INTRODUCTION

1.1. General Introduction

Modern wireless communication is exponentially growing sector of the communication systems. Scientist and Industries have shown profound interest in development of such systems. The wireless communication technology has transformed the lifestyle of today's society due to the intensifying demand for wireless communication networks such as wireless gadgets, cell phone services, mobile units, WLAN and Wi-Fi etc. For this cause, during the recent years, an enormous growth in the development of such microwave systems rapidly evolving worldwide. The field of antenna engineering is the central to all wireless technologies and plays a major role in the development and optimization of such system. Electromagnetic spectrum subsists the greatest source for the human communication and the ANTENNA is the only key to explore that source. An antenna is well-defined by Webster's Dictionary as "a usually metallic device (or a rod or wire) for radiating or receiving radio waves". The IEEE Standard defines of term for Antennas (IEEE Std. 145-1983) defines the antenna or aerial as "a means for radiating or receiving radio waves". Basically, an antenna can be considered as the connecting link between free-space and the transmitter or receiver.

Antenna play an important role in communication engineering. Antennas are generally categorised into various types depending on material type, design properties and applications. In present day modern communication systems demand smaller size, low profile, high gain and compatibility to meet miniaturization requirements. Microstrip patch antenna is the successful to be introduced to all the requirement of present day communication systems.

1.1.1. The State of Art Technologies

The thesis is primarily concentrating on the design then enhancement of miniaturized patch antennas using Defected Ground Structures (DGS) for wireless application. So, a brief information of the design methodologies of various patch antennas is described. Table 1.1, shows communication frequencies which are commonly used by the Federal Communication Commission (FCC) and the International Telecommunication Union (ITU) regulation [18] [33]. The antenna proposed in the thesis are designed mainly concentrating on ISM/ WiMAX/ WLAN bands. The succeeding section describes various patch antennas with state of art technology.

1.2. Microstrip Antenna

1.2.1. Introduction

Microstrip antenna study started since its proposal in 1953 by G A Deschamps [1]. Popularity about Microstrip Patch Antennas (MSA) in field of microwave engineering started by the practical implementation of study after two decades in 1970s. John Q Howell [5] and Munson R [3] are the pioneers in microstrip patch antennas. Constitutional advantages of structure low cost and packed in design for RF applications and wireless systems with its monolithic design made of MSA used in most of modern mobile communication and satellite applications. Primary stages dealt with theoretical analysis of different patch geometries and their experimental verifications. The developments, occurred up to late 1970's was documented by Bhal and Bhartia [8][9] in 1980. The analysis aspects were sited in another book by James, Hall and Wood [11] published in 1981.

Table. 1.1: Commonly used communication frequency bands

Application	Services used for	Allocated Band of frequency
RFID	Radio Frequency Identification Technology	0.865 – 0.868 GHz, 2.446 -2.454 GHz
DVB-H	Digital Video Broadcasting-Handheld	0.470 GHz – 0.702 GHz
GSM 900	Global System for Mobiles	0.890 GHz – 0.960 GHz
DCS1800	Digital Communication System Technology	1.710 GHz, 1.880 GHz
GPS1200 GPS1575	Global Positioning System Technology	1.227-1.575 GHz 1.565-1.585 GHz
PCS 1900	Personal Communication System Technology	1.850-1.990 GHz
3GIMT-2000	International Mobile Communication 2000	1.885-2.200 GHz
UMTS 2000	Universal Mobile Telecommunications Systems	1.920-2.170 GHz
ISM 2.4 ISM 5.2 ISM 5.8	Industrial, Scientific, Medical	2.400-2.484 GHz 5.150-5.350 GHz 5.725-5.825 GHz

Microstrip antenna has involved much interest for the reason that of their small size, low cost on bulk manufacture, light weight, low profile and comfortable addition with the added components [32]. Although MSA's are having some considerable features but, they generally fall off from few drawbacks such as narrow band (typically 1-5%) due to resonance nature, low gain, spurious feed radiation from edges, poor polarization and major manufacturing tolerance problems. To conquer these issues without distressing their major advantage (such as plain printed circuit structure, planar profile, light weight and less cost), a number of new methods and novel structures have in recent time have been investigated and developed [18].

