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Contribution to the Analysis of Microstrip Antennas With Defects

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Contents

Abstract

In this project a new shape of DMS is proposed and applied for an antenna designed to radiate at 2.5 GHz. The same shape is applied as defected ground structure. It is found that size reduction with both techniques is possible. The proposed DMS achieves 55.4% of size reduction whereas DGS achieves 67%.

Effects of using both techniques with the proposed shape on bandwidth and radiation pattern are also compared.

Key words: shape of DMS, shape of DGS, size reduction, bandwidth, radiation pattern.

Résumé

Dans ce projet, une nouvelle forme de DMS est proposée et appliquée pour une antenne patch conçue pour émettre à 2,5GHz. La même forme de défaut est appliquée sur le plan de masse. On constate que la réduction de la taille par les deux techniques est possible. Le DMS proposé atteint 55,4% de réduction de la taille tandis que DGS atteint 67%. Effets de l'utilisation des deux techniques avec la forme proposée sur la bande passante et diagramme de rayonnement sont également comparés.

Mots clé : forme de DMS, forme de DGS, réduction de taille, bande passante, diagramme de rayonnement.

ملخص

في هذا المشروع يقترح شكل جديد منDMS وتطبيقه لتصميم هوائي يشع في 2.5 غيغاهرتز. يتم تطبيق نفس الشكل على الهيكل الأرضي للهوائي .وجد أن الحد من الحجم باستعمال كل من التقنيتين ممكنا. وDMS المقترح يحقق 55.4٪ في الحد من حجم الهوائي في حين DGS يحقق 67٪.
كما تمت مقارنة آثار استخدام كل من التقنيتين بالشكل المقترح على عرض النطاق الترددي ونمط الإشعاع.

الكلمات المفتاحية :شكل DMS،شكل DGS ،الحد من الحجم، النطاق الترددي، نمط الإشعاع.

Introduction

The trend in technology today is toward miniaturization and circuit size reduction. It is required that microstrip antennas respond to this criterion since they are used in some miniaturized systems.

Recently two techniques are mainly used for that purpose: Defected Microstrip Patch (DMS) and Defected Ground Structure (DGS) and a variety of shapes have been proposed by researchers.

In this project a new shape of defect is proposed and used both as DMS and DGS and a comparison is made on the obtained results.

In chapter one, the state of the art in microstrip antennas is presented, where the basics of patch antenna and the development in this field are exposed.

Chapter two is dedicated to DMS and chapter three gives an overview on DGS.

In chapter four the obtained results for the conventional patch antenna, defected microstrip antenna and defected ground patch antenna are exposed, discussed and a conclusion is drawn from this work.

Chapter One

State of the Art

CHAPTER ONE

State Of The Art

1.1 Introduction

The concept of microstrip radiator was first introduced by Deschamp [1] in 1953 but it was not until 1970 that this type of antennas has started to evolve due to the advancement in PCB and in computer technologies. Since then, it has gradually found many applications from satellite communications to biomedical applications.

Communication systems are unceasingly evolving, implying more and more requirements on antenna technology such as light weight, low profile and the ability to maintain high performance over a large frequency spectrum. In other words, size reduction and broadband capability are two main design trends of today. In wireless communication systems mainly, size reduction is extremely important where it is desirable to bring down the antenna size while achieving the same performance. An example of this is the mobile phone technology that has significantly reduced weight and size. The antennas used for mobile hand held devices have to be small, light-weighted, low profile, and have an omnidirectional radiation pattern on the horizontal plane [2]. Antennas used in transceivers for personal communications are recognized as crucial elements that can improve or limit system performance [2].

Microstip antennas, in addition to their low profile and light weight are easy to integrate with MMICs, what makes them an attractive choice for these communication systems. Over the years many methods have been proposed to enhance their performance, mainly bandwidth. With the today trend of small size, new techniques are developing to achieve miniaturization of microstrip antennas.

Although antenna engineering has over 60 years of history [3] it remains a very dynamic field bursting with creativity.

CHAPTER ONE

State Of The Art

1.2 communication systems requirements

Antenna design is a fundamental part in designing any wireless system. It has to cope with the explosive growth in the demand for wireless communication and information transfer using handsets and personal communication devices [2], which created new needs and requirements. Antennas used for wireless systems are most of the time close to biological tissue and to the surrounding crowded with electromagnetic waves at the same time. Hence the system must radiate low power and provide reliable communication [4]. So the designer must pay attention to the following requirements during the design:

1. Antenna tuning
2. VSWR and return loss
3. Bandwidth
4. Gain and directivity

And significant new variables:

1. Size
2. Specific absorption rate [5]

Often, these needs are conflicting, so the designer has to look for a compromise between them.

1.3 Microstrip antenna

Microstrip antennas have a variety of configurations and have been the topic of what is currently the most active field in antenna research and development [6].

A microstrip antenna is constituted of a metallic sheet of an appropriate shape, the radiating element, printed on a grounded dielectric substrate as shown in fig.1.1. The substrate thickness is very small compared to wavelength. There are numerous

substrates [7] that can be used for microstrip antennas and their dielectric constants are usually in the range: $2.2 \leq \varepsilon_r \leq 12$.
For a rectangular patch the length L of the radiating element is usually in the range [3]: $\lambda_0/3 \leq L \leq \lambda_0/2$ (where λ_0 is free space wavelength).

The feeding used in early microstrip antennas is microstrip feed line or a coaxial probe [3]. These two techniques are very similar and offer the possibility of adjusting the input impedance level through changing the position of the feed.

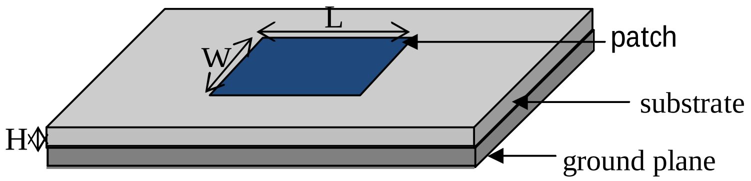


Fig.1.1 Basic shape of a microstrip antenna

The radiation mechanism can be simply explained using the cavity model [8]. When the microstrip is provided with power, a charge distribution is set up on the upper and lower surfaces of the patch and the bottom of the ground plane, an illustration of that is given in fig.1.2. This charge distribution is controlled by two mechanisms: an attractive mechanism and a repulsive mechanism. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which keeps the charge concentration intact at the bottom of the patch. On the other hand, the repulsive mechanism between the like charges on the bottom of the patch causes pushing some charges from the bottom to the top of the patch. The charge movement creates currents flowing at the top and bottom surface of the patch.

The cavity model assumes that the substrate height to patch width ratio is very small allowing the attractive mechanism to dominate leading to most of the charge concentration and the current to be below the patch surface.

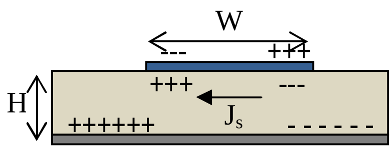


Fig.1.2 Charge distribution on a microstrip antenna

1.3.1 The transmission line model

Fig.1.3 shows the transmission line model [9] that can be used to approximate the performance of the patch antenna. The length of the radiator is modeled as length L of a transmission line, the radiation edges are modeled as slots with admittance
Y = G+jB where the conductance G represents the radiation from the slot whereas the susceptance jB accounts for the capacitance between the edges of the patch and ground plane.

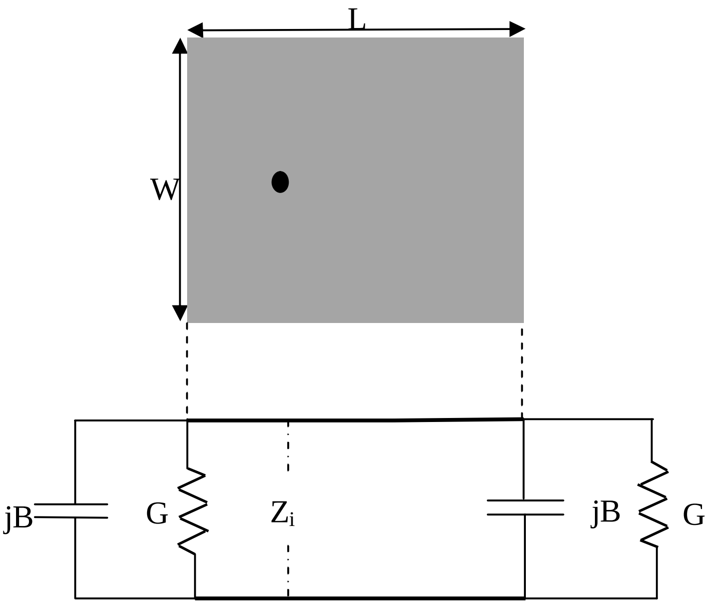


Fig.1.3 The transmission line model for a patch antenna.

1.3.2 Feeding techniques

There are different methods for transferring power to the microstrip antenna. The most popular ones are the microstrip transmission line feeding, the coaxial probe feeding, aperture coupling and proximity coupling [9], as shown in fig.1.4. With the microstrip feeding and the coaxial probe, which are direct contact feedings, it is possible to adjust the position of the feeding allowing the designer to control the impedance match between the feed and the antenna. Often, a trial and error approach is used to obtain an optimum match.

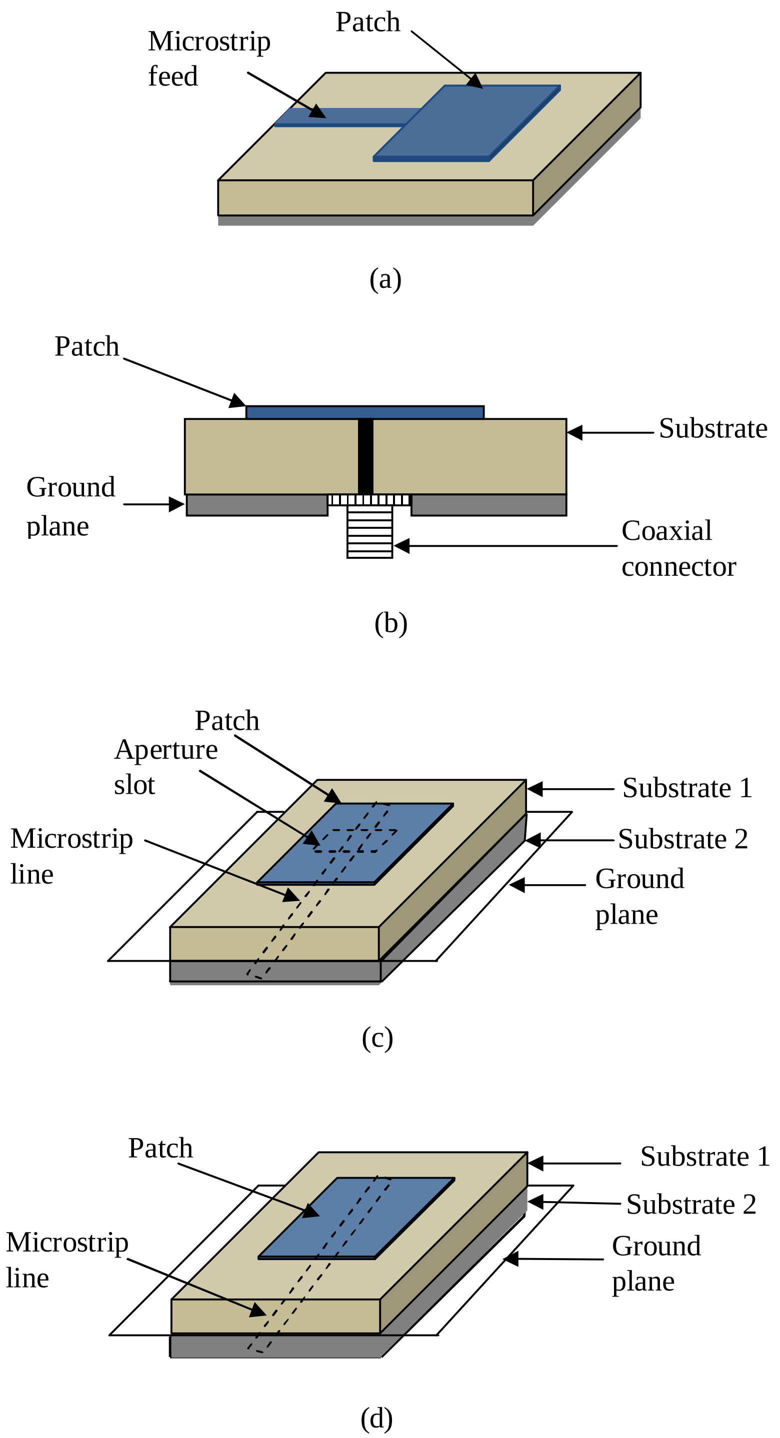


Fig.1.4 Feeding techniques
(a) Microstrip feed line (b) Coaxial probe (c) Aperture coupling (d) Proximity coupling

1.3.3 Waves in a microstrip structure

Depending on the direction toward which the waves are transmitted, waves in microstrip structures fall in four categories [10], these are shown in fig.1.5.

Space waves: waves transmitted upwards, with elevation angles between 0 and $\pi/2$, move toward free open space, thus radiated, with field amplitudes decreasing with distance from the antenna. They are undesirable in transmission lines and circuits as they produce spurious leakage; however they contribute directly to antenna radiation efficiency.

Guided waves: they are trapped between the upper and lower conductors. They provide the normal operation for transmission lines and circuits but they are undesirable in patch antennas.

Leaky waves: they are directed more sharply downward, with θ lying between π-arcsin($1/\sqrt{\varepsilon_r}$) and $\pi/2$. They contribute in radiation; therefore they are useful for patch antennas.

Surface waves: waves transmitted slightly downward, with elevation angles between $\pi/2$ and π-arcsin($1/\sqrt{\varepsilon_r}$). They experience total reflection between the two conductors. The fields remain mostly trapped within the dielectric, decaying exponentially above the interface. Surface waves take up some part of the signal energy, hence decreasing the antenna efficiency.

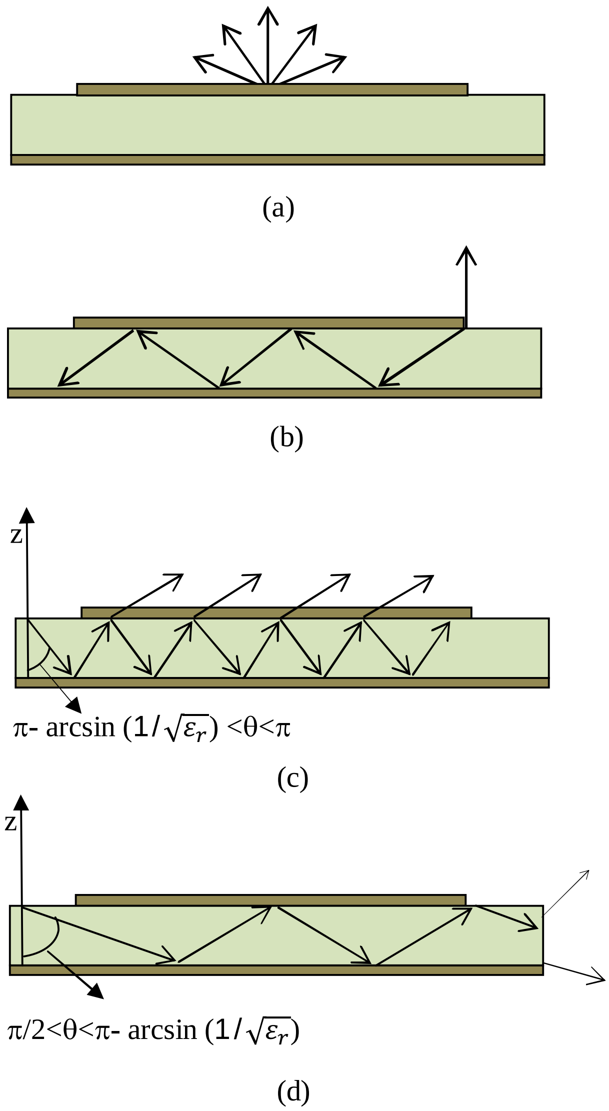


Fig.1.5 Waves in a microstrip structure

(a) Space waves (b) Guided waves (c) Leaky waves (d) Surface waves

1.3.4 Advantages and disadvantages of microstrip antenna

Progress in printed circuit technology, integration of active elements and the use of higher frequencies on one hand and the attractive features of microstrip antenna on the other hand, made it suitable for many applications. Nevertheless it suffers from some disadvantages [9, 11] as well. They should be taken into consideration before making a choice for a particular application.

Advantages of microstrip antenna include:

-Low profile.

-Light weight.

-Possibility of integration with microwave integrated circuits.

- Conformability with non planar surfaces.

-Possibility of multiple frequency operation.

These advantages allowed the use of patch antennas in many applications [3] such as radar, navigation and landing systems, direct broadcast TV, mobile radio, biomedical systems and others.

Disadvantages of microstrip antenna include:

-Narrow bandwidth.

-Small efficiency.

-Poor polarization purity.

-Parasitic radiation by feeding lines and discontinuities.

-Arrays require complex feeding system.

Much of the efforts in the development work of microstrip antenna have gone into trying to overcome these problems in order to satisfy rigorous requirements [3].
These include feeding and shape manipulation and techniques for bandwidth enhancement.

1.3.5 Applications of microstrip antennas

CHAPTER ONE

State Of The Art

The advancements made in microstrip technology were first driven by defense and space application where needs are for maximum performance with little constraint on cost. Then this technology emerged the commercial sector where it has achieved an enormous growth but often the cost is a constraint. Some of the commercial applications are presented in the following table [2]:

Application	Frequency
Global positioning satellite	1575 MHz and 1227 MHz
GSM	890-915 MHz and 935-960 MHz
Wireless Local Area Network	2.40-2.48 GHz and 5.4 GHz
Cellular Video	28 GHz
Direct Broadcast Satellite	11.7-12.5 GHz
Automatic Toll Collection	905 MHz and 5-6 GHz
Collision Avoidance Radar	60 GHz, 77 GHz, and 94 GHz
Wide Area Computer Networks	60 GHz

Table1.1 Microstrip Antenna Applications

1.3.6 Shapes of the patch

Since the original configuration was proposed many variations of the patch shape have been developed by researchers throughout the world. The variation in design possible with patch antennas surpasses any other type of antennas [3]. Different authors have been studying shapes like: dipole [12], rectangle or square [13], disc [14], ellipse [15], triangle [16, 13] circular ring [17], and polygon [13], some of these shapes are shown in fig.1.6. Other shapes, more or less complicated, are also introduced due to their low size [18], and their ability to generate circular polarization [19, 20].

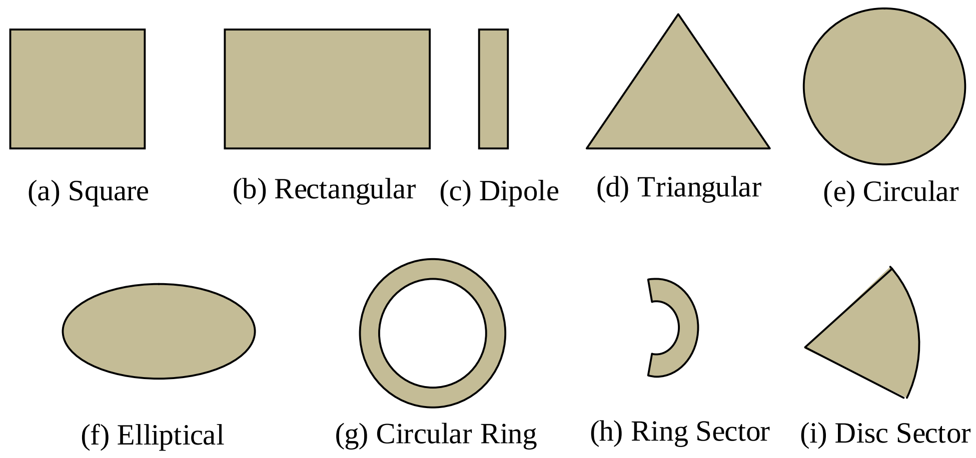


Fig.1.6 Representative shapes of patch elements

1.4 Design of a microstrip antenna

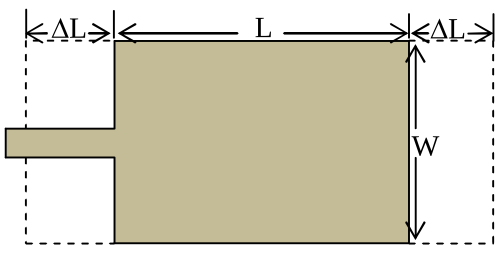


Fig.1.7 Physical and effective length of a patch

In this section some formulas of the design procedure are given [9].

