Fig. 5.9 Radiation pattern for $\epsilon_r = 1.03, 3.2, 3.55$ and 4.4 mm in (a), (b), (c) and (d) respectively

In Fig. 5.9 the antenna is simulated for four different dielectric constant values and it is found that in (a) with the antenna radiates almost bidirectionally and in (b), (c) the antenna incorporates the significant side lobes and back lobe. In case (d) the front radiation is better as compared to other cases.

5.7 EFFECT OF SLOT LENGTH VARIATION

Coupling level is primarily decided by the slot length. There are two types of slots i.e. resonant and non-resonant type based on the length of the slot. If the slot length is comparable to the half of the wavelength of the antenna, it is called resonant slot. If the smaller length slots are used, it is non-resonant slot. As the slot length is decreased, input resistance also decreases. But there can also be decrease in the coupling between patch and feed line. In this section, when the slot length is increased between 65 mm to 70 mm, there is an increase in the coupling level and decrease in the resonant frequency. Fig. 5.10 shows the simulated result for the slot length variation.

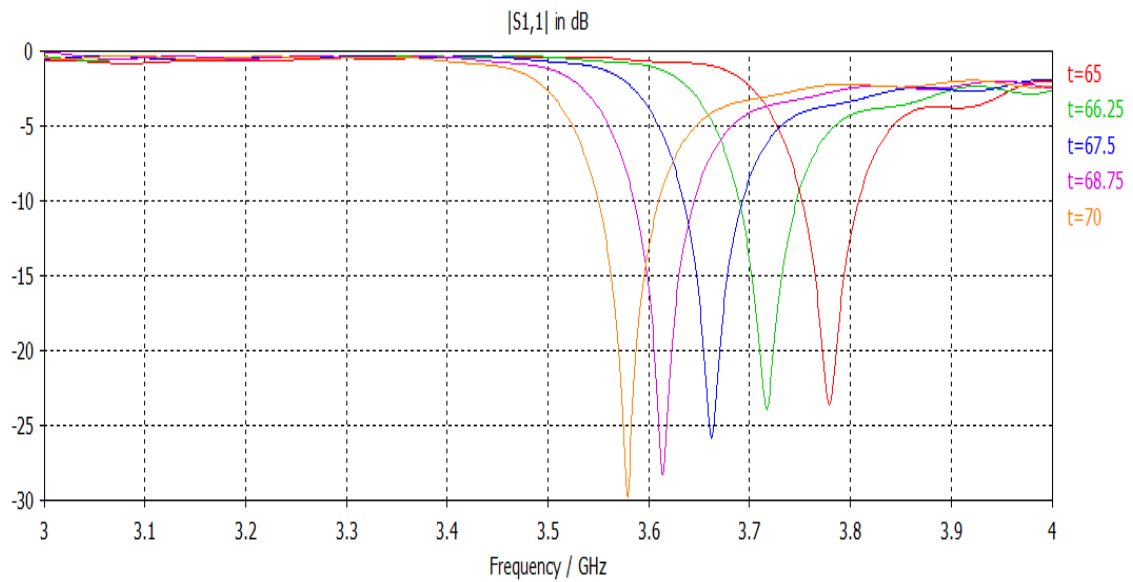


Fig. 5.10 Effect of Slot length variation

Basically, the slot length is kept around 1.5 wavelengths to get the positive peak of the voltage at the centre of the slot.

This chapter concludes that the array of patches in a slot antenna improves the gain from approximately 6 dB to 8.9 dB along with the reduced back radiation.

CHAPTER 6

FABRICATION AND TESTING

This chapter describes the fabrication and testing of the microstrip slot antenna with patch array at the bottom. The fabricated structure is the same as designed and simulated in chapter 5. This design is useful for WLAN application.

6.1 FABRICATED ANTENNA

Fig. 6.1 and Fig. 6.2 shows the top and bottom view of the fabricated design respectively. As per the design proposed in chapter 5, the slot is etched into the ground and it is also the radiating element in the antenna. The array of patches is at the bottom of the substrate layer along the slot axis. This antenna resonates at 3.6 GHz and has improved front to back ratio and gain. The feed line is aperture coupled and it is also beneath the substrate along with patches.