Several novel approaches have been implemented to increase the bandwidth by disturbing the higher order mode by means of introducing surface alteration into patch geometry by introducing slots and defects. Gain enhancement by embedding rectangular slot and using various layer of different substrate. The most conventional technique to trim down the size of patch is to create slots on ground plane. Using DGS on Microstrip antenna for parameter enhancement and virtual size reduction is the major development that we obtain. The percentage of decrease in size be contingent upon the ground space that is etched out. Defected Ground Structure (DGS) has the current shielded that is interrupted and can be denoted by the dimension and structure of the defect used on ground plane of antenna [37].

1.2.2. Research Scope and Objectives

This work addresses the single band and narrow band issues of square MSA with special focus on miniaturization by virtually reducing the antenna size, with improvement in bandwidth, efficiency and other parameters by introducing defect in the antenna ground plane, due to which current flow and input impedance of antenna are then prejudiced by the disturbance of current the distribution of shielded current occurred due to the defect embedded on ground plane [37]. The DGS can correspondingly be used to temper the excitation of higher order harmonics and the electromagnetic waves which propagating through the substrate layer of antenna. A ground plane defect of antenna, increase or reduce the value of applicable capacitance and inductance in the transmission line. In this thesis, MSA for low frequency at 2.45 GHz and 5 GHz is designed and tested using simulation software, later result of fabricated antenna of same with defect embedded is compared with conventional design.

1.2.3. Basics Microstrip Antenna

Figure 1.1, shows a conventional Microstrip antenna which consist of a set of parallel conducting plates, i.e. ground and patch separated by dielectric medium referred as substrate. In this pack in configuration, the layer at the upper conduction is also called as “Patch” which is the radiation source caused, where the energy electromagnetically fringes off from the patch edges with dimension and penetrate into the substrate material. The below conducting layer which is also referred as “Ground” acts as a reflecting plate perfectly, which vigorous energy back over the substrate and within the free space. Materially, the patch is a conductor that is of substantial equal to wavelength fraction in size. The patch which has resonant actions is liable to achieve satisfactory bandwidth [32].

Conventional patch designs followed till date yield few percent bandwidths (typically 1-5 %). In most of practical applications used, patch antenna is rectangular, circular or triangular in shape. In spite of this in common, any geometry is likely to use as patch antennas, various shapes of patches used are revealed in Figure 1.2. The various shapes of MSA's used in various microwave engineering applications. For further understanding working methodology of the MSA, a square patch antenna is selected for the study since square patch antenna is easy to design.