For low frequencies the effective dielectric constant is essentially constant and is given by equation 1.1.

For W/H > 1:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\left[1 + 12\frac{H}{W}\right]^{-1/2} \qquad 1.1$$

Due to the fringing effect, electrically the patch of the microstrip antenna looks greater than its physical dimensions. This is modeled by an extension distance ΔL along the length of the patch and is given by the following approximate relation:

$$\frac{\Delta L}{H} = 0.412\frac{(\varepsilon_{reff} + 0.3)\,(\frac{W}{H} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{H} + 0.8)} \qquad 1.2$$

And the effective length, shown in fig.1.7, is given by:

$$L_{eff} = L + 2\Delta L \qquad 1.3$$

So to design a microstrip antenna patch we first specify: the dielectric constant of the substrate ε_r, the resonant frequency f_r and the height of the substrate H. Then we determine the width W and the physical length L using the following relations:

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad 1.4$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \qquad 1.5$$

1.5 Microstrip antenna performance enhancement

Much of the conducted researches in the microstrip antenna domain are devoted to enhance this antenna characteristics by removing as much as possible the disadvantages it suffers from. The impedance bandwidth is generally the limiting factor. Thick substrates with low dielectric constant are preferred to achieve large bandwidth, but these substrates lead to surface waves' excitation, hence lowering the efficiency and in some cases may lead to spurious radiation and pattern degradation.

In addition to this, they have the disadvantage of greater weight and higher cost. The bandwidth is also affected by the shape of the element; studies showed [4] that wider elements have better bandwidth because their radiation resistance is lower since the edges are larger. There have been dozens of different designs and variations proposed for bandwidth improvements. Another way of achieving larger bandwidth is by impedance matching using a matching network and by using multiple resonances mainly stacked patches or parasitic patches. Fig.1.8 shows some of these techniques Bandwidths of 10-12% for the former and 10-20% for the latter are reported [21].

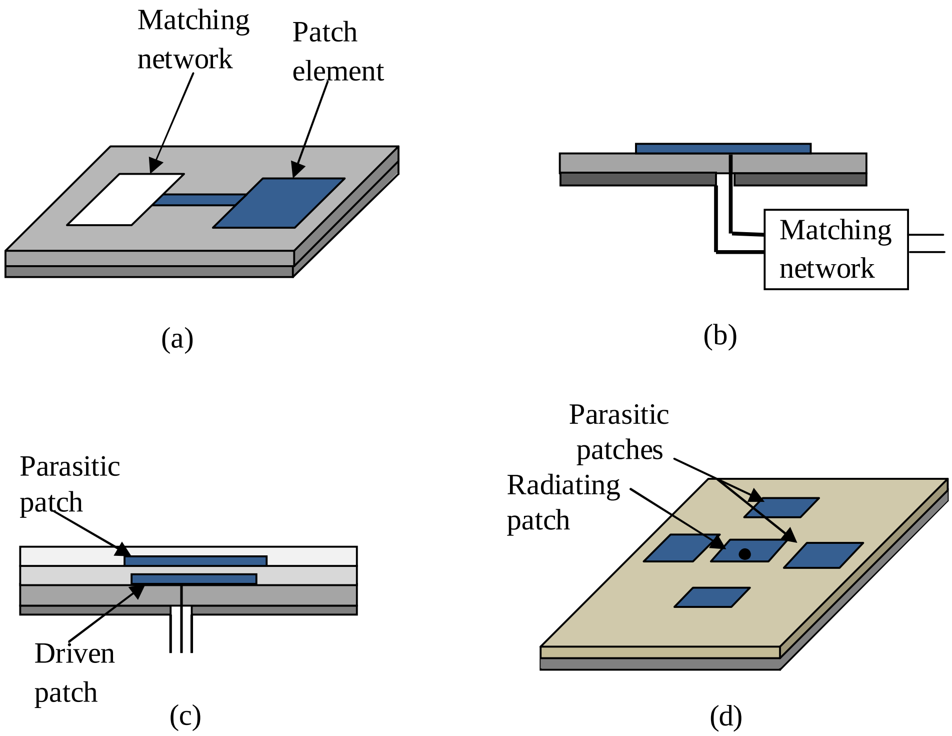


Fig.1.8 Bandwidth enhancement techniques
(a),(b) Matching network (c) Stacked patches (d) Parasitic patches

With the advancement in this field, new methods have emerged which consist mainly of altering the substrate or the ground plane by introducing electromagnetic gaps.

These are called electromagnetic band gaps (EBG) or photonic band gaps (PBG). They are periodic structures, applied either in the substrate or on the ground plane, in which propagation of certain frequency bands is prohibited. In [8], a lattice of square structures is applied on the ground plane resulting in a little shift down of the frequency and a larger bandwidth. A pattern of split square rings inserted in the substrate [22] led to surface waves suppression. High gain and directivity and improved return loss as well is achieved in [23] by combining an EBG substrate with a metamaterial superstrate. A bandwidth enhancement of 35% is achieved in [24] using square structures of PBG on the ground plane. A bandwidth of 65% is reached along with enhanced return loss by introducing a lattice of reverse square rings (RSR) on a square patch [25]. A dual band array with reduced mutual coupling between the patches is realized using ring structure EBG [26]. EBG applied for a microstrip antenna array resulted in better isolation between the array elements and enhanced return loss, radiation efficiency and VSWR.

Recently, new techniques have been proposed, achieved either by introducing defects on the ground plane that is defected ground structure (DGS) or on the patch itself, that is defected microstrip structure (DMS). These techniques came in response for the new trend of size reduction of relatively low frequency microstrip antennas.

1.6 Size reduction

The miniaturization of antenna structure is usually limited by physical laws of nature [2].Usually size reduction is on the expense of other antenna characteristics as bandwidth and gain. For small size antennas, there is always a tradeoff between radiation quality factor Q, bandwidth BW and efficiency η [27].

The rule of thumb is:

$$\frac{BW\,\eta}{V} = \text{Constant} \tag{1.6}$$

Where

V: antenna volume.

$$BW.\eta \cong (ka)^3 \cong 1/Q \quad 1.7$$

Where a: radius of a sphere that includes the small antenna. From this equation we can say that the smaller the antenna the higher the Q factor.

The microstrip antenna can be considered small if its largest dimension is less than or equal to (a) where:

$$a = 1/k = \lambda/2\pi \quad 1.8$$

λ: wavelength.

The concept of size reduction means that it is desirable to bring down the size of the antenna while achieving the same performance of the original large size antenna. But there is a lower limit to the size of any antenna for a given resonant frequency since other important characteristics like gain and bandwidth are drastically affected for small size antenna. However, a balance is possible [28]. To achieve size reduction many techniques have been used, some of these are shown in fig.1.9 and fig1.10.

- Using dielectric substrates with high permittivity [29]. With this technique size reduction of about 90% is reported using a square patch truncated at the corners for GPS applications [30].
- Applying resistive or reactive loading [31].
- Increasing the electrical length of the antenna by optimizing its shape [32].
- Utilization of strategically positioned notches on the patch antenna [33].
- Using shorting pins, walls and edges [30]. It is found that using this technique antenna fundamental frequency can be lowered and hence the size can be reduced. It is reported that 98% of size reduction is possible with this technique [34]. The following figures show some of these techniques.

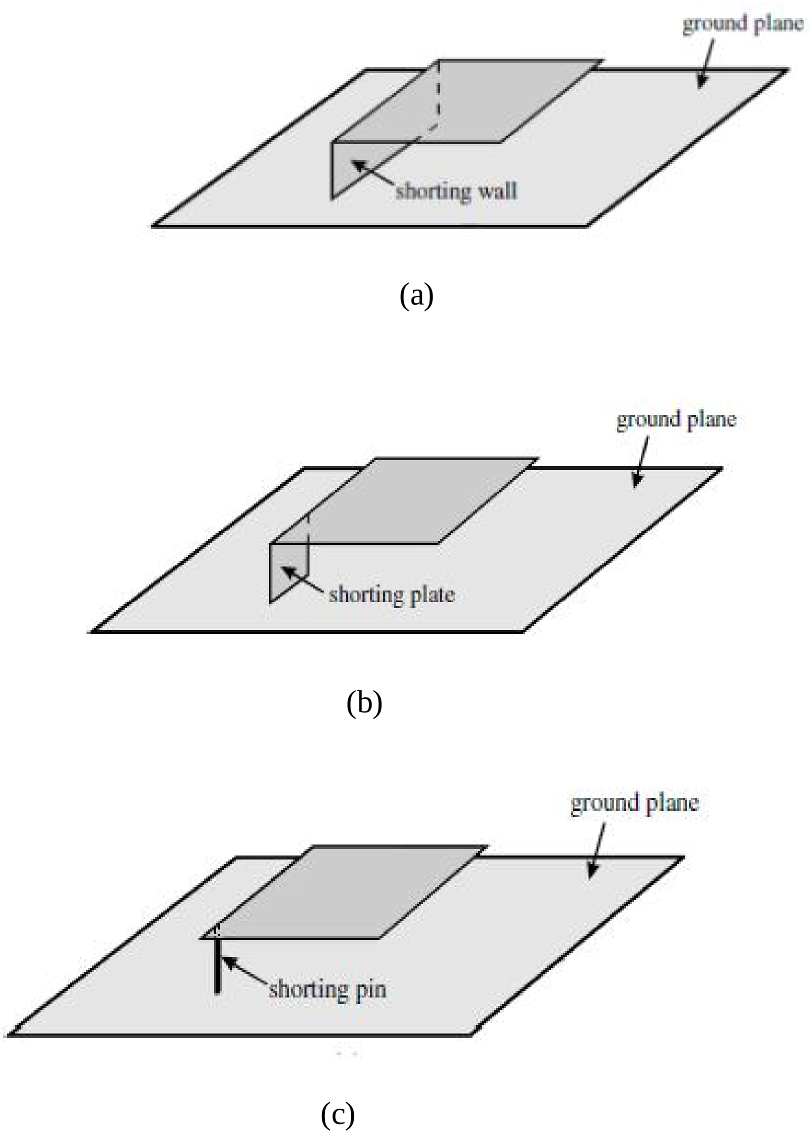
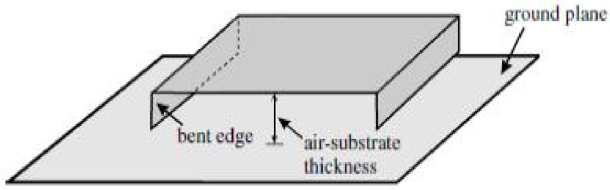
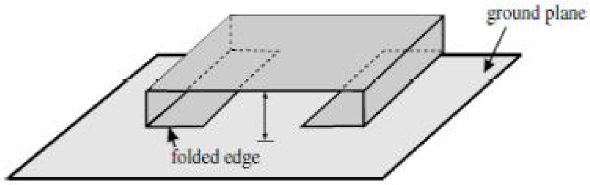


Fig.1.9 Shorting techniques for size reduction

(a) Shorting wall (b) Shorting plate (c) Shorting pin



(a)



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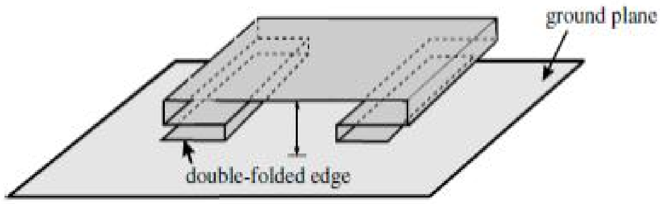
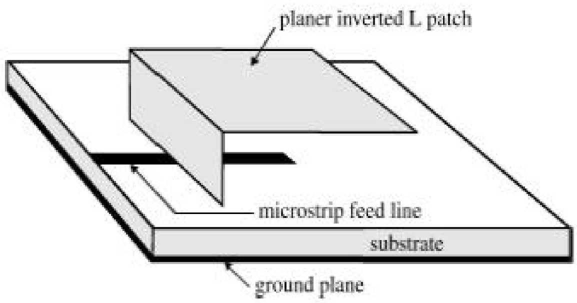


(c)



(d)

Fig.1.10 Compact microstrip antennas

(a) An inverted U-shaped patch (b) A folded patch

(c) A double folded patch (d) Planar inverted -L

1.7 Analysis methods and software tools

A field that is closely related to antenna development is computational electromagnetics. Antenna complexity is raising and simple models (like transmission line and cavity model) are not sufficient anymore; full wave solution is necessary. The existing full wave modeling techniques are [35]:

- Integral equation (IE) solved by method of moments (MOM), one software employing this technique is Zeland IE3D.
- Finite element method (FEM) used in Ansoft HFSS.
- Finite differences in time domain (FDTD) used in Empire.
- Finite integration technique (FIT) used in CST microwave studio.

A benchmarking study on software tools for planar antennas has been done [35]. It showed that MOM-based solvers show better convergence when a dielectric substrate is considered as infinite. Moreover, the use of two different solvers based on different theoretical methods may provide a means to characterize the quality of simulation results.

In this project IE3D of Zeland is used.

Chapter Two

Defected Microstrip Structure

CHAPTER TWO

Defected Microstrip Structure

2.1 Introduction

Defected Microstrip Structure (DMS) is an emerging technique used for major enhancements in microstrip circuits such as bandwidth enhancement [30] and size reduction of microstrip circuits [36]. It has the advantage of easiness of realization and shape diversity; moreover it does not raise any circuit integration problems.

2.2 Defected microstrip structure

The defect is realized by etching a uniform or non-uniform, periodic or non-periodic pattern on the microstrip structure. In case of microstrip antennas, it is etched on the patch (radiating element). We distinguish two ways [30] for the realization of the defect either by slot loading on the surface of the printed patch or by slit cutting at the boundaries of the patch.

In slot loading, the defects are etched on surface of the patch and can have various shapes like bent slots [37], square slot [38], cross [39, 40], circular slot [41], and others as shown in fig.2.1.

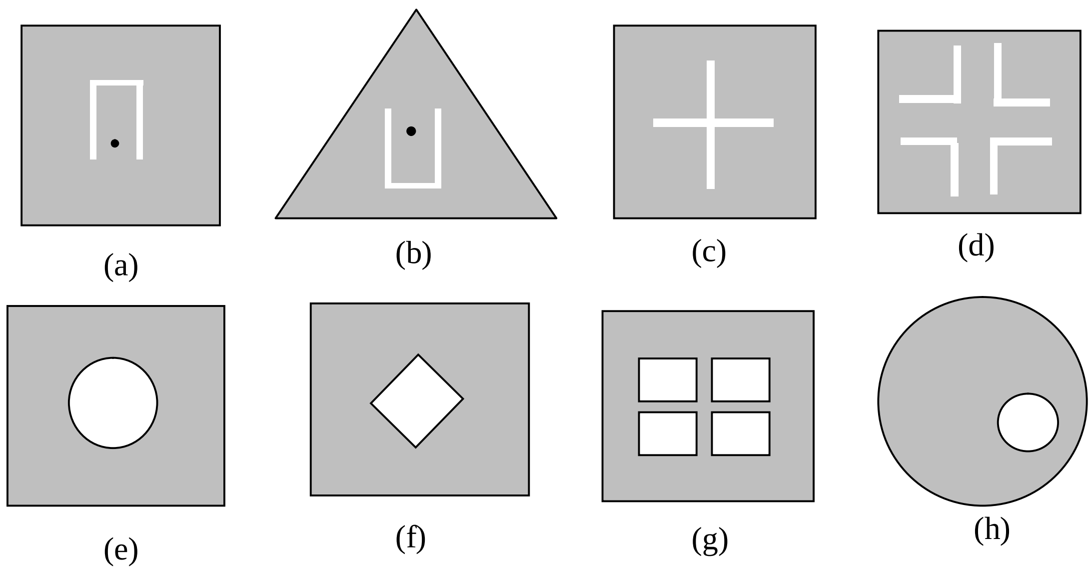


Fig.2.1 Slot loading shapes of DMS

Defected Microstrip Structure

In slit loading the defects are cut on the boundaries of the radiating element as shown in fig.2.2 where the current path is determined by the patch length and the slit depths.

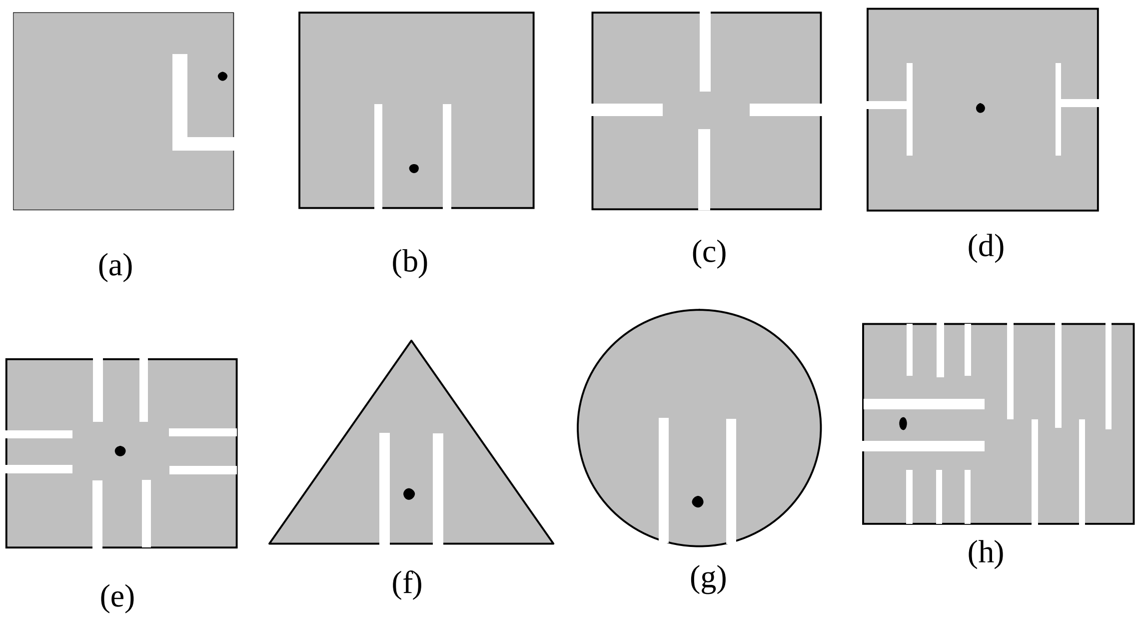


Fig.2.2 Slit loading shapes of DMS

Also a combination of slot and slit loadings can be used allowing versatility and resulting in shapes more or less complicated as illustrated in fig 2.3.

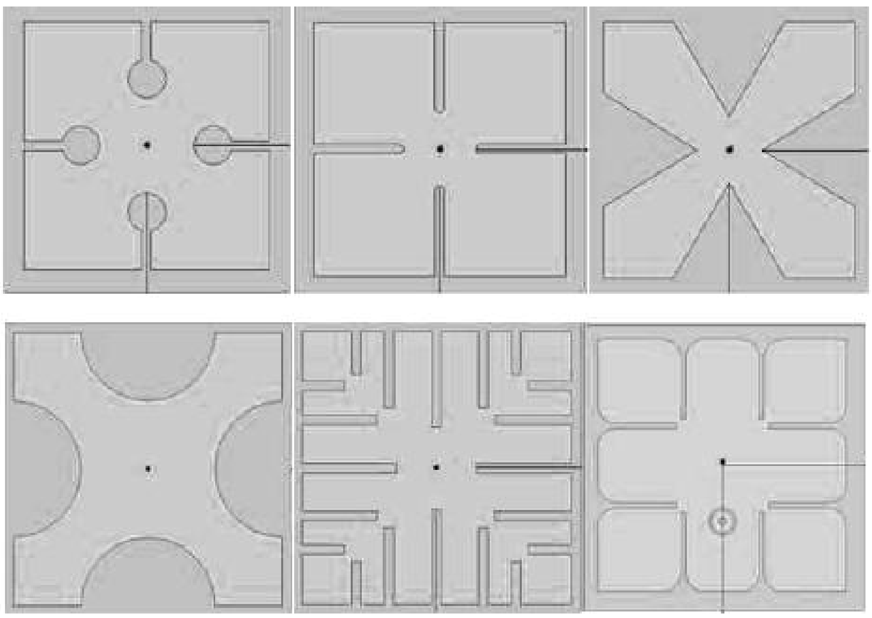


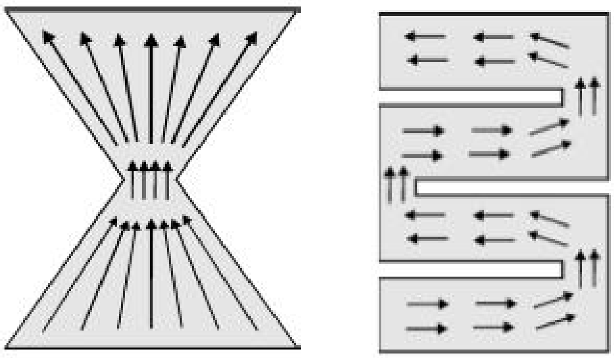
Fig.2.3 Other shapes of DMS

These defects constitute an obstruction in the current path resulting in altering the microstrip structure performance. Important parameters that affect the performance of the microstrip structure are the slit or slot length, the width and the position [42]. But, unfortunately, mathematical modeling for these parameters even empirical formulas that allow having a pre-specified operation of the microstrip structure, are not available yet [30] due to the difficulty of analysis[42].