The PEC can be seen on the front view of the antenna in which the slot is etched and also on the bottom view in the form of patches and feed line. The substrate material used is FR4 lossy dielectric with ϵ_r 4.4.



Fig. 6.1 Top view of the fabricated antenna



Fig. 6.2 Bottom view of the fabricated antenna

6.2 SIMULATED RESULTS OF THE SLOT ANTENNA AT 3.6 GHZ

The simulated result of the slot antenna discussed in chapter 5 has been discussed below:

6.2.1 Return Loss: Figure 6.3 shows the S11 parameters (return loss) for the proposed antenna which resonates at 3.6 GHz having value of -28.99dB. The bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 62 MHz and resonant frequency is 3.6 GHz. More is the return loss means more of the coupling. The dimensions of the antenna are given below in the Table 6.1.

Table 6.1 Design specifications of the Antenna

Dimensions	Value
Substrate height (h)	1.6mm
Dielectric constant of substrate ϵ_r	4.4
Length of slot (L_1)	78mm
Width of slot (W_1)	2mm
Length of patch (L)	12mm
Width of patch (W)	12mm

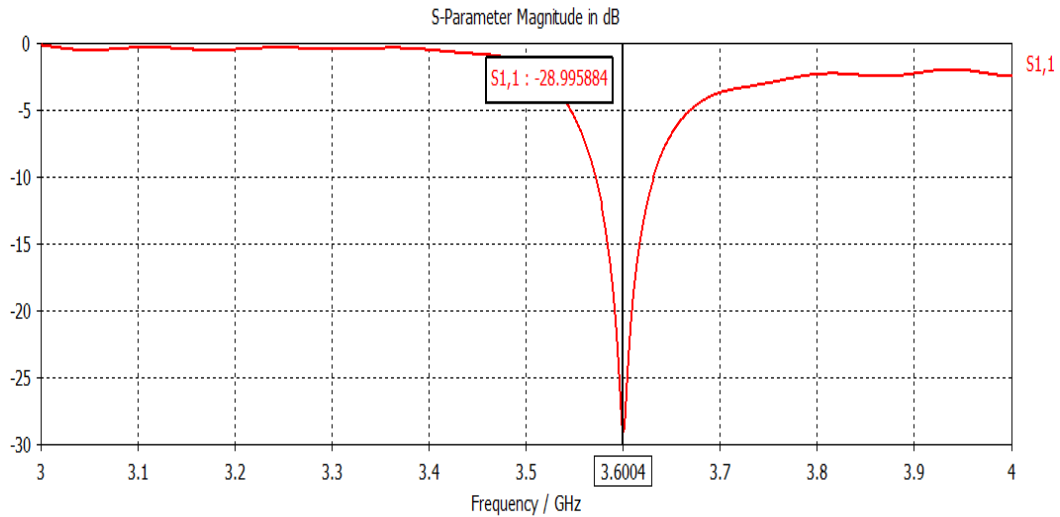


Fig. 6.3 Return loss S11 (in dB) at 3.6GHz

6.3 TESTING OF ANTENNA ON VNA

A vector network analyzer is a test system that enables the RF performance of radio frequency and microwave devices to be characterized in terms of network scattering parameters or S parameters. The information provided by the vector network analyzer is then used to ensure that the RF design of the circuit is optimized to provide the best performance. The fabricated design is now tested using VNA model no: E5071C in the frequency range of 9KHz-8GHz and is shown in Fig.6.4 below.

The test antenna resonates at 3.61GHz frequency with S11 parameter of -19.244 dB as compared to the -28.99 GHz return loss of the CST simulated result Figure 6.10 shows the graph at 3.61GHz.