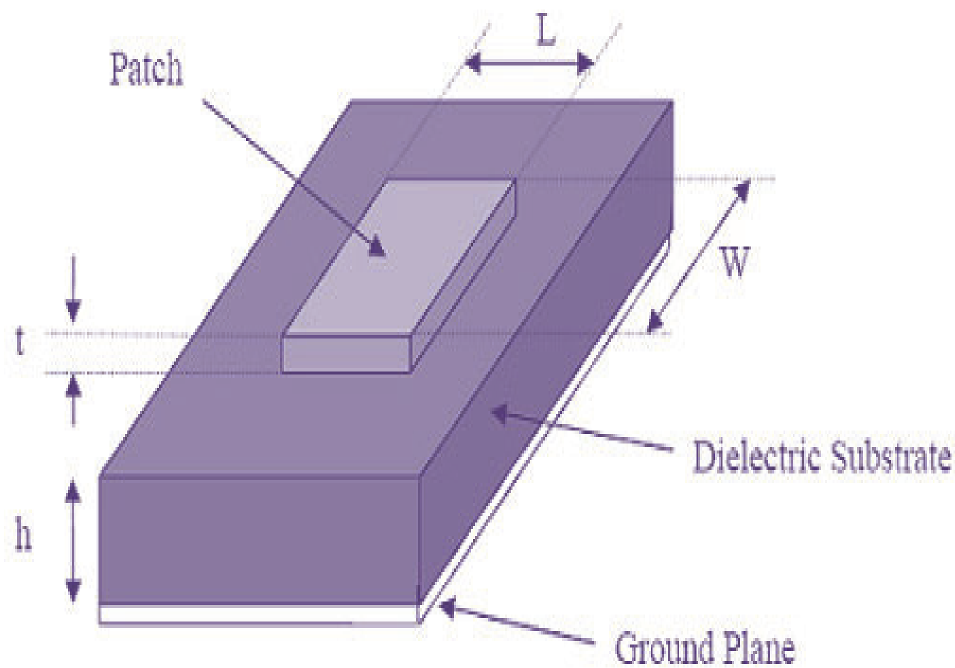


Figure 1.1: Microstrip Patch Antennas

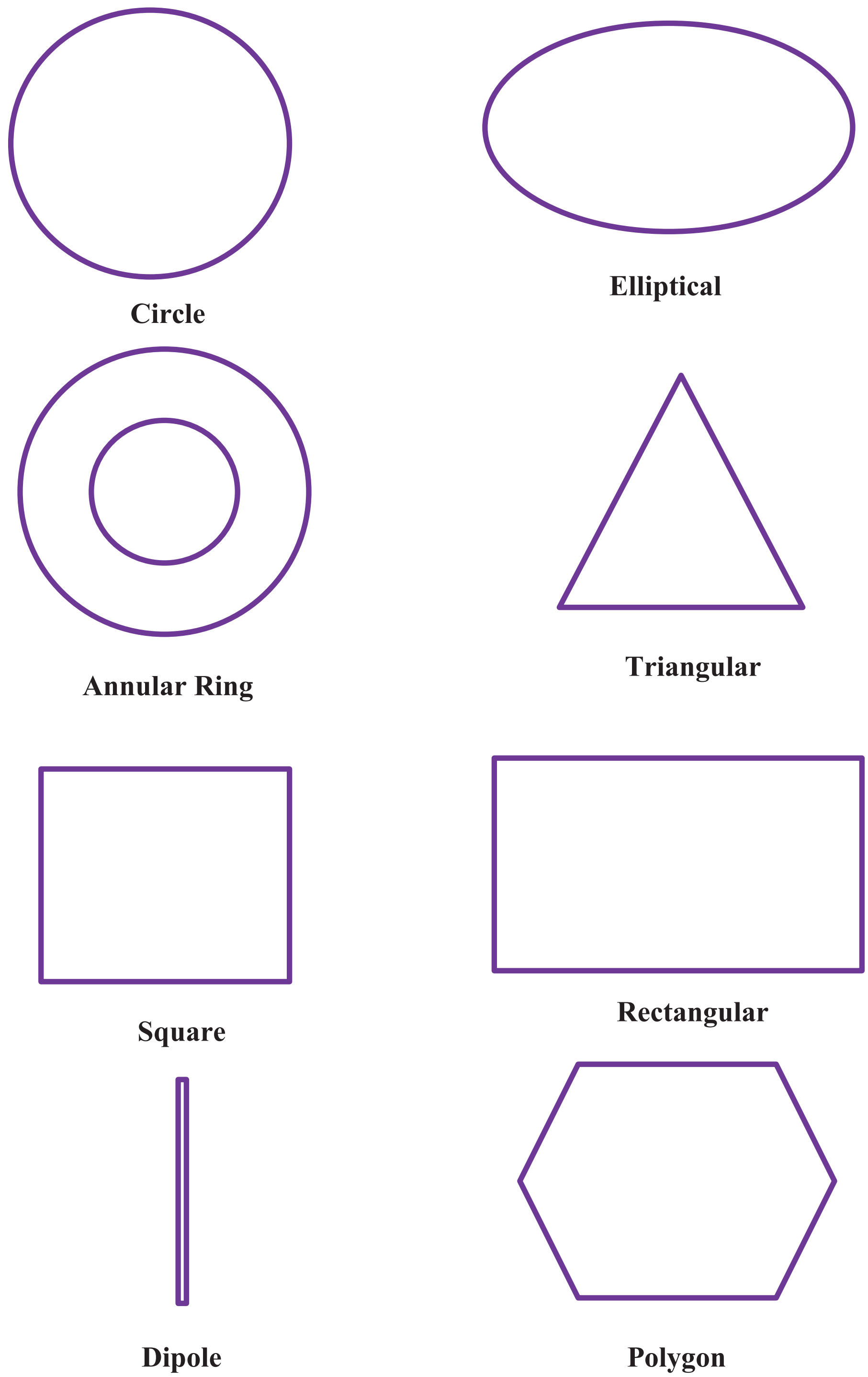


Figure 1.2: Various shapes of microstrip patch elements.