Some of the presented defects have been used for bandwidth enhancement purpose [30] and some of them for microstrip antenna size reduction [36].

2.3 Surface current distribution for DMS

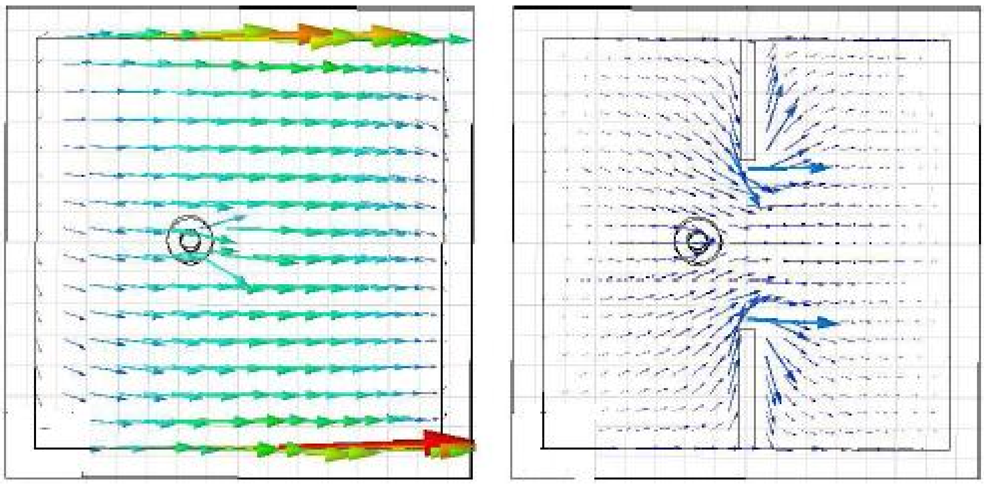
The introduced defect on the microstrip structure constitutes an obstruction in the current path. Physically the defect is a gap on the metallic sheet constituting a discontinuity in the current path, hence the current is forced to circumvent this gap and take a longer trajectory [43] as shown in Fig.2.4 and Fig.2.5. This results in a larger electrical length for the radiating element and thus leading to lowering the resonating frequency. It is this effect that is exploited in reducing the size of microstrip antennas [43].



(a) (b)

Fig.2.4 Surface current distribution of

(a) A pair of rectangular notches (b) meandering slits



(a) (b)

Fig.2.5 Surface current distribution

(a) Without slots (b) With slots

2.4 DMS circuit model

As shown in fig. 2.6, the slot may be modeled by an inductor placed in series with the transmission line model for the patch antenna. The reasoning behind this inductive model is that the slots cause a concentration of the magnetic field interior to the slots, due to the currents forced to flow along the edge of each slot [36]. From this lumped model, the inductor stores magnetic energy and resists phase changes in the current flow, hence introducing a phase delay between voltage and current, as in the physical model where current is delayed by taking a longer path around the slot. But, since the inductance changes over the length of the slot, the single lumped inductor model is a very coarse approximation. To improve it, many inductances have to be used [45].

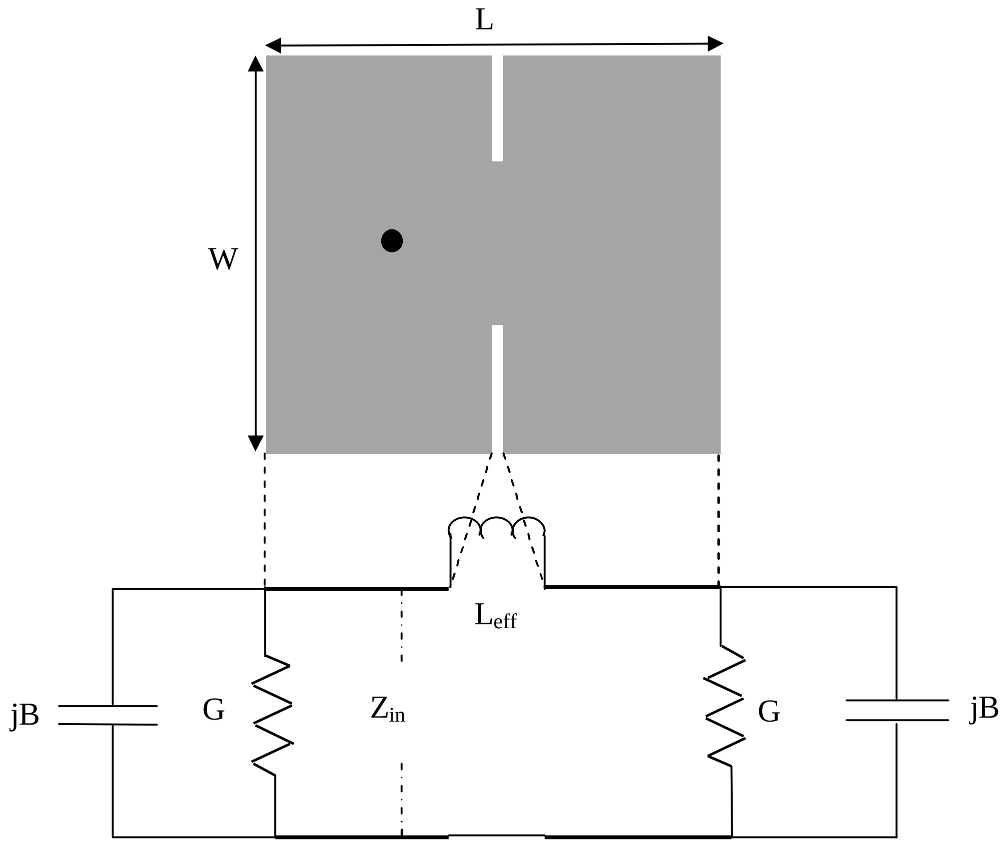


Fig.2.6 The equivalent circuit of a pair of triangular slits DMS

2.5 Effects of the different parameters

A study has been conducted [36] as to see the effect of slot length, slot width and slot position on the resonant frequency, the bandwidth and the gain of patch antenna loaded with four slots.

First, the slot length is varied while keeping the other parameters fixed, this showed that the resonant frequency decreases approximately linearly with increasing slot length. This is accompanied by a decrease in bandwidth and gain.

Second, the width of the slot is varied while keeping the other parameters fixed, this also decreases the resonant but in a nonlinear manner. It has the same effect as the slot length on bandwidth and gain of the patch antenna.

Third, the slots are moved along the length of the patch to observe the effect of slot placement. This study showed that placing the slots at the center of the patch where larger currents are, has the most impact on performance. As the slots are moved away from the center of the patch in either direction the resonant frequency rises in the same manner independently of which direction the slots are moved. This can be explained from circuit theory point of view, where the inductance has the most effect when there is high current involved.

Also, it is observed that for substrate thickness less than the slot width, the frequency is decreased further by the capacitance developed between the ground and the patch. Moreover, no slot shape performs better than another with respect to the bandwidth.

Finally, the slot loading can be used to allow the use of low permittivity substrates while obtaining the same frequency tuning of much higher permittivity materials. This allows avoiding high losses.

2.6 Applications of DMS

2.6.1 A tuning technique

It is known that microstrip antennas have high quality factor (Q), therefore, any slight difference in the design procedure can lead to an abrupt change in the resonant frequency. However, it is required that the antenna operates at some specified frequency, which means the antenna needs to be tuned [42]. Several techniques to tune the resonant frequency of square patch antenna can be found in literature. Some of these techniques include the use of stubs, shorting posts and adjusting an air gap to modify the permittivity of the substrate. Such techniques increase the resonant frequency of the patch antenna meaning that the tuning goes form a lower to a higher resonant frequency [46]. But some of these techniques are difficult to achieve. DMS can be employed easily to achieve tuning. In this method the slots, the slots are placed along the non-radiating edges of the patch, increasing the electrical length, hence resulting in lowering the operating frequency. This method does not alter the performance of the antenna with respect to radiation pattern or gain [46].

2.6.2 Filtering

In some electronic systems, it is desired to achieve electromagnetic compatibility (EMC) to avoid electromagnetic interferences [46] which may damage the system in some cases. In many recent applications Defected Ground Structures (DGS) are involved in the suppression of the undesired harmonics. These applications include antennas and filters. It is shown that DMS is also a very good option for the harmonics suppression without introducing a large attenuation in the fundamental frequency or in the passband [43].

2.6.3 Dual-band operation

Sometimes it is desirable to have an antenna operating at more than one frequency such as in GPS [36]. The dual-band antenna is realized by cutting slots of different shapes like U-slot, V-slot, pair of rectangular slots, etc. This means that DMS can also provide dual-band operation [30].

2.6.4 Size reduction

Size reduction is the new trend in communication technology. Patch antennas, inherently, have a low profile but still large at relatively small frequencies compared to today's miniaturized systems. In order to be able to integrate microstrip antennas with these systems, they must be reduced in size. Moreover with smaller area we can reduce the cost in designing microstrip antennas and we can even pack more than one antenna in a system if needed. DMS is a way of achieving patch size reduction, total area reduction of 22% [46, 47], 37% [48] and 47% [49] were reported and more is to be done in the coming future.

2.7 Formulation of size reduction using defects

Simple and accurate mathematical formula is derived [50] to predict the reduced dimension of the microstrip circuit when a defect is introduced; it is based on the change in the input impedance and can be generalized for all microstrip circuits. Defects lead to increased slow wave factor (SWF) in microstrip lines in which they are introduced and this phenomenon can be used to reduce the size of passive planar circuits. The SWF is raised whenever discontinuity is introduced in the path of EM waves increasing the impedance of the line. For a lossless microstrip line it is given by:

$$\mathrm{SWF} = \frac{\lambda_0}{\lambda_g} = \sqrt{\varepsilon_{eff}} = \frac{\beta}{k_0} \qquad 2.1$$

Where ε_{eff} is given by equation 1.1.

λ_0 : free space wavelength.

λ_g : guided wavelength

β: propagation constant

k_0: free space wave number

Every circuit based on transmission line model presents an electrical length, for microstrip lines it is given by:

$$\theta = \beta l = \sqrt{\varepsilon_{eff}}\, k_0\, l \qquad 2.2$$

We know the input impedance of the line:

$$Z_{in0} = Z_0 \frac{Z_l + j Z_0 \tan(\beta_0 l_0)}{Z_0 + j Z_l \tan(\beta_0 l_0)} \qquad 2.3$$

After inserting the defect the input impedance becomes:

$$Z_{ind} = Z_0 \frac{Z_l + j Z_0 \tan(\beta_d l_0)}{Z_0 + j Z_l \tan(\beta_d l_0)} \qquad 2.4$$

But after inserting the defect, the resonating frequency changes and the input impedance also changes:

$$Z'_{ind} = Z_0 \frac{Z_l + j Z_0 \tan(\beta'_d l_0)}{Z_0 + j Z_l \tan(\beta'_d l_0)} \qquad 2.5$$

Now the change in the electrical length can be compensated by changing the length of the line:

$$Z_{indm} = Z_0 \frac{Z_l + j Z_0 \tan(\beta_{dm} l_{dm})}{Z_0 + j Z_l \tan(\beta_{dm} l_{dm})} \qquad 2.6$$

After this if we achieve the same resonant frequency and the same electrical length again as it initially was then the performance of the circuit is almost the same, so that we can say:

$$Z_{in0} = Z_{indm} \qquad 2.7$$

From this we can deduce that:

$$\beta_{dm} l_{dm} = \beta_0 l_0 \qquad 2.8$$

And the electrical lengths are equal:

$$\theta_{dm} = \theta_0 \qquad 2.9$$

Hence we can deduce:

$$\frac{l_{dm}}{l_0} = \frac{\beta_0}{\beta_{dm}} \qquad 2.10$$

We know:

$$\theta_0 = \beta_0 l_0 = \frac{2\pi\, f_0}{c}\sqrt{\varepsilon_{eff}}\; l_0 \qquad 2.11$$

After inserting the defect into the transmission line:

$$\theta_d = \beta_d l_0 = \frac{2\pi\, f_0}{c}\sqrt{\varepsilon_{effd}}\; l_0 \qquad 2.12$$

But since the resonant frequency changes the electrical length becomes:

$$\theta'_d = \frac{2\pi\, f'_d}{c}\sqrt{\varepsilon_{effd}}\; l_0 \qquad 2.13$$

After miniaturization the length of the transmission line is l_{dm} and the electrical length is:

$$\theta_{dm} = \frac{2\pi\, f_0}{c}\sqrt{\varepsilon_{effd}}\; l_{dm} \qquad 2.14$$

The electrical lengths before and after miniaturization should be the same:

$$\theta'_d = \theta_{dm} \qquad 2.15$$

$$\frac{2\pi\, f'_d}{c}\sqrt{\varepsilon_{effd}}\; l_0 = \frac{2\pi\, f_0}{c}\sqrt{\varepsilon_{effd}}\; l_{dm} \qquad 2.16$$

Therefore $$\frac{l_{dm}}{l_0} = \frac{f'_d}{f_0} \qquad 2.17$$

Chapter Three

Defected Ground Structure

CHAPTER THREE

Defected Ground Structure

3.1 Introduction

In recent years, many efforts have been made in order to enhance the performance of microwave circuits and many concepts were proposed [51]. One such technique is modifying the ground of the microstrip circuit. The photonic band gaps that were proposed by Yablonovitch and John [52, 53] can be used to modify the ground plane. They are periodic structures known to provide rejection of certain frequency bands. However, it is difficult to use them for the design of microwave components due to the modeling complexity caused by the various parameters that affect the band gap property. Park et al [54] proposed a defected ground structure which is designed by connecting two square PBG cells with a thin slot. DGS adds an extra degree of freedom to microwave circuit design and is already used in several applications.

Several novel DGSs have been proposed and had become one of the most interesting areas of research.

3.2 Defected ground structure

DGS is an etched periodic or non periodic pattern on the ground plane. The name of this technique simply means that a defect is placed on the ground plane which is generally considered to be an approximation of an infinite perfectly conducting current sink, but this does not render the ground plane defective. Depending on the shape and dimensions of the defect, the shielded current distribution in the ground plane is disturbed [55]. This disturbance changes the characteristics of the microstrip circuit such as capacitance and inductance. Any defect introduced in the ground plane of a microstrip circuit leads to increasing the effective capacitance and inductance. This shows the resonance property of the DGS which makes it find applications in a number of microwave circuits [55] such as filters, antennas and amplifiers. Furthermore DGS shows slow wave effect that allows considerable size reduction that is required for system miniaturization. The shape may be changed from simple to complicated shape for better performance.

3.2.1 DGS element

Since the dumbbell shape was first proposed, many variations of the shape of the DGS elements have been proposed. They range from a simple rectangular slot to more complicated configurations. We can find in literature, in addition to the dumbbell[56] , square[57], circular[58], spiral[59], concentric ring[60], L-shaped[61], U-shaped[62], V-shaped[63], hexagonal [64], cross-shaped[65] and combination of these shapes [66]. Some of these shapes are shown in fig.3.1, fig.3.2, fig.3.3 and fig.3.4.