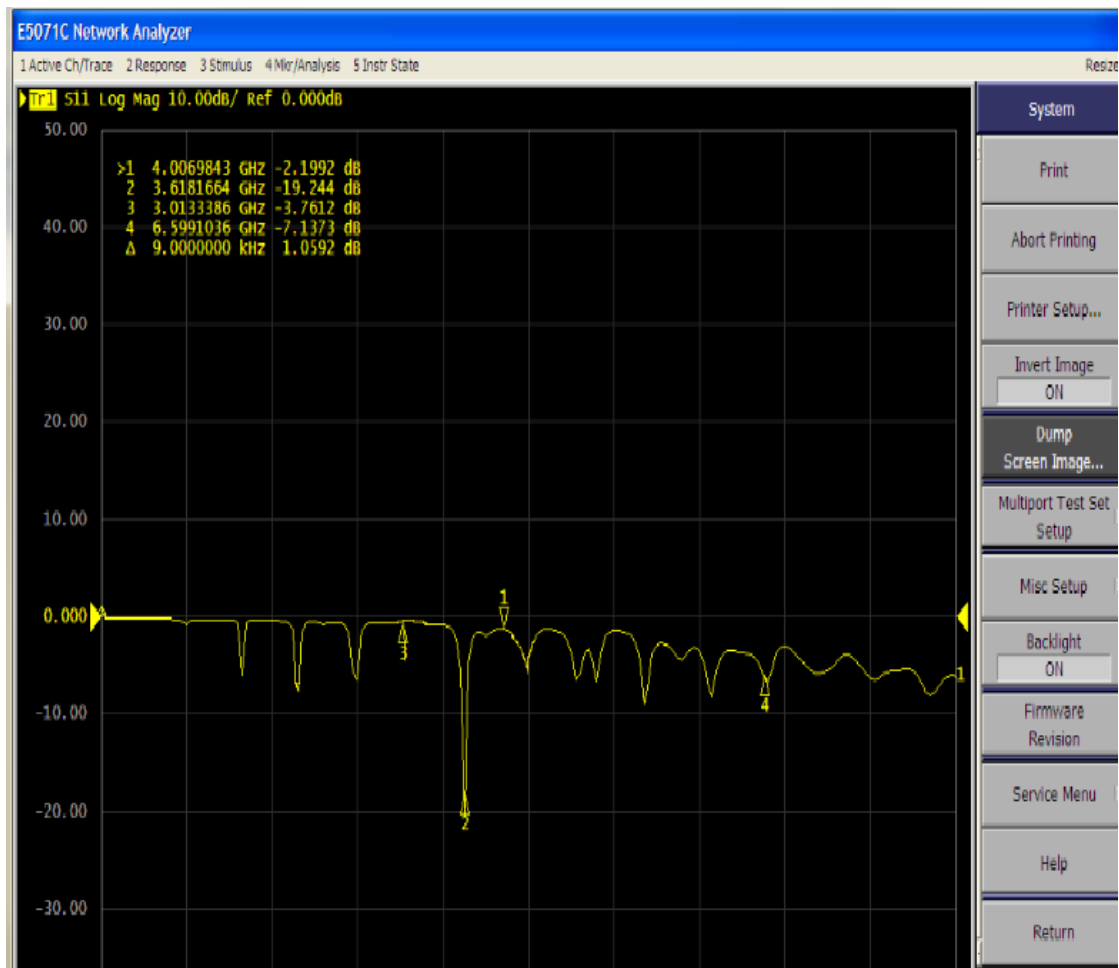


Fig. 6.4 Tested Results on VNA

The return loss graph shows that the resonant frequencies have shifted in the magnitude from the designed frequency. The root cause of the shift could be due to the FR-4 board, which varies from 4.0 to 4.9. In practical world, a material which is varying along a length, width, and height, will affect resonant frequency to shift, during simulation it is assume a constant. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for shifting the resonant frequency. Also for the variation on the return loss, resonant frequency and bandwidth, from the simulation software is a constraint which means that, the conductor is not easy to draw under the substrate. In simulation, the design is ideal and no air gap exists between the patch and the ground plane. Practically, with the use of adhesive to glue the patch to the ground plane, the variation is more visible as the adhesive will affect the effective dielectric constant value and contribute some height to the gap. Other than that, electromagnetic coupling is also one of

the important mechanisms in aperture coupled microstrip antenna. But, in the simulation, the electromagnetic coupling to the environment is not modeled.