Square Microstrip antenna is selected and designed to obtain maximum wave pattern which is usual to the patch, which can be accomplished by properly selecting excitation mode below the patch. Generally, patch of MSA's thickness is very high in the choice of $t << \lambda_0$ where (λ_0 is free space wavelength) and height 'h' of selected dielectric material should be in range of $0.003\ \lambda_0 < h < 0.05\ \lambda_0$. For a particularly rectangular path, the length L of the patch is normally $\lambda_0 /3 < L < \lambda_0 /2$. The substrate needed to be sandwiched in between patch and ground is selected from wide range available based on requirement various substrates that is utilized for the MSA design, and dielectric constants values are generally in the choice range of $2.2 < \varepsilon_r < 12$, where 'ε_r' is relative dielectric constant. The substrate with thicker size and dielectric constant which is of lower end provides improved efficiency and greater bandwidth however at the cost of large size of antenna [30]. Conventional MSA's in typical have a printed conducting patch on the ground connected microwave substrate, which has the appealing features of low profile, light weight, can be effortlessly fabricated and more comfortable for mounting hosts. However, MSA's inherently have a very narrow bandwidth and enhancement of bandwidth in antenna is major demanded for practical communication applications.

1.2.4. Radiated Fields of Microstrip Antenna

Radiating fields contained by the substrate and within the element "Patch" and "ground plane" is revealed in Figures 1.3. The electromagnetic wave feed by source traveling laterally the line feed of a microstrip spreads out underneath the patch. Hence, the resulting reflections at the open circuit set a standing-wave pattern at the edges, it is amply clear that the emitted fields go through a phase reversal alongside the length of the structure but is approximately uniform along the width of the structure.

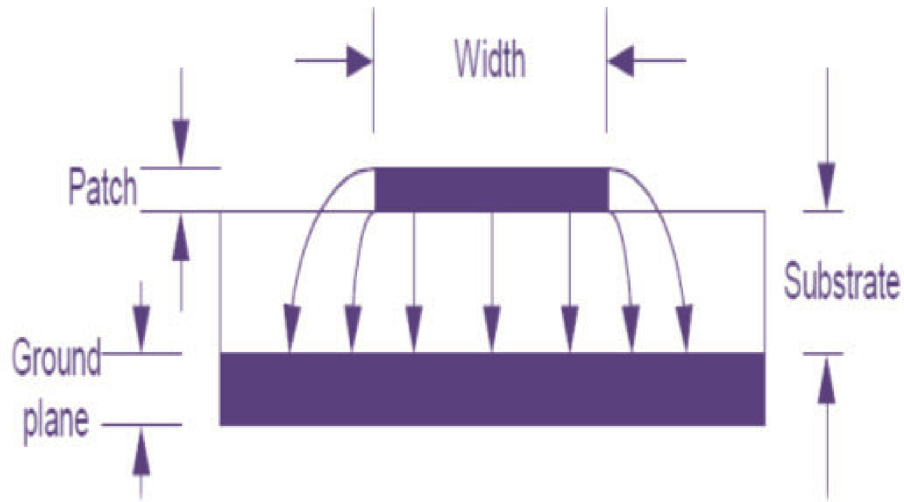


Figure 1.3: Radiating Field of MSA

Radiating patch consists of two slots, divided by an appropriate low impedance parallel-plate transmission line that performances as a transformer. The length of the transmission or communication line has to be approximately $\frac{\lambda_g}{2}$ in direction for the fields at the aperture of the two slots to take opposite polarization. The components of the field from each slot add in phase and provide a maximum radiation normal to the element [17].

The electric field generally is equal to zero at patch centre, maximum at one side, and minimum on the other/opposite side. It should be stated that the minimum and maximum constantly change side rendering to the rapid phase of the applied signal. It instigates field extensions identified as fringing fields which makes the patch of the antenna to radiate. Some standard investigative exhibiting methods for patch of antennas are constructed on this leaky cavity model. Therefore, the essential mode of a square patch is regularly designated using cavity theory as the TM_{10} which prominent mode since this notation is frequently used. This income that only three field components are measured instead of six the field components are: The electric field in the z direction and the magnetic field components in x and y direction using a Cartesian coordinate system, where the x and y axis is parallel with ground plane and the z-axis is perpendicular, due to the fact that the microstrip thickness is usually precise small, and the electromagnetic waves created within the dielectric substrate undergo significant reflection when they reach at the strip's edge. Hence, only a marginal fraction of the incident energy is radiated because of which efficiency of antenna is compromised.

1.2.5. Advantages v/s. Disadvantages of Microstrip Antennas

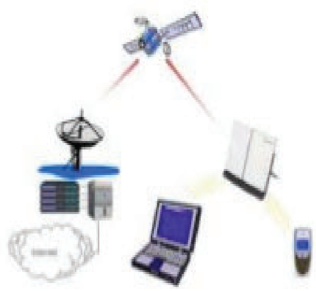
Attractiveness of the MSA's methods roots from the idea of making use of it in printed circuit technology. Due to the fact that the microstrip antenna's structure is planar in its configurations, it's the most advantageous for all applications of printed circuit board such as power dividers, matching networks, phasing circuits and radiators. Table 1.1 provides some list of advantages and shortcomings of MSA's [32].