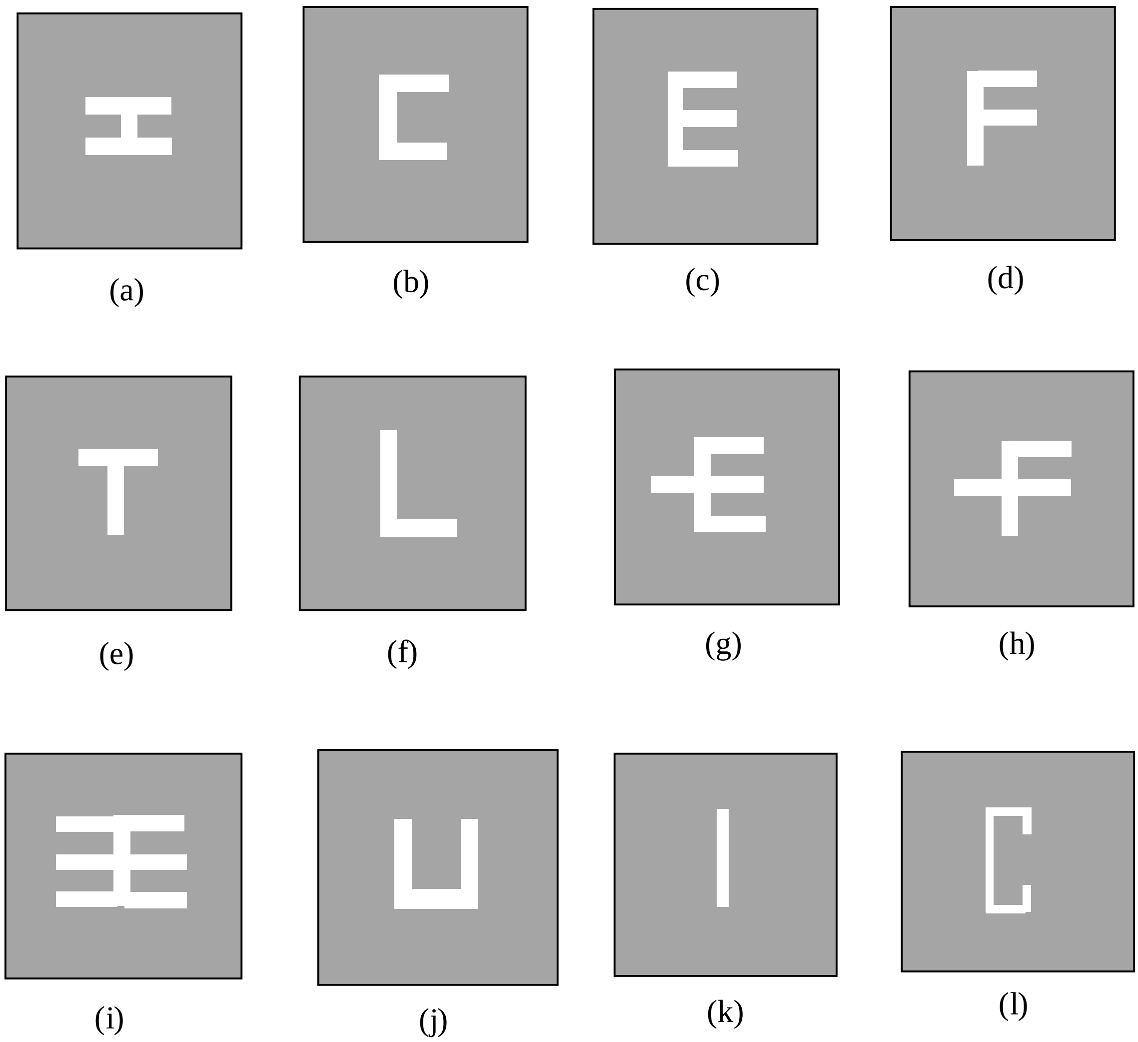


Fig.3.1 Letter-like shaped DGS

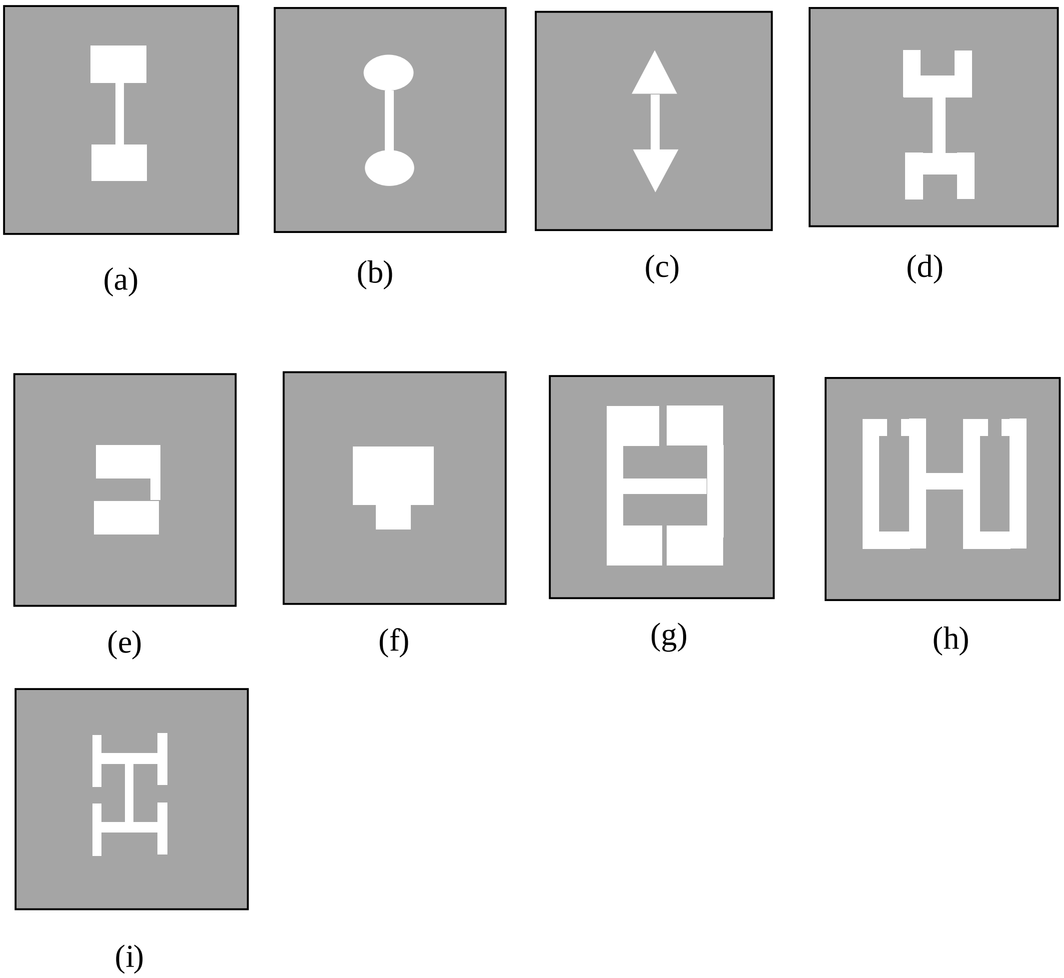


Fig.3.2 Slot with heads shapes for DGS

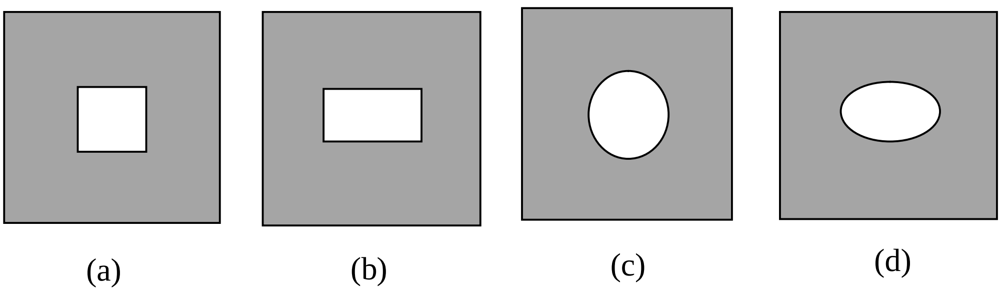


Fig.3.3 Simple slot shapes for DGS

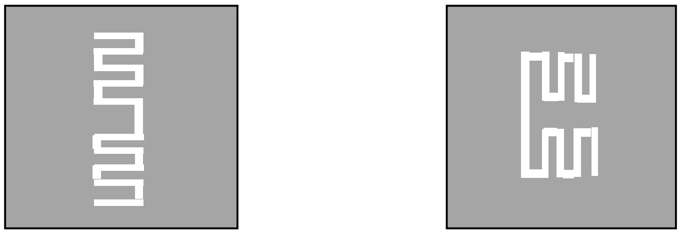


Fig.3.4 Meander lines DGS

3.2.2 The current distribution for DGS

In conventional microstrip lines, the fields are mostly confined under the line. The return current on the ground plane is the negative image of the current distribution on the microstrip line [51]. When DGS is introduced, the current is fully disturbed and confined to the periphery of the defect and returns back to underneath the microstrip line when the defect is over. Fig.3.5 shows the current distribution when a dumbbell DGS is used. Based on this observation of the concentration of surface current on the ground plane the gap is represented as a capacitance and the side arms as an inductance.

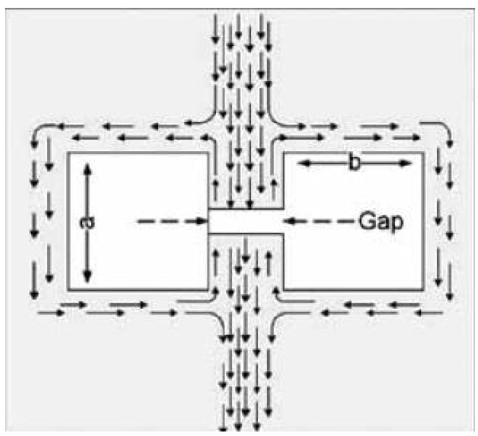


Fig.3.5 Ground current distribution when using a dumbbell DGS

3.2.3 The equivalent circuit

The equivalent circuit of DGS can be represented by an L-C resonator in parallel with the transmission line to which it is coupled [68] as shown in fig.3.6. The equivalent values of L and c are determined by the dimensions of the DGS structure and its position relative to the transmission line. For a given DGS shape, the part that lengthens the current path and increases the effective inductance of the transmission line is modeled by an inductor and the part that accumulates charge increasing the effective capacitance is modeled by a capacitor. So a resonance occurs at certain frequency because of the parallel L-C circuit.

On the other hand, the simulated [51] S-parameters for dumbbell DGS shows a band-rejection property as shown in fig.3.6. This band-rejection property depends on the type of the used DGS.

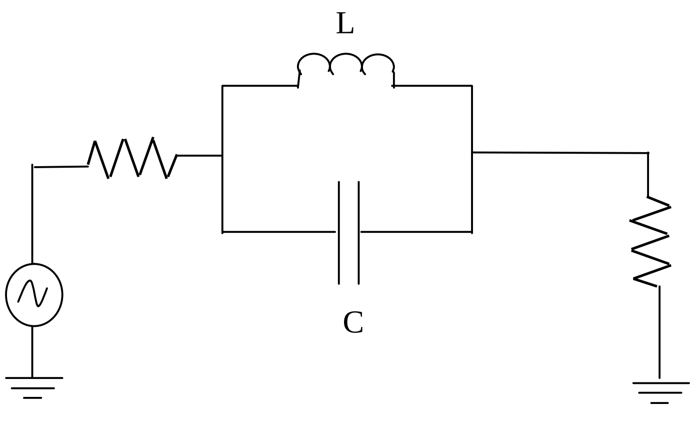


Fig.3.6 The equivalent circuit of DGS

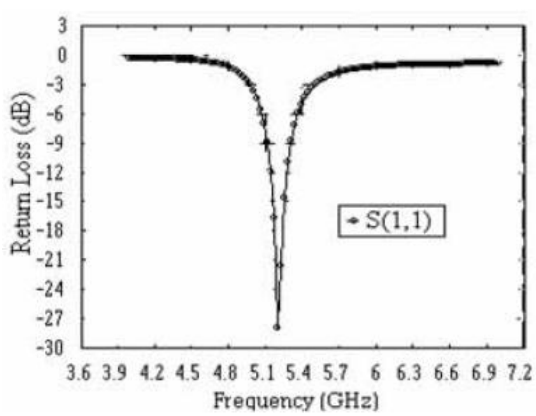


Fig.3.7 Return loss of a unit DGS

3.3 Characteristics of DGS

DGS finds many applications in passive and active circuits due to its effects. Since each DGS structure has its distinctive characteristics, the user should select the appropriate one for a given application, for example For example, suppressing unwanted harmonics can be accomplished by placing the corresponding DGS pattern that achieves this desired circuit functionality. The main effects of DGS are the following [51]:

-Stop band effects.

-Slow wave effect.

-High surface impedance effect.

3.3.1 Stop band effects

It is found that DGS can provide rejection of certain frequency bands along with enhancing the rejection band characteristics and this is known as the band gap effects. This is due primarily to the fact that the slots increase the inductance making the total structure to behave as a band reject filter. The stopband is useful in filtering the undesirable surface waves, spurious and leakage signals. Using DGS improves the filtering operation through: making the transition band sharper and achieving broader stopband response in addition to improving the characteristics of the passband.

3.3.2 High characteristics impedance

It is accepted that in conventional microstrip structure the impedance is generally around 100-130 Ω. By etching DGS on the ground it is possible for the designer to raise the impedance of the microstrip line to a level more than 200 Ω [51]. The high characteristic impedance of DGS is used for Wilinkson power divider [51] as it can also find applications in digital systems.

3.3.3 Slow wave effect

This is the effect that plays a major role in size reduction. The discontinuity introduced in the path of current increases the impedance of the line resulting in slowing the electromagnetic wave [48]. The transmission lines with DGS have much higher impedance and increased slow-wave factor than conventional lines. Hence, with these properties circuit size can be reduced [48] such as microwave amplifiers and couplers [57].

3.4 Applications of DGS

We can find in literature various applications for DGS:

3.4.1 Patch antenna size reduction

Size reduction becomes necessary when the designed antenna for a certain frequency using the transmission line model is large and hence not compatible with the intended application. As mentioned before several techniques have been used to reach this objective such as shorting pins or walls and using substrates with high dielectric constant but each of these techniques has its drawback regarding the fabrication. Etching DGS is relatively simpler and it has proven that it achieves the objective of size reduction in many works. A size reduction for two different shapes of DGS of 50% and 45% has been reported [68].

3.4.2 Harmonic reduction

Feed line losses can be reduced by integrating an active device very close to the radiating patch. But these antennas suffer from the harmonic radiation giving rise to nonlinearities. This harmonic radiation is a drawback of active integrated microstrip antennas. It is desired to have the radiation of both active and passive devices at harmonic frequencies at a very low level. It is suggested to reduce this harmonic radiation by using DGS. In DGS antennas the harmonic resonance is strongly eliminated [51]. Different DGS units have been used for this purpose such as H-shaped, spiral-shaped and dumbbell shaped.

3.4.3 Cross polarization reduction

Since the defected ground structure is simple and easy to etch on a commercial microstrip antenna substrate it is also used to reduce the cross polarized radiation level for these antennas that is generally unwanted phenomenon. It only reduces the cross polarization field without affecting the input impedance or the co-polarized radiation pattern of the conventional antenna at its resonant frequency. This new concept is verified experimentally for a particular DGS pattern etched on a patch radiator of circular shape [70].

3.4.4 Mutual coupling reduction

In microstrip arrays which are formed by using a set of identical patch radiators, the field radiated by one element induces voltages across the terminals of other elements resulting in a parasitic radiation in the far field. This is called mutual coupling. The mutual coupling does not only affect the radiation pattern but also the input impedance, the gain, the effective receiving area and other parameters of the array antenna. a defected ground structure (dumbbell) is successfully used to reduce the mutual coupling of a two element array antenna [71]. It has been shown that in comparison with other methods used for mutual coupling reduction, DGS is an efficient technique.

3.4.5 Circular polarization

DGS is used under the feed line including the feed line structures which are edge coupled to the microstrip antenna using a single layer substrate to achieve circular polarization [72]. The design can be easily extended to other bands satellite and terrestrial systems that require circularly polarized antennas. This type of antennas can also be integrated for RFID reader systems and also other communication systems involving circular polarization.

3.4.6 Elimination of scan blindness

A dumbbell DGS is used to remove the blindness angle of a microstrip antenna array. The frequency band gap of the DGS forbids the propagation of surface waves that cause the blindness at the antenna design frequency and hence eliminates the scan blindness. This approach is much easier to implement than EBG methods [73].

3.4.7 Radiation properties enhancements

Surface waves are an undesired phenomenon in patch antenna. When a patch radiates part of the signal available power is trapped along the surface of the substrate due to these surface waves. Hence, surface waves can reduce the antenna efficiency, gain and bandwidth, therefore degrading its performance. Particularly for arrays surface waves have a significant impact on the mutual coupling between the elements. A solution to eliminate surface waves is using a technique with band gap properties such as PBG or DGS [64] and may be used for gain improvement too [74]

3.4.8 Dual band operation

With the advancement of communication systems stress is put on antennas to satisfy the different requirements such as dual band operation. It reported that using DGS dual band operation is possible. In [75] a pentagonal DGS is used for a patch antenna to operate at 2.5 GHz and 5 GHz. A skew F-shaped DGS is used on stacked patch antenna for dual band operation at 3.15 GHz and 4.47 GHz [76]. Using a rectangular slot DGS along with a metallic strip resulted in three bands with the center frequencies being 10.3 GHz, 8 GHz and 4.98 GHz [77]. A microstrip antenna with a new DGS operating at five different frequencies was designed and realized in [68].

3.4.9 Bandwidth enhancement

Narrow bandwidth is still the most dominant drawback of microstrip antennas. Despite the several techniques used to improve this bandwidth, researchers did not miss to apply the defected ground structure for this purpose. A bandwidth improvement of 112.4% using a trapezoid microstrip antenna with a double u-shaped defected ground structure was reported in [78]. Also, a bandwidth enhancement of 3.36% has been reported [79] for a hexagonal patch antenna employing a triangular slot DGS.

3.4.10 Microwave filter enhancement

A compact E-shaped DGS has been proposed for a tunable bandstop resonator [80]. It presents both the advantages of small circuit area and a sharper transition knee. In order to improve the response of a microwave low pass filter which suffers from a low attenuation in the stop band, DGS is used to increase the attenuation [43].

Chapter Four

Results and Discussion

CHAPTER FOUR

Results and Discussion

4.1Introduction

I n this chapter the different steps of the work are presented. First, a conventional rectangular patch antenna is designed. Then, a defect is introduced on the patch (DMS) and the effects are observed. After that the same defect is applied on the ground plane (DGS) and again the effects are observed. From the observed effect on the resonance frequency, an attempt to reduce the size of the patch antenna is made with both DMS and DGS. Finally, the results of this size reduction with the two techniques are compared.

4.2 Design of conventional patch antenna

4.2.1 Structure of the patch

The conventional rectangular patch antenna shown in fig. 4.1 is designed to radiate at 2.5 GHz. The probe feeding is used to energize the structure. The design is achieved following the design steps described in chapter one. Table.4.1 summarizes the different patch antenna parameters.

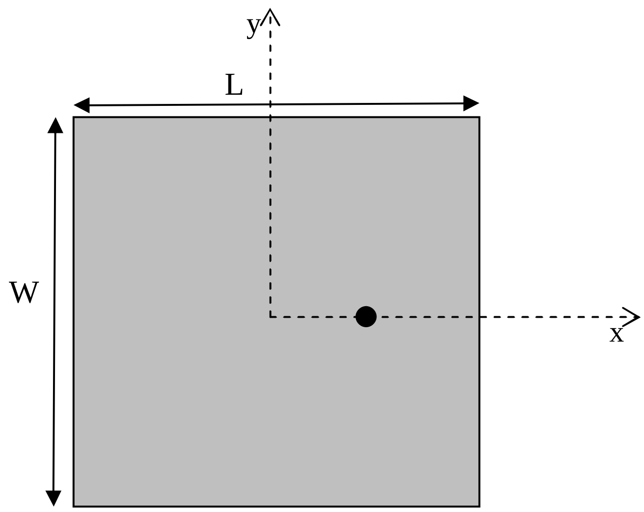


Fig.4.1 Conventional rectangular patch antenna

Substrate permittivity ε_r	Substrate thickness	Patch length L	Patch width W	Feed position
4.4	1.5 mm	27.67 mm	34.32 mm	(x, y) = (7, 0)

Table.4.1 The different patch antenna parameters

4.2.2 The return loss of the conventional antenna

To verify the resonant behavior of the structure, the return loss is drawn in fig. 4.2. This figure shows clearly that the resonant frequency of the designed rectangular patch antenna is at 2.5 GHz as required. The level of the magnitude of the return loss $|S_{11}|$ is approximately at -35 dB; meaning that the selected feed position ensures good matching.

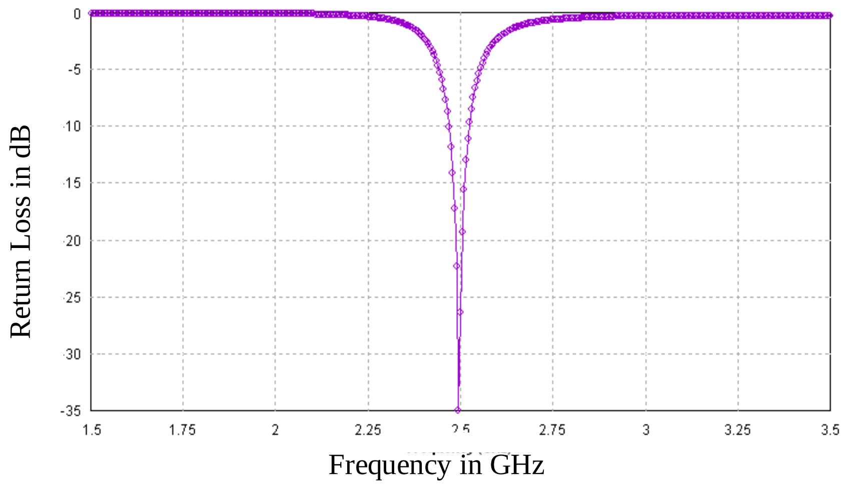


Fig .4.2 The return loss of the designed antenna

4.2.3 Current distribution of the conventional antenna

The vector current distribution of the considered patch antenna is presented in fig. 4.3. It shows a straight current path along the x-direction as expected since the patch surface is continuous.

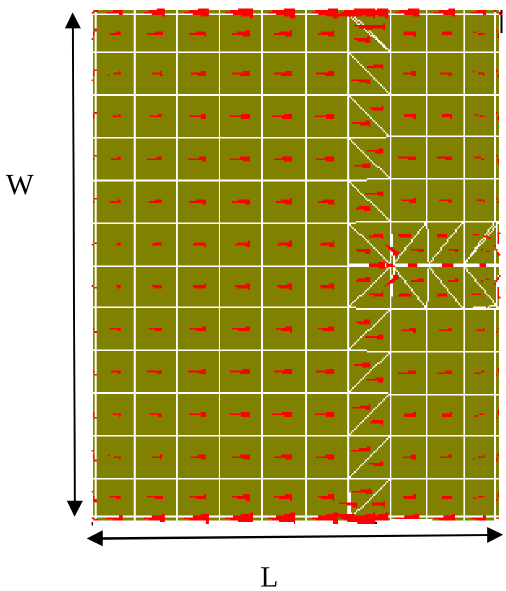


Fig.4.3 The current distribution on the patch surface

4.2.4 Input VSWR of the conventional antenna

The standing wave ratio (VSWR) for the conventional rectangular patch antenna is shown in fig. 4.4. From the VSWR pattern, the calculated bandwidth (VSWR ≤ 2) is found to be 2.36 % which is very small. As stated before the bandwidth is considered to be the main disadvantage of microstrip antennas and the designed conventional rectangular patch antenna is of no exception.