6.4 COMPARISON OF FABRICATED AND SIMULATED RESULTS

The comparison between simulated and fabricated results for the single band slot antenna referring to Fig. 6.4 and 6.5 is given below:

Table 6.2 Comparison between Simulated and Fabricated Results

Parameters	Simulated Results	Fabricated Results
Frequency Covered	3.6 GHz	3.61 GHz
Return Loss	-28.99 dB	-19.244 dB
Application Covered	WLAN	WLAN

The fabricated and simulated results are in close proximity with each other. Hence the results are validated.

7.1 CONCLUSION

In this report, the microstrip antenna designs for reduced back radiation have been design, simulated and fabricated.

- Firstly, an antenna using a dielectric reflector to block the back radiation of aperture-coupled structures has been designed. This design uses a thin dielectric substrate as a reflector which offers advantages: First, the production of the parallel modes and high-order resonant modes from a metal reflector or cavity, respectively, can be avoided. Second, there is no inherent conductor loss. Third, it can effectively suppress the excitation of surface waves by using a thin substrate with very high dielectric constant. The dielectric loss is quite small compared to the other losses resulting from a metal reflector. In addition, this new design allows a possibility for a planar aperture-coupled antenna of integrating with a substrate platform in circuit systems. The front to back ratio of 25 dB is achieved in this design.

- Another design, which incorporates a compact aperture coupled antenna, operates in C band. It is a single band antenna with improved front radiation. It is achieved by positioning the patches, which are at the bottom of the substrate, along the slot axis. The design is simulated for different patch displacements and the radiation pattern is analyzed for it.

Table 7.1 Parameter Variation

Parameters Varied	Different values of varied parameters (dx)	Effect of the parameters varied
Distance between patches 'dx'	9mm 13mm 17mm 21mm	By varying the distance between the patches within 1/8 to 1/2 wavelength of the distance, the return loss decreases as the distance increases. Further the gain and directivity are higher at dx= 13mm and it decreases at all the other three displacements. This deduces a conclusion that when patch is centred at $\lambda/2$ distance away from the centre of the slot, the antenna radiates better in the front direction with improved gain, return loss and directivity.

- A single band antenna is designed and simulated at resonating frequency of 3.6 GHz. It is a compact design having an array of patches at the bottom; which are positioned for a better front radiation. The inclusion of an array also carried out the improvement of about 8dB. Further, this design is simulated for different dielectric materials and substrate thicknesses for better results. The effect of using different dielectric materials has been elaborately discussed and shown in Fig. 5.10 earlier.

Fig. 7.2 Parameter Variation

Parameters Varied	Different values of varied parameters (L_s)	Effect of the parameters varied
Slot Length	65 66.25 67.5 68.75 70	Coupling level is primarily decided by the slot length. As the slot length is decreased, input resistance decreases. But there can also be decrease in the coupling between patch and feed line. When the aperture length (slot length) is increased from 65 mm to 70 mm, there is an increase in the coupling level and decrease in the resonant frequency

- The simulated antenna in chapter 5 is fabricated and tested. The fabricated results approximately close to the simulated results. It is a single band antenna and the resonating frequency is shifted to 3.61 GHz from 3.6 GHz. This antenna is useful for WLAN applications. Since its significant advantage is its better front radiation it is more useful in radar and military applications also.

7.2 FUTURE SCOPE

Slot antennas with patch arrays have proven to exhibit better front back radiation ratio to satisfy the needs of various mobile communication applications.

- The proposed configuration will be further optimized for increased bandwidth by using corrugated ground structures.
- The propose design will be further studied for different slot shapes in order to improve the front radiation.

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