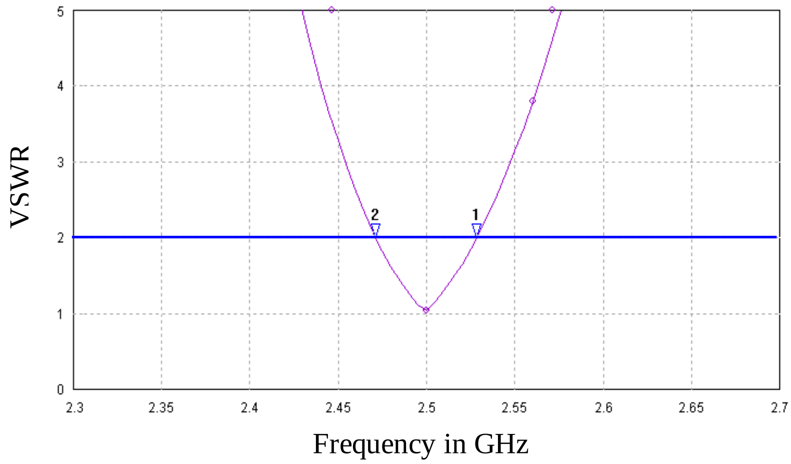


Fig.4.4 The standing wave ratio of the antenna

4.2.5 Radiation pattern of the conventional antenna

The radiation pattern at the resonant frequency for the conventional rectangular patch antenna in both E-plane and H-plane are presented in fig. 4.5 and fig. 4.6 respectively. These planes are perpendicular to the patch antenna. As can be seen from fig. 4.5 the pattern is symmetrical and the level of the cross-polar component is at -90 dB which is very low meaning good polarization purity. The beam-width is large and it is equal to 158°. Also in the H-plane, as shown in fig.4.6, the pattern is almost symmetrical and the cross-polarization component is at about -30 dB which is considered to be low. The co-polar component beam-width in the H-plane is about 82.1°. The three dimensional pattern is shown in fig. 4.7.

CHAPTER FOUR

Results and Discussion

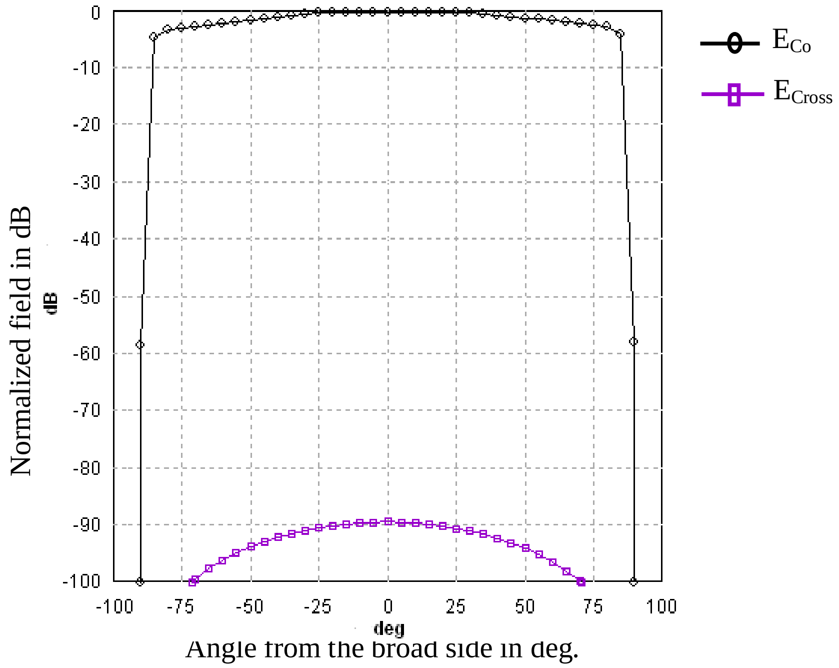


Fig.4.5 E-plane radiation pattern of the antenna

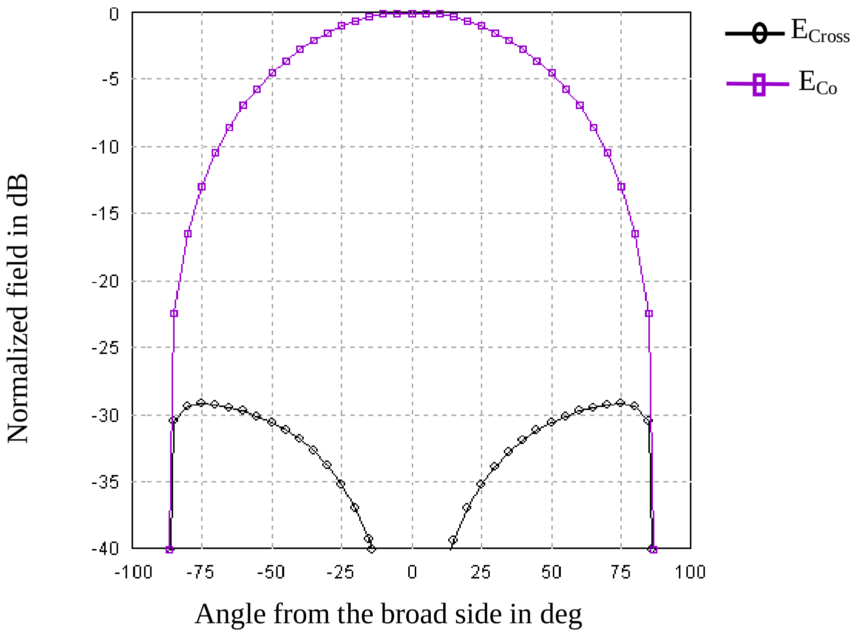


Fig.4.6 H-plane radiation pattern of the antenna

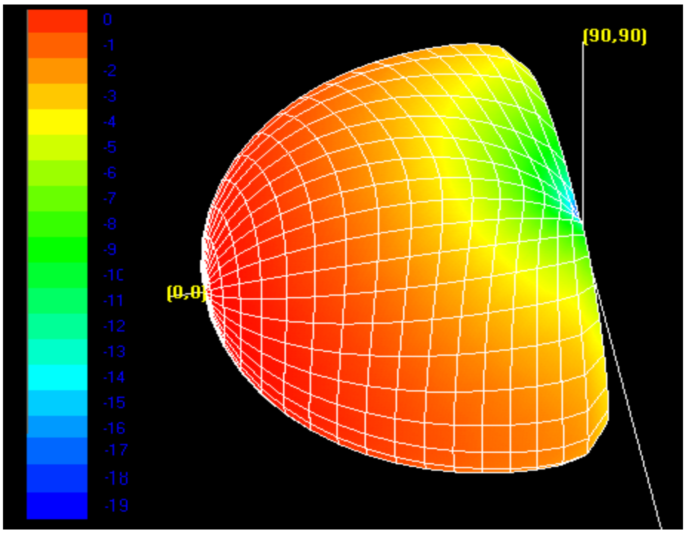


Fig.4.7 The 3D total field pattern for the antenna in dB

4.3 Introducing the defect on the patch (DMS)

Now, we introduce a defect at the center of the radiating patch and observe its effect on the frequency, the bandwidth and the radiation pattern. The form of the chosen defect is original has never been utilized in the literature and it is inspired from the letter H. As seen in fig. 4.8, the proposed shape has opening slots along both longitudinal directions. The numerical values of the dimensions of the proposed defect are given in table 4.2.

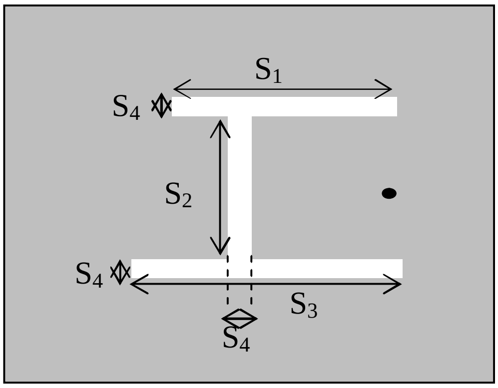


Fig.4.8 The proposed defect shape

S_1	S_2	S_3	S_4
13 mm	13 mm	16 mm	2 mm

Table.4.2 The defect dimensions

4.3.1 Return loss of the antenna with DMS

As illustrated in fig. 4.9, after introducing the defect on the patch surface, the resonant frequency shifts down from 2.5 GHz to 1.8 GHz. This is mainly attributed to the inserted defect which lengthens the current path making the patch radiator to appear larger hence radiating at a lower frequency than before.

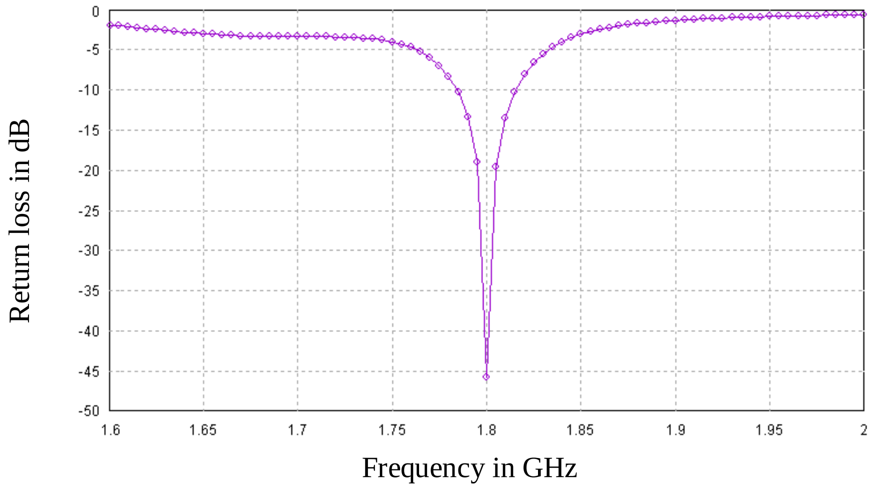


Fig.4.9 The return loss of the antenna with DMS

4.3.2 Current distribution of the antenna with DMS

The vector current distribution of the defected patch is shown in fig. 4.10. From this figure, it is clear that the current changes its direction when it encounters the defect. Therefore the current takes a longer trajectory and makes the patch radiate at a lower frequency as seen before. Furthermore, the existence of the opening slots in both longitudinal directions has led to longer path than using simple slot.

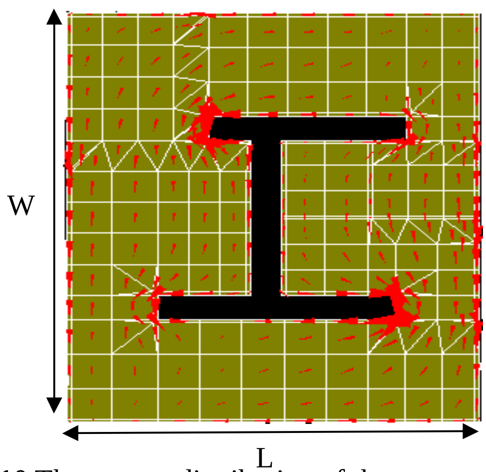


Fig.4.10 The current distribution of the antenna with DMS

4.3.3 Input VSWR of the antenna with DMS

The standing wave ratio of the defected patch antenna is illustrated in fig. 4.11, the bandwidth is calculated for VSWR = 2 and it is found to be equal to 1.89%. This means that after introducing the defect the bandwidth is reduced by 0.47%. So the DMS reduces further the bandwidth which is already small. This effect may be attributed to the fact that when part of the metal is removed, the resistive losses are decreased hence leading to a higher Q factor. Moreover, the DMS can be modeled as an inductor which in its turn increases the Q factor too.

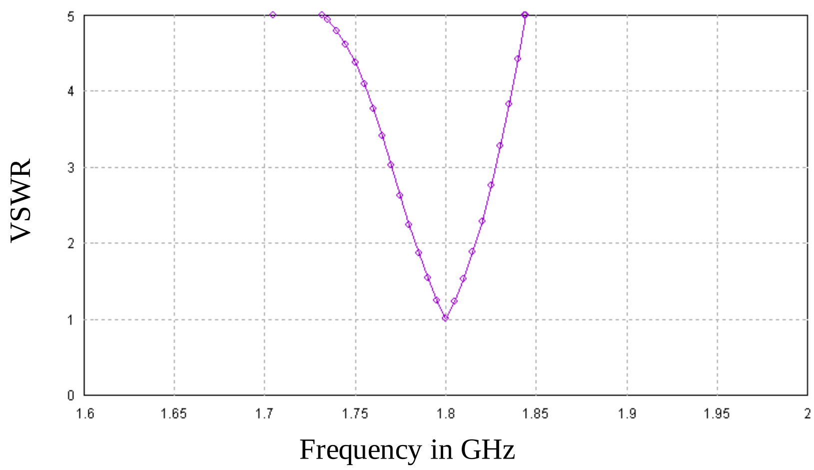


Fig.4.11 The standing wave ratio

4.3.4 Radiation pattern of the antenna with DMS

The far field radiation pattern for the defected patch antenna in both E- and H- planes at the resonant frequency is shown in fig. 4.12 and fig. 4.13. From these graphs, a change in polarization is observed. This change is due to the fact the current component along y-axis (previously ignored) becomes more significant than that along x-axis. The slots along x-axis are responsible for the creation of the component along y-axis. Moreover, the level of the field component due to x-current has decreased to about -10 dB. In fact, the existence of this kind of the defect result in radiated wave which is linearly polarized along an oblique direction. The directivity is about 6.19 dBi. Fig. 4.14 shows the three dimensional radiation pattern of this antenna.

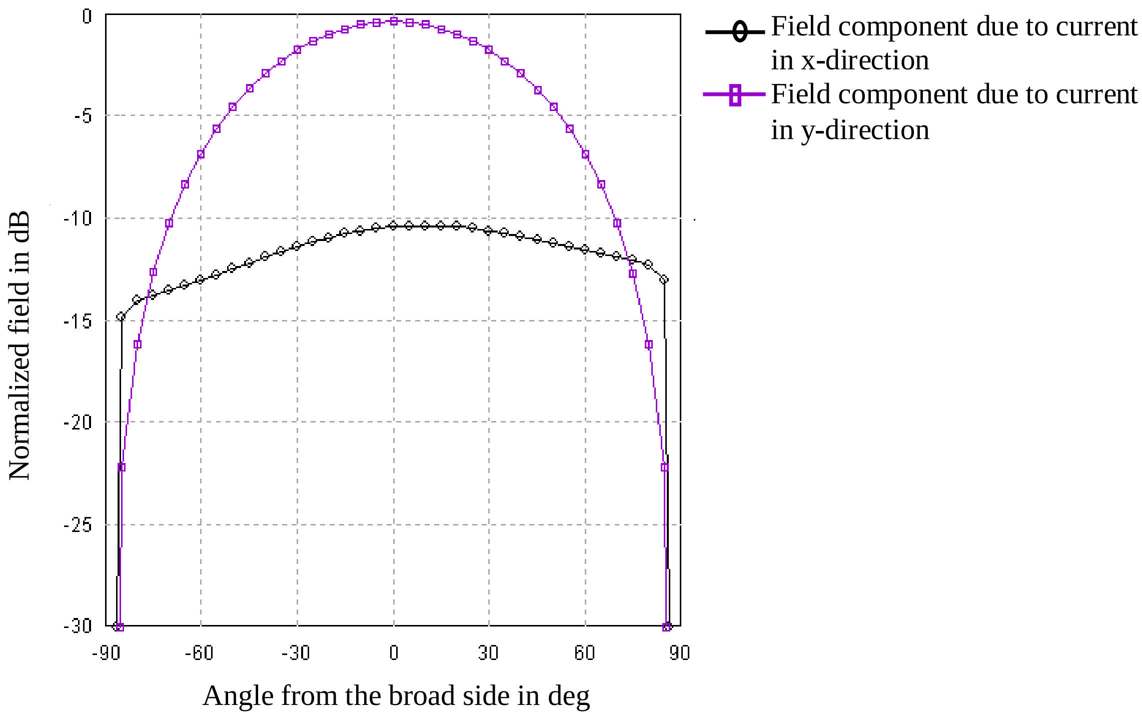


Fig.4.12 The E-plane radiation pattern of the antenna with DMS

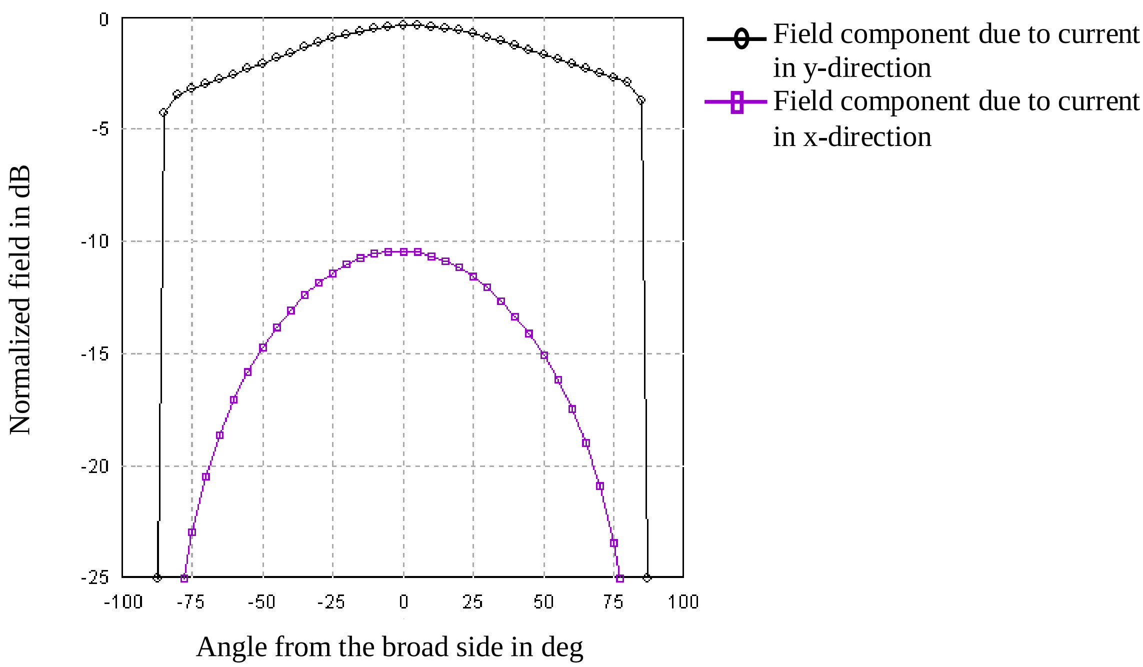


Fig.4.13 The H-plane radiation pattern of the antenna with DMS

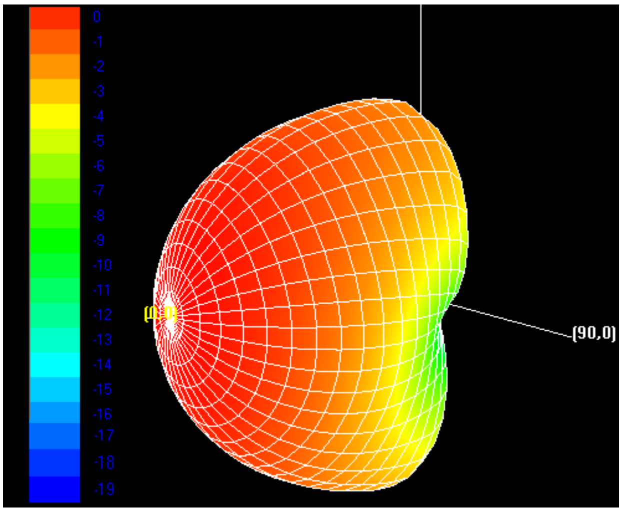


Fig.4.14 The 3D total field pattern for the defected patch antenna in dB

4.4 Introducing the defect on the ground plane (DGS)

The same defect that is applied on the radiating patch is introduced on the ground plane of the patch antenna. The observed effects are presented in the following sections.

4.4.1 Return loss of the antenna with DGS

The return loss of the defected ground patch antenna is given in fig. 4.15. As might be noticed there is a frequency shift down to about 1.8 GHz. This is also attributed to the effect of the defect introduced on the ground plane which disturbs the shield current return path.

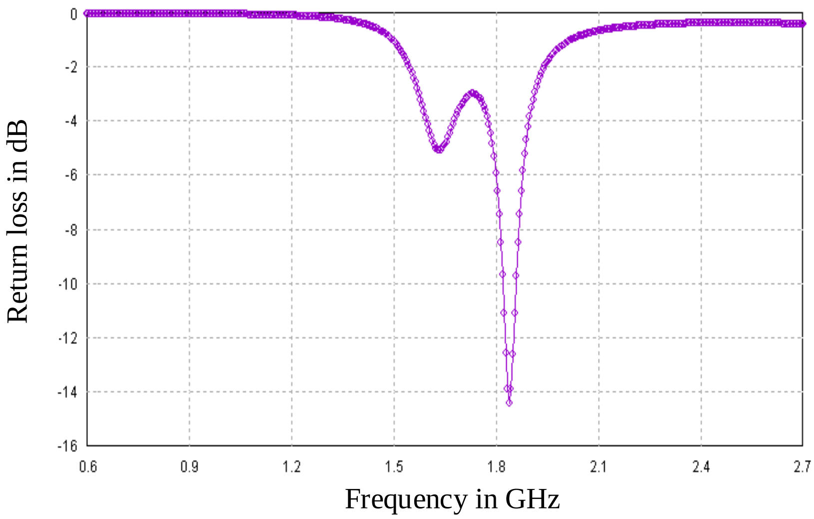


Fig.4.15 The return loss of the antenna with DGS

4.4.2 Current distribution of the antenna with DGS

The vector current distribution of the defected ground patch is shown in the following figures. Fig. 4.16 shows the current distribution on the back side of the antenna, meaning on the ground plane that is defected whereas fig. 4.17 shows this current on the radiating patch. For both sides, the current path is disturbed. The current goes around the defect following a longer path. Also it is apparent that the current component along y-direction should not be ignored.

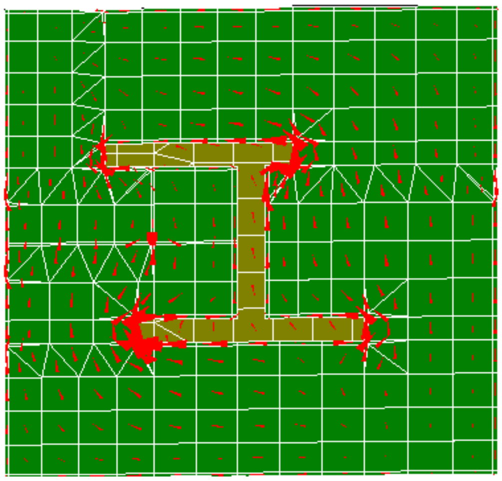


Fig.4.16 Current distribution on the ground plane

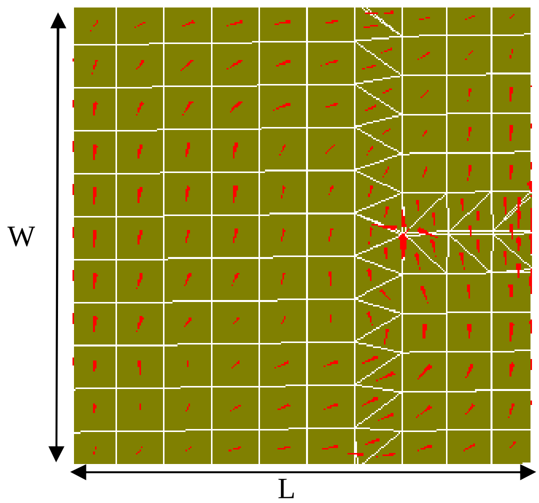


Fig .4.17 Current distribution on the patch

4.4.3 Input VSWR of the antenna with DGS

The standing wave ratio of the ground plane defected patch antenna is given in fig. 4.18. The calculated bandwidth for VSWR = 2 is 2.23% which is close to the original one.

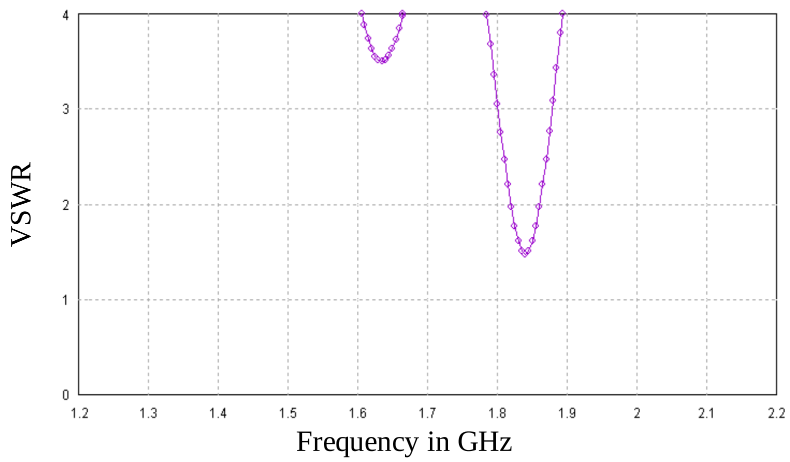


Fig.4.18 The input VSWR of the antenna with DGS

4.4.4 Radiation pattern of the antenna with DGS

The far field radiation pattern of the defected ground patch in E-plane and H-plane are given in fig.4.19 and fig.4.20 respectively. For this case there is a noticeable change in the radiation pattern. As can be depicted from the figures there is the appearance of the back lobes with considerable level of approximately -4 dB. This may be attributed to slot on the ground plane acting as an aperture antenna. Hence part of the signal leaks through this defect on ground as a back radiation. As in the case of DMS, the polarization of the radiated wave from this structure is linearly oblique. The directivity is found to be equal to 4.58 dBi. The three-dimensional radiation pattern is shown in fig. 4.21

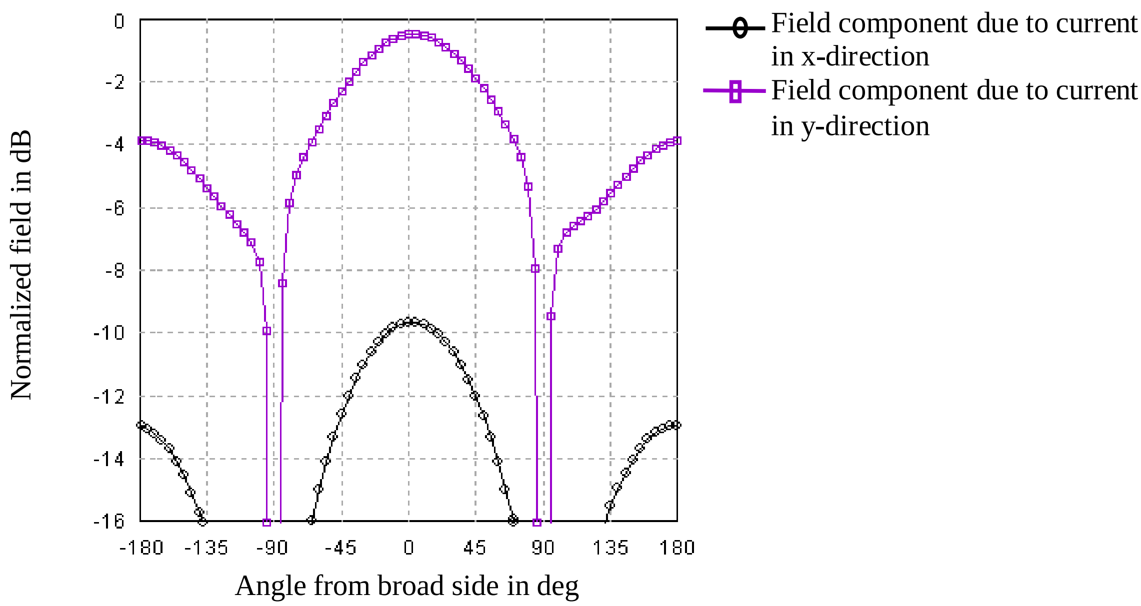


Fig.4.19 The E-plane radiation pattern of the antenna with DGS

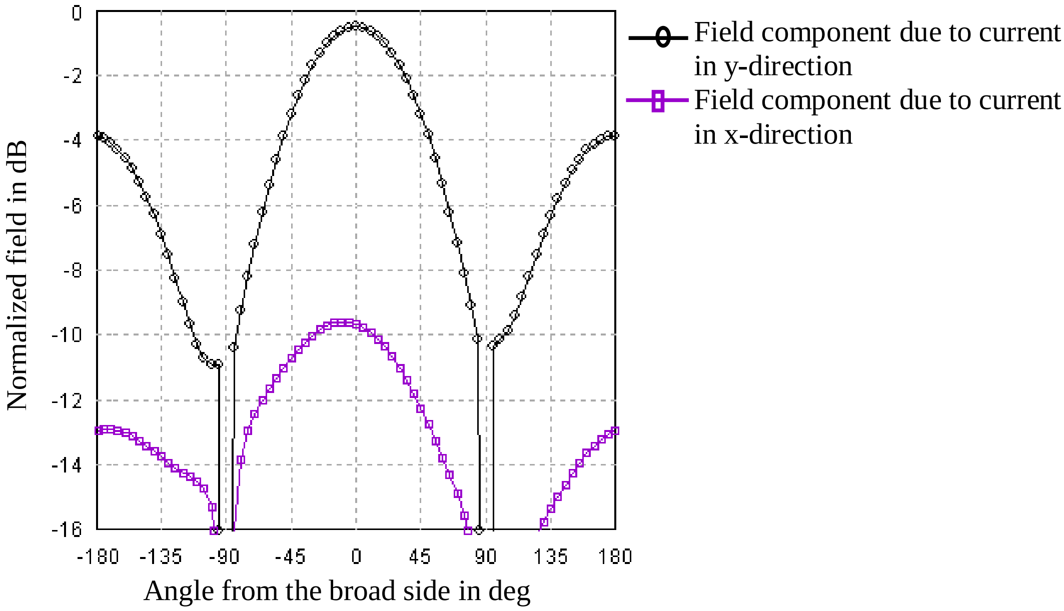


Fig.4.20 The H-plane radiation pattern of the antenna with DGS

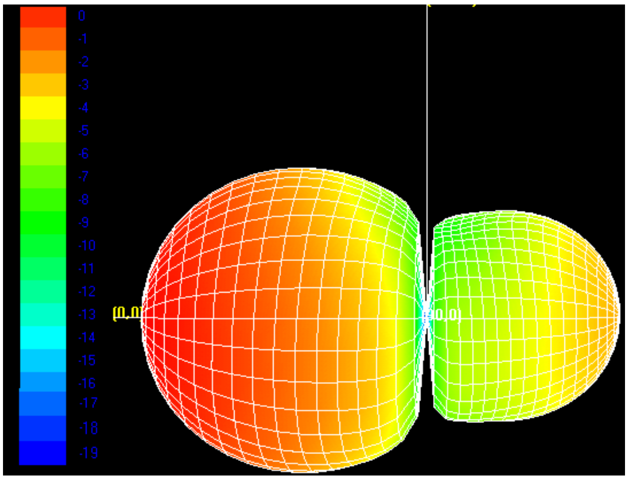


Fig.4.21 The 3D total field pattern for the antenna with DGS in dB

Remark: It is seen that for both the DMS and DGS techniques the resonant frequency of the patch antenna shifts down to around 1.8 GHz. This implies that it is possible to reduce the size of the patch antenna with both techniques to reproduce the original frequency (2.5GHz).

4.5 Retuning back to the original frequency using DMS

At this stage of the work, to make the defected patch antenna radiate at the original frequency of 2.5 GHz, the dimensions of the patch must be reduced. This means that compensating for the current path already lengthened. The obtained reduced length is 18.22 mm and the reduced width is 23.16 mm. This reduction in patch dimensions leads to about 55.4% in patch area reduction. We notice that this length is close to the length predicted by equation 2.17.

4.5.1 Return loss of the reduced antenna with DMS

The return loss of the reduced size defected patch antenna is given in fig. 4.22. The resonant frequency is again 2.5 GHz. The level of the return loss is higher, about -14 dB but still acceptable.

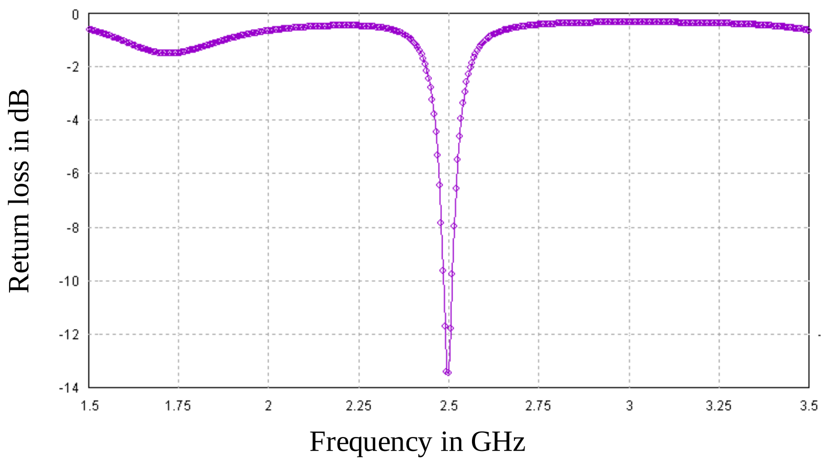


Fig.4.22 The return loss of the reduced antenna with DMS

4.5.2 Current distribution of the reduced antenna with DMS

The current distribution of the reduced size defected patch antenna is given in fig.4.23. As might be seen from this figure there is no change in the current distribution after reducing the patch dimensions.

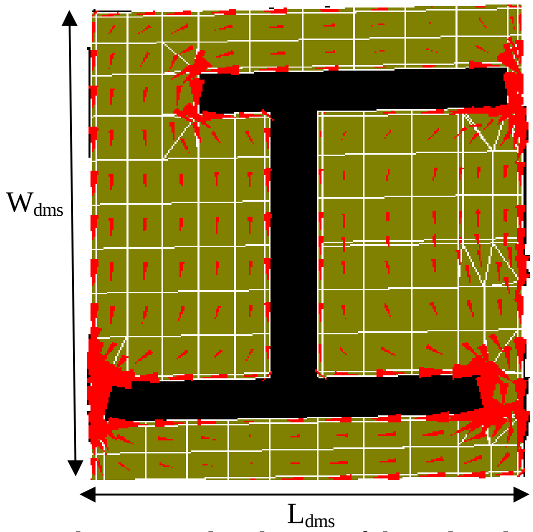


Fig.4.23 The current distribution of the reduced antenna with DMS

4.5.3 Input VSWR of the reduced antenna with DMS

The standing wave ratio of the reduced size defected patch is given in fig.4.24. The bandwidth found at VSWR = 2 is 0.96% which is very small. It means that the bandwidth of the antenna, after being defected and reduced in size, has decreased by 1.4%.

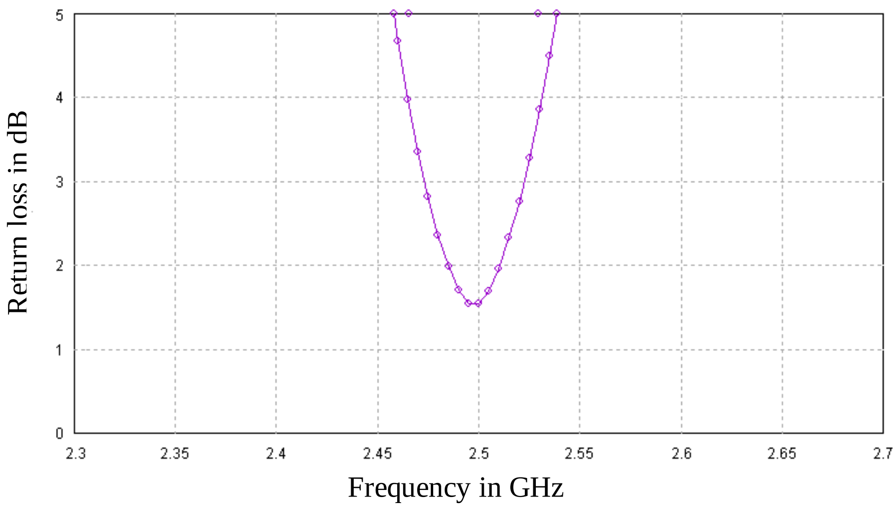


Fig.4.24 The standing wave ratio of the reduced antenna with DMS

4.5.4 Radiation pattern of the reduced antenna with DMS

The far field radiation pattern for both E-plane and H-plane are shown in fig. 4.25 and fig. 4.26, the three-dimensional version of the radiation pattern is shown in fig. 4.27. As the case of antenna with DMS studied previously, the polarization is linearly oblique. The difference that may be seen is that the level of the x-component is reduced to -15 dB. This is due to the important reduction of the length as with the slots along x dimensions are kept unchanged. The directivity is about 6.22 dBi.

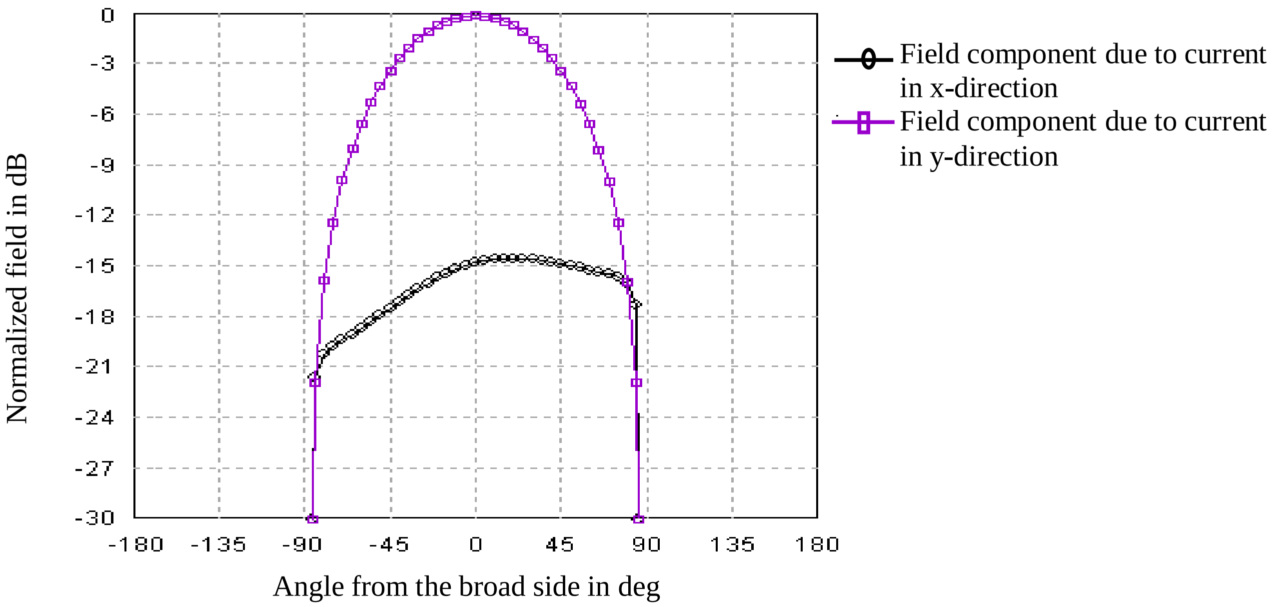


Fig.4.25 The E-plane radiation pattern of the reduced antenna with DMS

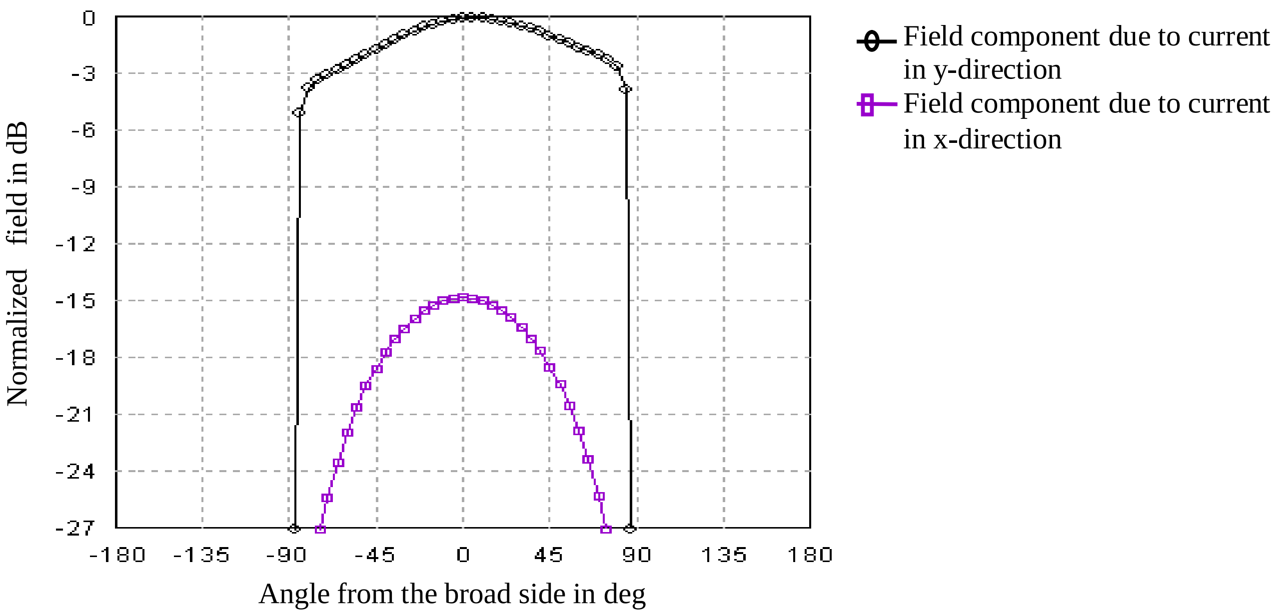


Fig.4.26 The H-plane radiation pattern of the reduced antenna with DMS

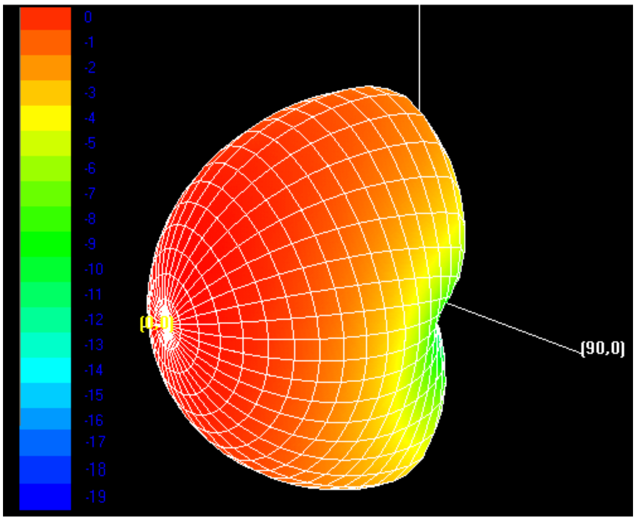


Fig.4.27 The 3D total field pattern for the reduced antenna with DMS in dB

4.6 Returning back to the original frequency using DGS

Now keeping the defect on the ground plane, the patch dimensions are reduced to achieve radiation at the original frequency of the conventional antenna. The new dimensions of the ground defected patch are: the length is 13.52 mm and the width is 23.16 mm. This means that a size reduction in the patch surface of about 67% may be achieved.

4.6.1 Return loss of the reduced antenna with DGS

The return loss for this reduced patch that is given in fig. 4.28 shows that the patch radiates at 2.5 GHz. the return loss level is about -16 dB.

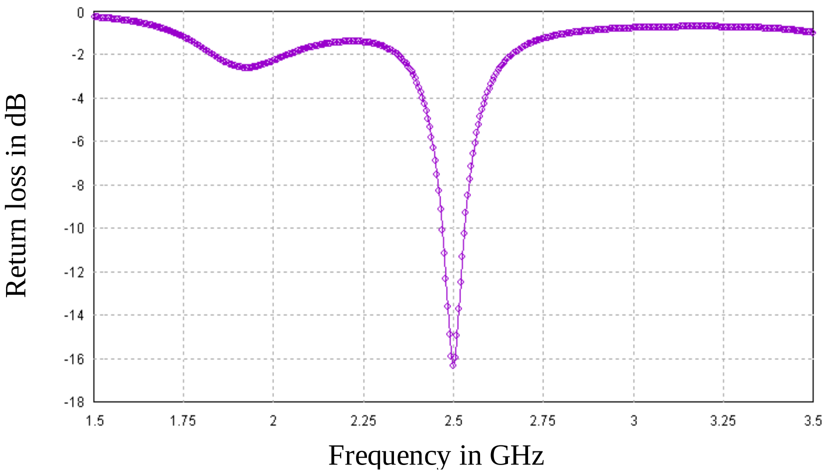


Fig.4.28 The return loss of the reduced antenna with DGS

4.6.2 Current distribution of the reduced antenna with DGS

The current distribution for both the patch and the ground plane of the microstrip antenna after size reduction is shown in fig. 4.29 and fig. 4.30 respectively. There is no major change for the current path after size reduction.

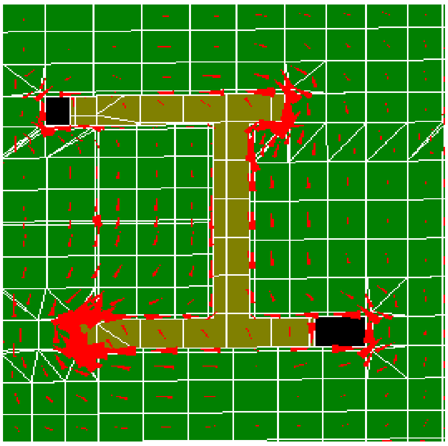


Fig.4.29 Current distribution on the ground plane

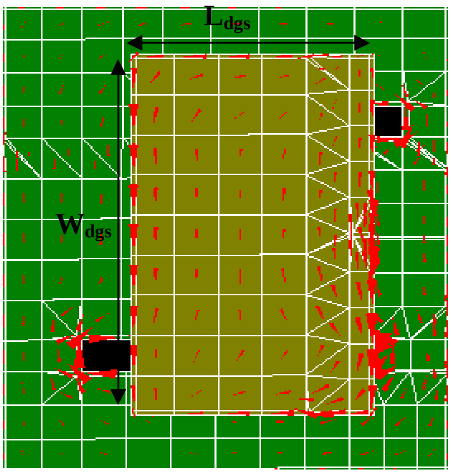


Fig.4.30 Current distribution on the patch

4.6.3 Input VSWR of the reduced antenna with DGS

The standing wave ratio of the defected ground patch after size reduction is shown in fig. 4.31 the bandwidth calculated for VSWR = 2 is about 2.6%. This means that there is a bandwidth enhancement of 0.24%.

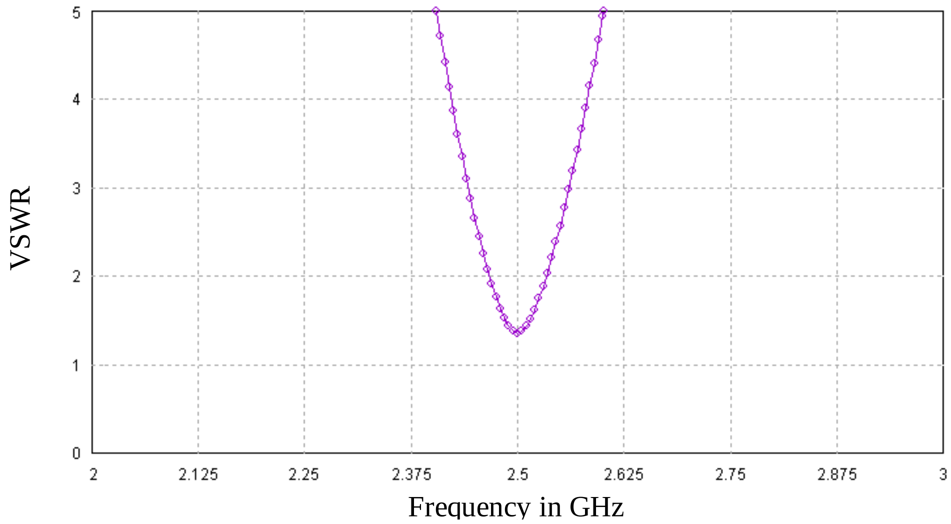


Fig.4.31 The standing wave ratio of the reduced antenna with DGS

4.6.4 Radiation pattern of the reduced antenna with DGS

The far field pattern at the resonant frequency in both E-plane and H-plane are shown in fig. 4.32 and fig. 4.33. As for the defected ground patch antenna there is the appearance of the back lobes caused mainly by the slot on the ground plane. Similar to the previous case (Antenna with DGS) the polarization is linearly oblique and the directivity is found to be about 4.34 dBi. A three-dimensional radiation pattern is shown in fig. 4.34.

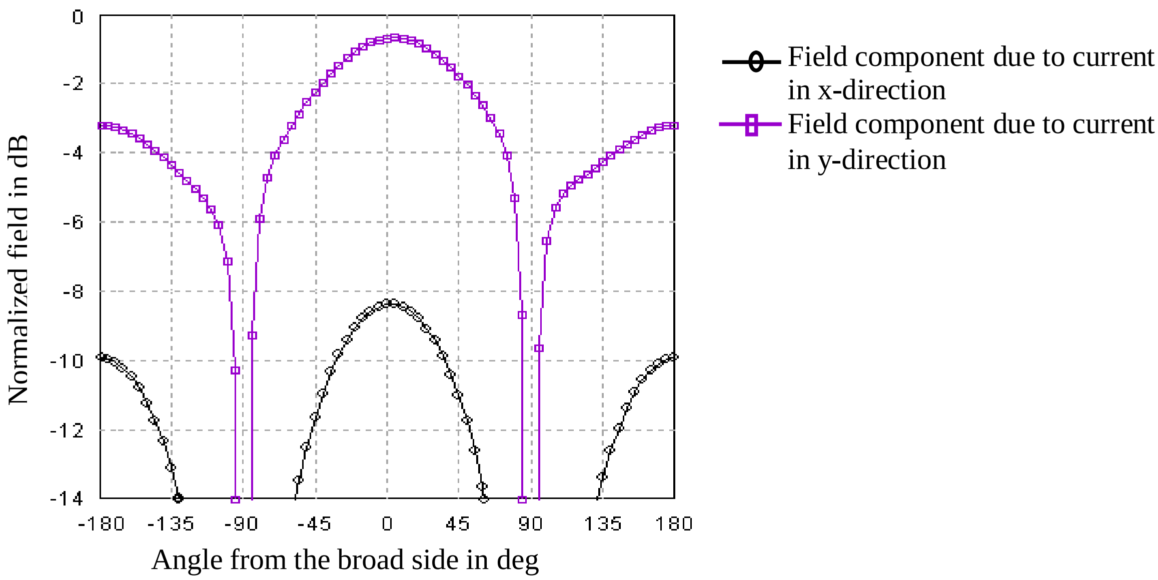


Fig.4.32 E-plane radiation pattern of the reduced antenna with DGS

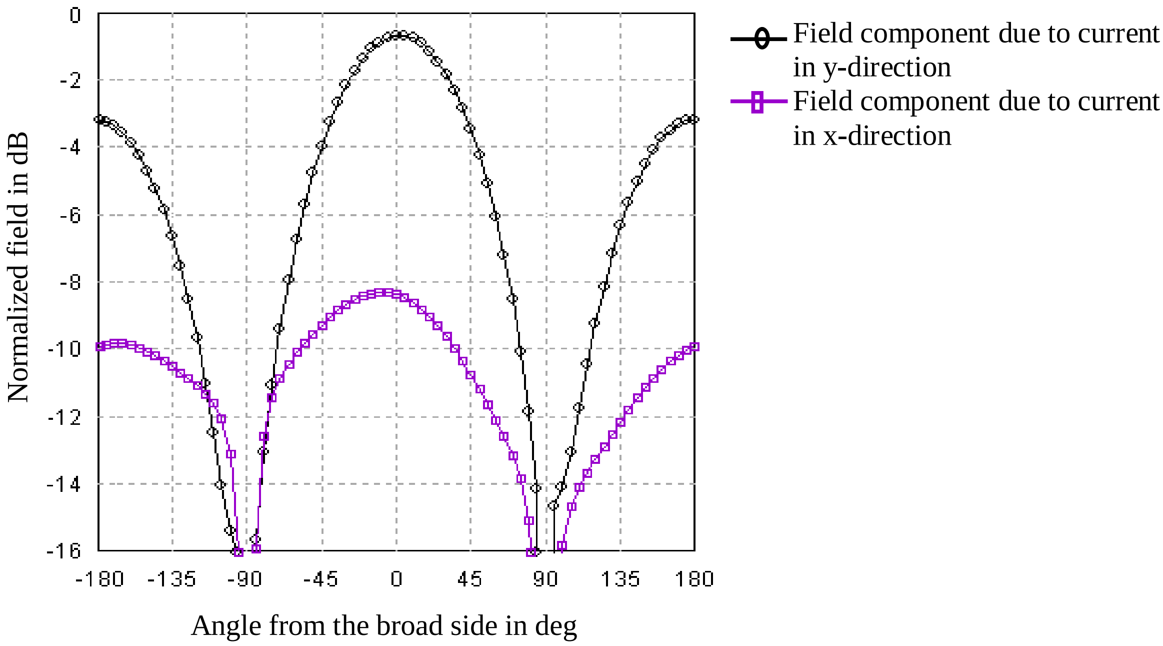


Fig.4.33 H-plane radiation pattern of the reduced antenna with DGS

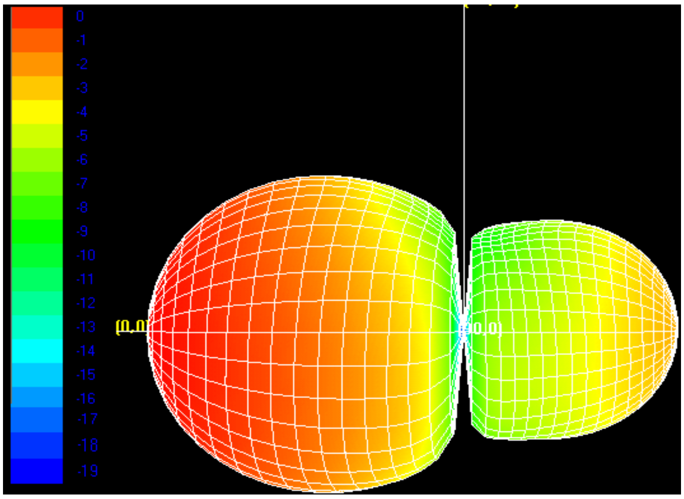


Fig.4.34 The 3D total field pattern of the reduced antenna with DGS in dB

4.7 Comparison between reduced antennas with DMS and DGS

In this section, an attempt is done to compare the performance of the antenna which reduced in their size using the DMS and the DGS techniques. The comparison will be done on both the near zone and the far zone characteristics.

1. The size reduction achieved by DGS (67%) is greater than the one achieved by DMS (55.4%).

2. The bandwidth of the antenna with DGS is greater than the one of the antenna with DMS.
3. The radiation pattern of the antenna with DGS presents back lobes whereas the antenna with DMS does not have.
4. Both antennas with the proposed shape of the defect have linearly oblique polarization. In case of the antenna with DMS, the x-component may be ignored leading to linear polarization along y-direction.
5. The reduced antenna with DGS is less directive than the reduced antenna with DMS.

4.8 Conclusion

The goals of this project are to design an antenna that can operate at 2.5 GHz frequency and reduce its size using both defected microstrip and defected ground techniques.

A rectangular patch antenna on a dielectric material whose permittivity constant 4.4, is designed and analyzed. This antenna has linear polarization along x-axis. It has been found that the resonant frequency shift down after introducing a defect either on the patch or on the ground plane. Furthermore, the radiated field polarization has switched from x-direction to oblique direction because of the chosen shape of the defect.

To compensate for the frequency diminution, the antenna sizes are reduced. The obtained antennas with both DMS and DGS are radiating almost linearly oblique waves with domination of the y-component.

It has also been remarked that the performance of the reduced size antenna with DGS is better than that of the reduced size antenna with DMS.

As further work, it is suggested to perform the following tasks:

- Implementation the proposed structures to verify their performances;
- Parametric study on the proposed defect to optimize the antenna characteristics;
- Introducing structure modification to enhance the performance;
- Modeling of the proposed defect to obtain mathematical relationships to help in future design.

REFERENCES

[1] DESCHAMPS G.G, "Microstrip microwave antennas", Third U.S.A.F. Symposium on antennas, USA, 1953.

[2] ELSADEK H., "Microstrip antennas for mobile wireless communication systems", Electronic Research Institute, Microstrip Department Cairo, Egypt.

[3] POZAR D.M., "Microstrip Antennas", Proceedings of the IEEE, VOL. 80, NO. 1, Jan. 1992.

[4] POZAR D.M.; SCHAUBERT D.H., "Microstrip antennas the analysis and design of microstrip antennas and arrays", IEEE Antenna and Propagation Society, John Wiley, 1995.

[5] FARUQUE M.R.I., MISRAN N., MOHAMMAD T.I., YATIM B., BIAS B., "New low specific absorption rate (SAR) antenna design for handsets", International Journal of the Physical Sciences Vol. 6(24), pp. 5706-5715,October, 2011.

[6] JAMES. J. R., "What is new in antennas?", IEEE Antennas Propagat. Mag., pp. 6-18, Feb. 1990.

[7] Huang J., "Microstrip antenna for commercial applications", Jet Propulsion Laboratory, California Institute of Technology, Pasadena**.**

[8] GOSWAMI K., DUBEY A., TRIPATHI G. C., SINGH B., "Design and analysis of rectangular microstrip antenna with PBG structure for enhancement of bandwidth", Global Journal of Research Engineering, Vol 11, Issue 2, Version 2, March 2011.

[9] BALANIS C. A., "Antenna Theory- Analysis and Design", 3rd edition., New Jersey. John Wiley, 2005.

[10] STUZMAN W., THEILE G., "Antenna Theory and Design", 2nd edition, John Wiley& Sons, USA, 1998.

[11] AKSAS R., " Analyse d'antennes microrubans de forme quelconque par une approche basée sur la technique des lignes de transmission. Application aux géométries circulaires.", Thèse de doctorat d'état, Ecole Nationale Polytechnique, Alger, Juin 1995.

[12] RANA I.E, ALEXOPOULOS N. G, "Current distribution and input impedance of printed dipoles", IEEE Trans. Antenna propagat., vol. AP-29,No.1, pp. 99-105,1981.

[13] BAHL I.J., BAHARTIA P., "Microstrip antennas", Artech House, Delham, Mass, USA, 1980.

[14] LONG S., SHEN L. C. and MOREL P.B., "Theory of circular-disk printed-circuit antenna", Proc. IEEE, UK(1978), 125, pp. 925-929.

[15] BAILEY M. C., DESHPANDE M. D., "Analysis of elliptical and circular microstrip antennas using moment method", IEEE Trans. Antennas propagate., vol. AP-33, no. 9, pp.99-105, Sept. 1985.

REFERENCES

[16] LUK K. M., LEE K. F. and DAHELE J. S., “Theory and experiment on equilateral triangular microstrip antenna”, Proc 16th European microwave conference, 1986.

[17] BHATTAACHARYYA A. K., GARC R., “Input impedance of annular ring microstrip antenna using circuit theory approach”, IEEE Trans. Antenna Propagat., vol. AP-33, no. 4, pp.369-374, Apr. 1985.

[18] DUBOST G., GUEHOS S., “Réseaux d’antenne a large bande du type doublet replié plaque”, L’onde electrique, vol. 69, no. 3, pp. 32-38, Mai-Juin 1989.

[19] HANEISHI M., et al.,”Broadband microstrip array composed of single feed type circularly polarized microstrip element”, IEEE AP-S Int. Symp. Dig., pp. 160-163, May 1982.

[20] BHATTACHARYYA A. K., SHAFAI L., “ A wider band microstrip antenna for circular polarization”, IEEE Trans. Antennas Propagat., vol. AP-36, no. 2, pp. 157-163, Feb. 1988.

[21] PUES H. F., A. R. Van de Capelle, “An impedance matching technique for increasing the bandwidth of microstrip antennas”, IEEE Trans. Antennas and Propagation. Vol. AP-37, pp. 1345-1354, Nov. 1989.

[22] HAO H., PARINI C. G., “A novel embedded UC-PBG structure for microstrip antennas”, Department of Electronic Engineering, London, UK.

[23] SADEGHZADEH R. A., KHAJEHMOHAMMADLOU R., JALALI M., “A novel high directive EBG structure and metamaterial superstrate for microstrip antenna”, International Journal of Engineering Science & Emerging Technologies, vol 4, Issue 2, pp. 1-12, Feb. 2013.

[24] TYAGI S., VYAS K., “Bandwidth enhancement using slotted U- shape microstrip antenna with PBG ground”, International Journal of Advanced Technology & Engineering Research, vol 3, Issue 1, Jan. 2013.

[25] CHENG H. R., SONG Q. Y., GUO Y. C., CHEN X. Q., SHI X. W., “Design of a novel EBG structure and its application in fractal microstrip antenna”, Progress In Electromagnetics Research C, vol. 11, pp. 81-90, 2009.

[26] GU J.J., WANG Y., “Dual-band microstrip antenna array with EBG structures”, PIERS Proceedings, China, Sept. 2011.

[27] HUANG C. P., “Analysis and design of printed antennas for wireless communications using the finite difference time domain technique”, Ph.D Dissertation, Electrical Engineering Department, University of Mississippi, December 1999.

[28] Sathya.K., M.Tech., K.J.Vinoy., “Size reduction of low frequency microstrip patch antennas with KOCH fractal slots”.

[29] LO, T.K. and Y. Hwang, “Microstrip antennas of very high permittivity for personal communications”, 1997 Asia Pacific Microwave Conference, 253-256, 1997.

[30] WONG K. L., “Compact and broadband microstrip antennas”, John Wiley&Sons,2002.

REFERENCES

[31] SINATI R. A., "CAD of Microstrip Antennas for Wireless Applications", Artech House, Noorwood, MA, 1996.

[32] WANG H. Y., LANCASTER M. J., "Aperture-coupled thin film superconducting meander antennas", IEEE Transaction on Antennas and Propgation, Vol. 47, 829-836, 1999.

[33] WATERHOUSE, R., "Printed Antennas for Wireless Communications", John Wiley&Sons Inc, 2007.

[34] Dey S., Mittra R., "Compact microstrip patch antenna," *Microwave Opt. Technol. Lett.* 13, 12–14, Sept. 1996.

[35] VANDENBOSH G. A.E., VASYLCHENKO A. SCHOLS Y., DE RAEDT W, "Quality assessment of computational techniques and software tools for planar antenna analysis",IEEE Antennas Propagat., Vol, 51, No. 1, pp. 23-38, Feb. 2009.

[36] HOLLAND S.S., SHAUBERT D., " Miniaturization of microstrip patch antennas for GPS applications", Master Thesis, university of Massachusetts Amherst, USA, May 2008.

[37] WONG K. L., YANG K. P., "Compact dual-frequency microstrip antenna with a pair of bent slots," *Electron. Lett.* **34**, 225–226, Feb. 5, 1998.

[38] ChEN W. S., "Single-feed dual-frequency rectangular microstrip antenna with square slot,"*Electron. Lett.* **34**, 231–232, Feb. 5, 1998.

[39] IWASAKI H., "A circularly polarized small-size microstrip antenna with a cross slot," *IEEE Trans. Antennas Propagat.* 44, 1399–1401, Oct. 1996.

[40] YANG K. P., WONG K. L., "Inclined-slot-coupled compact dual-frequency microstrip antenna with cross-slot," *Electron. Lett.* 34, 321–322, Feb. 19, 1998.

[41] LU J. H., WONG K. L., "Compact dual-frequency circular microstrip antenna with an offset circular slot," *Microwave Opt. Technol. Lett.* 22, 254–256, Aug. 20, 1999.

[42] TIRADO-MENDEZ J. A., JARDON-AGUILAR H., ITURBIDE-SANCHEZ F., "application of defected microstrip structure as a tuning technique for rectangular printed antennas", MICROWAVE AND OPTICAL TECHNOLOGY LETT, Vol. 48, No. 2, February 2006.

[43] TIRADO-MENDEZ A., JARDON-AGUILAR H., FLORES-LEAL R. "Improving frequency response of microstrip filters using defected ground and defected microstrip structures", Progress In Electromagnetics Research C, Vol. 13, pp.77-90, 2010.

[44] GUPTA V. R., GUPTA N., "Two Compact Microstrip Patch Antennas for 2.4 GHz Band, A Comparison", Microwave Review, Nov. 2006.

[45] ZHANG X, YANG F., "Study of a slit cut on a microstrip antenna and its applications," Microwave and Optical Technology Letters, vol.18, no.4, pp.297-300, 1998.

REFERENCES

[46] TIRADO-MENDEZ J. A., PEVROT-SOLIS M.A., JARODO AGUILA H., ANDRAD-GONZALEZ E. A.; REYES-AYALA M., "Applications of Novel Defected Microstrip Structures (DMS) in Planar Passive Circuits", Proceedings of the 10th WSEAS International Conference on CIRCUITS, pp366-369,Vouliagmeni, Athens, Greece, July 2006.

[47] TIRADO-MENDEZ J. A., JARDON-AGUILAR H., ITURBIDE-SANCHEZ F., GARCIA-RUIZ I., MOLINA-LOPEZ V., ACEVO-HERRERAL R., "A proposed defected microstrip structure (DMS) behavior for reducing rectangular patch antenna size", MICROWAVE AND OPTICAL TECHNOLOGY LETT. Vol. 43, No. 6, Dec. 2004.

[48] KUSHWAH V.S., TOMAR G.S., "Size reduction of microstrip patch antenna using defected microstrip structure", International Conference on Communication Systems and Network Technologies, IEEE, 2011.

[49] AZRAR A., NAIT BELAID M., **MAKEDHI B.,** "Planar antenna size reduction based on defected microstrip structure", final year project, Jul 2013.

[50] KUMAR P., KISHOR J., SHRIVASTAV A.K., "Formulation of size reduction technique in microstrip circuits using DGS and DMS", IEEE Proceedings of International Conference on Microwave, 2008.

[51] WENG L. H., GU Y. C., SHI X. W., CHEN X. Q., "An overview on defected ground structure", Progress in Electromagnetic Research B, Vol. 7, pp 173–189, 2008.

[52] JOHN S., "Strong localization of photons in certain disordered dielectric superlattices," Physical Review Letters, Vol. 58, No. 23,2486–2489, 1987.

[53] YABLONOVITCH E., "Inhibited spontaneous emission in solid-state physics and electronics," Physical Review Letters, Vol. 58, No. 20,2059–2062, 1987.

[54] PARK J.I., Kim C.S., et al., "Modeling of a photonic bandgap and its application for the low-pass filter design," Asia Pacific Microwave Conf. Proc. APMC, Vol. 2, 331–334, 1999.

[55] ASHWINI K.A., KARTIKEYAN M.V., PATNAIK A., "Defected ground structure in the perspective of microstrip antennas, a review", Frequenz, 2010.

[56] AHN,D., PARK, J.S., KIM, C.S., KIM, J., QIAN,Y., ITOH, T., "A design of the low-pass filter using the novel microstrip defected ground structure," IEEE Trans. Microwave Theory and Techniques., Vol. 49, No. 1, 86– 91, Jan. 2001.

[57] SHARMA R., CHAKRVARTY T., BHOOSHAN S., "Design of a novel 3 db microstrip backward wave coupler using defected ground structure," Progress In Electromagnetics Research, PIER 65, 261–273, 2006.

[58] OSKOUEI D.H., ATLABAF Z., "Amodified dual-mode band pass filter with DGS structures," 13th Conference on Microwave Techniques, Prague, 2005.

[59] KIM C.S., LIM J.S., NAM S., KANG K.Y., AHN D., “Equivalent circuit modeling of spiral defected ground structure for microstrip line,” Electron. Lett., Vol. 38, No.19, 1109 – 1120, 2002.

[60] GUHA D., BISWAS S., BISWASM., SIDDIQUI J.Y., ANTAR Y.M. M., “Concentric Ring-Shaped Defected Ground Structures for Microstrip Applications”, IEEE Antennas and Wireless Propagation Letters, vol. 5, 2006

[61] HAMAD E. K. I., SAFWAT A. M. E., OMAR A. S., “Controlled capacitance and inductance behaviour of L-shaped defected ground structure for coplanar waveguide,” IEEE Proc. Microwave Antennas Propag., Vol. 152, No. 5, 299– 304, Oct.2005.

[62] WOO U., LEE T.K., PYO C.S., CHOI W.K., “High-q band rejection filter by using U-slot DGS”, Microwave Conference, 2005 European, Vol.2, Oct. 2005.

[63] WOO D.J., LEE T.K., LEE J.W., PYO C.S., CHOI W.Q., “Novel U-Slot and V-Slot DGSs for Bandstop FilterWith Improved Q Factor”, IEEE Transactions on Microwave Theory and Techniques, vol. 54, no. 6, June 2006

[64] ZULKIFLI F.Y., RAHARDJO E. T., HARTANTO D., “Radiation properties enhancement of triangular patch microstrip antenna array using hexagonal defected ground structure”, Progress in Electromagnetics Research, vol. 5, 101 –109, 2008

[65] CHENH.J., TSUNG H., CHANG C. S., CHEN L. S., WAN N.F., WANG Y.H., HOUNG M.P., “A novel cross-shape DGS applied to design ultra-wide stopband low-pass filters”, IEEE Microwave and Wireless Components Letters, vol. 16, no. 5, may 2006.

[66] CHEN J., WENG Z. B., JION Y. C., ZHANG F. S., “Lowpass filter design of hilbert curve ring defected ground structure,” Progress In Electromagnetics Research, PIER 70, 269 – 280, 2007.

[67] CHANG I., LEE B., “Design of Defected Ground Structures for Harmonic Control of Active Microstrip Antennas,” *IEEE* AP-S International Symposium,Vol. 2, 852-855, 2002.

[68] NASHAT D., ELSADEK H.A., ABDALLAH E., ELHENAWY H., ISKANDER M., “Miniaturized and Multiband Operations of Inset Feed Microstrip Patch Antenna by Using Novel Shape of Defect Ground Structure (DGS) in Wireless Applications”, Progress In Electromagnetics Research Symposium Proceedings, Moscow, Russia, Aug. 2009.

[69] SUN J., YANG X., SHENG J., “Circularly polarized microstrip antenna with harmonics suppression”, Microwave and Optical Technology Letters, Vol. 49, No. 11, Nov.2007.

[70] GUHA D., BISWAS M., ANTAR Y.M.M., “Microstrip patch antenna with defected ground structure for cross polarization suppression”, IEEE Antenna and Wireless Propagation Lett, Vol.4, pp.455 –458, 2005.

[71] SALEHI M., MOTEVASSELIAN A., TAVAKOLI A., HEIDARI T., “Mutual coupling reduction of microstrip antenna using defected ground structure”, IEEE Singapore International Conference on Communication System, pp. 1– 5, 2006.

REFERENCES

[72] THAKUR J.P., PARK J.S., “An Advance Design Approach for Circular Polarization of the Microstrip Antenna With Unbalance DGS Feedlines”, IEEE Antennas and Wireless Propagation Lett. vol. 5, 2006.

[73] MOGHADAS H., TAVAKOLI A., SALEHI M., “Elimination of scan blindness in microstrip scanning array antennas using defected ground structure” Int. J. Electron. Communication. (AE.) 62 pp.155 –158, 2008.

[74] CHALAL M., AZRAR A., DEHMAS M., “Rectangular Patch Antenna Performance Improvement Employing Slotted Shaped for WLAN Applications”, IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 3, No. 1, May 2011

[75] AKBARI M., KHALILPOUR J., MIGHANI M., RASTGAR S., “A novel very compact printed antenna using DGS for 2.4GHz and 5GHz communication”, International Journal of Electronics & Communication Technology, Vol. 2, Issue 4, Oct.-Dec. 2011.

[76] ARYA A. K., PATNAIK A., KARTIKEYAN M.V., “Microstrip patch antenna with skew-F shaped DGS for dual band operation”, Progress In Electromagnetics Research M, Vol. 19, 147-160, 2011

[77] SHARMA P.K., JADAUN V.S., “ Multi-Band Rectangular Microstrip Patch Antenna with Defected Ground Structure and a Metallic Strip”, International Journal of Technological Exploration and Learning ,Vol.1 Issue 1, Aug. 2012.

[78] CHIANG K.H., TAM K.W., “Microstrip Monopole Antenna With Enhanced Bandwidth Using Defected Ground Structure”, IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 7, 2008.

[79] GUPTA P.K., YADA A., SINGH S., “ Bandwidth Enhancement of Hexagonal Microstrip Patch Antenna by Ground Defect Technique”, International Journal of Scientific & Engineering Research Vol. 3, Issue 9, SEPT.2012.

[80] HUANG S.Y., LEE Y.H., “A Compact E-Shaped Patterned Ground Structure and its Applications to Tunable Bandstop Resonator”, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 57, NO. 3, MARCH 2009.

Appendix A

A.1 Input impedance bandwidth

In general the bandwidth of an antenna is defined as the range of frequencies within which the performance of the antenna, with respect to some characteristic conforms to a specified standard. The input impedance bandwidth is the range of frequencies in which the real part of the input impedance is greater or equal to 0.707 times its maximum value. Most of the times, it is taken to be the range of frequencies for which VSWR=2 and is given by the following relation:

$$\text{BW}\ (\%) = 200\ \frac{f_2 - f_1}{f_2 + f_1}$$

A.2 Co-polar and cross-polar components

The Ludwig definition of the co-polar and cross-polar components of an antenna polarized along the Oy axis is given by:

$$\begin{bmatrix} E_{co} \\ E_{cross} \end{bmatrix} = \begin{bmatrix} +\sin\phi & +\cos\phi \\ +\cos\phi & -\sin\phi \end{bmatrix} \begin{bmatrix} E_\theta \\ E_\phi \end{bmatrix}$$

If the antenna is polarized along Ox axis then these components are given by:

$$\begin{bmatrix} E_{co} \\ E_{cross} \end{bmatrix} = \begin{bmatrix} +\cos\phi & -\sin\phi \\ +\sin\phi & +\cos\phi \end{bmatrix} \begin{bmatrix} E_\theta \\ E_\phi \end{bmatrix}$$

Appendix B

Zeland IE3D Simulator

1. Features

Zealand Inc's IE3D is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the *S*-parameters, VSWR, current distributions as well as the radiation patterns. Some of IE3D's features are:

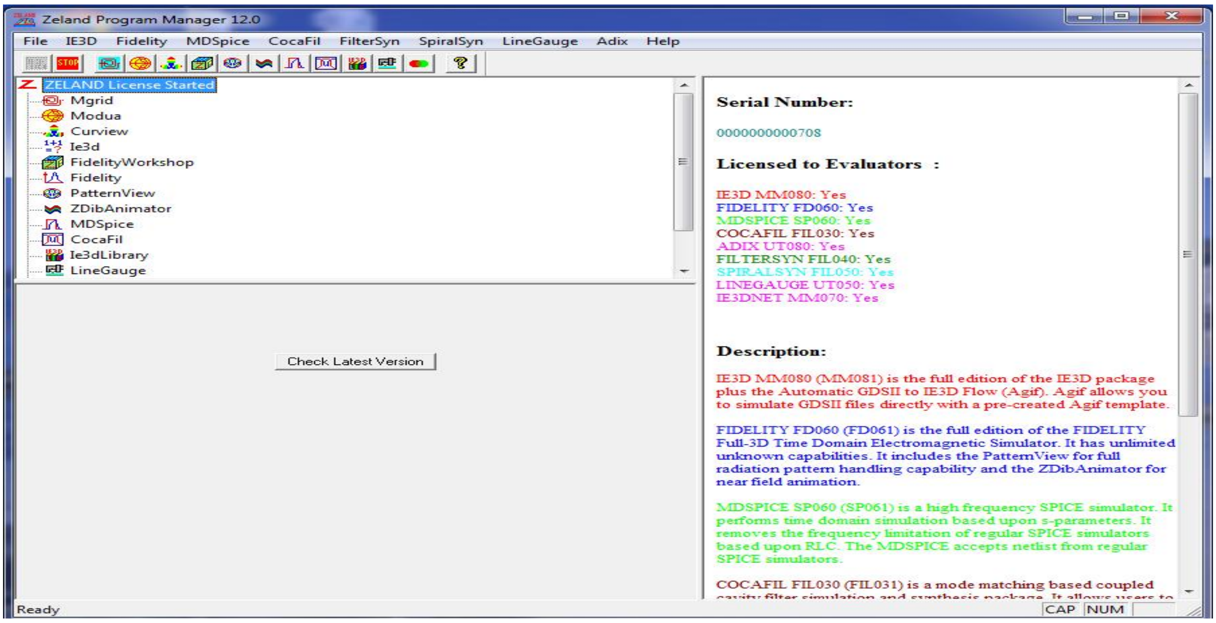
- High efficiency, high accuracy, low cost electromagnetic simulation tool on PCs with windows based graphic interface and efficient matrix solvers
- Automatic generation of non-uniform mesh with rectangular and triangular cells
- Can model structures with finite ground planes and differential feed structures
- Accurate modeling of true 3D metallic structures and metal thickness
- 3D and 2D display of current distribution, radiation patterns and near field.

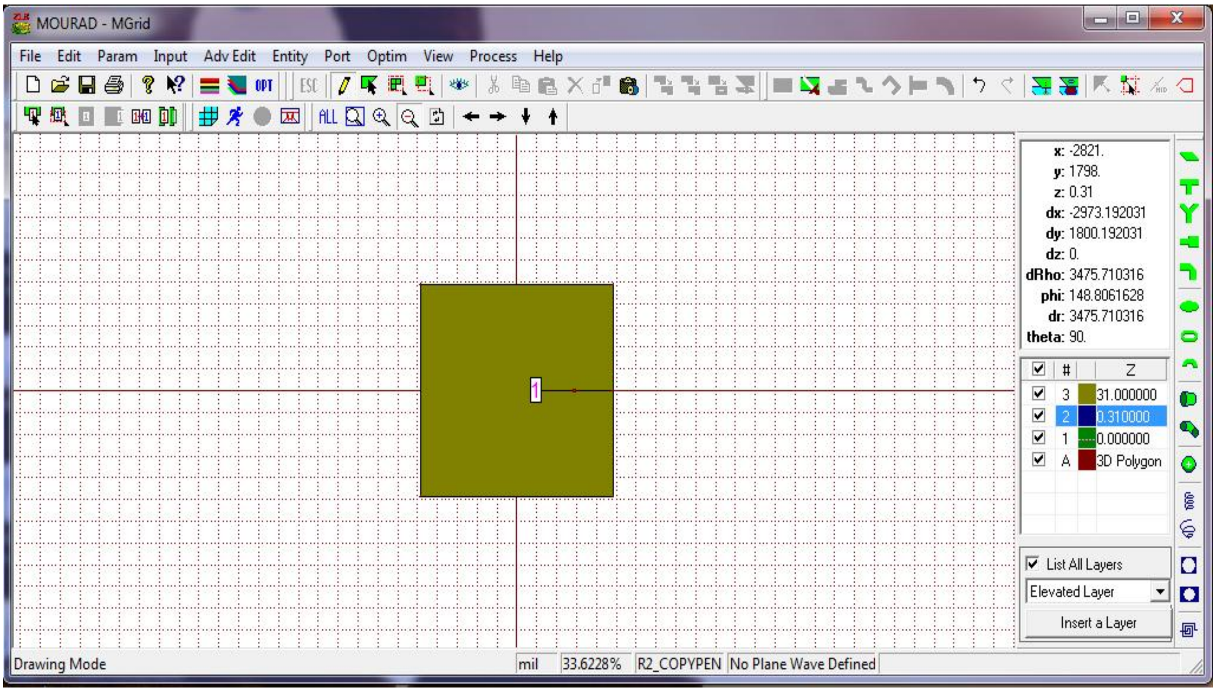
2. Modeling by Means of the IE3D Simulator

In the IE3D simulator, the shape of the antenna and conductor consist of the combination of polygons. There are two methods to model the antenna and human model in the IE3D simulator. One is to input the coordinates of the vertices of polygons in the text file and the other is to draw the polygons in the CAD (computer aided design) file. The IE3D simulator requires sub-dividing an antenna into small cells. The cell, which is a fundamental unit, is not a wire but a face. For example, monopole antenna consists of a thin strip conductor with the same width as a wire diameter. Rectangular cells are used in the regular region for the best efficiency and triangular cells are utilized to fit the irregular boundary. It is well known that current is concentrating on the edges of metallic strips. Precise modeling of the high current concentration along the edge is critical to accurate simulation. Cell on the edges of metallic strips, which is called the edge cell, can be installed in the simulation.

The IE3D simulator has several types of feed and the antenna model needs a suitable feed type. Feed types used in the simulation can be vertical or horizontal. Vertical port for feed and horizontal port for feed are called ‘Vertical localized port’ and ‘Extension for MMIC (Monolithic Microwave Integrated Circuit),’ respectively, it is also possible to use ‘probe feed to patch’. The antenna and conductor are divided into small cells automatically by the IE3D simulator when the parameters such as the number of cell per a wavelength and the highest frequency in the analysis are determined.

These two pictures illustrate the graphical interface of the Integrated Electromagnetic Simulator (IE3D)




MOURAD - MGrid
File
Edit
Param
Input
Adv Edit
Entity
Port
Optim
View
Process
Help
x: -2821.
y: 1798.
z: 0.31
dx: -2973.192031
dy: 1800.192031
dz: 0.
dRho: 3475.710316
phi: 148.8061628
dr: 3475.710316
theta: 90.
#
Z
3
31.000000
2
0.310000
1
0.000000
A
3D Polygon
List All Layers
Elevated Layer
Insert a Layer
Drawing Mode
mil
33.6228%
R2_COPYPEN
No Plane Wave Defined