Table1.2: Advantages and Shortcomings of MSA

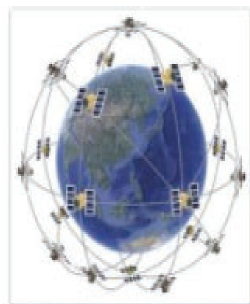
Sr. No	Advantages	Shortcomings
1	Light weight with low volume.	Very Narrow Bandwidth (BW)
2	Low profile planar configuration with can be made more compatible to host.	Low efficiency
3	Reduced cost of manufacturing, hence can be obtained in large quantity	Low Gain
4	Provisions both, linear as well as circular polarization.	Low efficiency
5	Easy fabrication together on Microwave Integrated Circuits (MICs)	Superfluous radiation along feeds and junctions causing damage to circuit board
6	Capable of dual, triple and multiband frequency operations	Poor end fire radiation excluding elongated slot antennas
7	Suitable for low profile applications	Low power management capacity.

1.3. Applications of Microstrip Patch Antenna

There are major advantages and shortcomings of MSA's, it can be observed that its advantages significantly over its shortcomings. Due to the fact that most modern-day communication systems demand for compact size, lightweight, cost effective and low-profile antennas, the engagement of microstrip technology has been developing extensively over the years. Even though conventional antennas possess far superior performance over MSA's, it is still clearly disadvantaged by the other properties of the MSA's. Revealed below are some specific system applications which engage microstrip technology [32] [33].

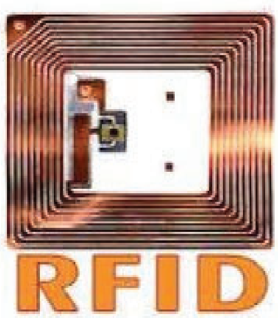


Mobile and satellite communication System

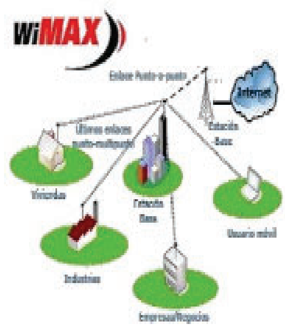


Global Positioning System(GPS)

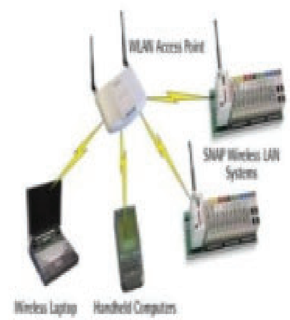
Direct Broad Cast Television(DBS)



Radio Frequency Identification (RFID)



Worldwide Interoperability for Microwave Access (WiMax)



Wireless LAN's

- In the telemetry systems and communications antennas on missiles.
- Used on radar altimeters which uses very smaller size arrays of microstrip radiators.
- Aircraft-related applications
- In most of Mobile system and satellite communications systems.
- Satellite imaging systems and communication.
- WLAN and WiMAX.

- High speed GPS.
- Military applications

1.4. Dielectric Substrate Material

Major step in designing the microstrip antenna is to select a suitable substrate. There are diverse types of substrate available that can provide considerable flexibility in choosing the substrate for our particular application requirement. The selection of the substrate that is used is a significant reason in the MSA design. Some of the significant qualities of the antennas dielectric substrate include [34].

1. The dielectric constant grounded on application requirement.
2. The frequency prerequisite of this dielectric constant that provides enlargement to "Material dispersion" in which the wave velocity is frequency-dependent.
3. The surface characteristic and evenness in substrate
4. The cost and manufacturability of material
5. The thermal enlargement and conductivity to identify the durability.
6. The breadth of the copper surface on substrate.
7. The dimensional steadiness with time.
8. The characteristics of the surface adhesion for the layers of conductor on surface.
9. The manufacturability (simplicity of cutting, shaping, and drilling) for edging.
10. The permeability (for high vacuum applications)

In order to provide proper support and protection for the patch element on surface, the dielectric substrate must be strong and should be capable to withstand high temperature during soldering process of source connection and should have high resistant towards chemicals reaction process that are used in fabrication. In addition, the loss tangent and also dielectric constant are functions of frequency. This problem is however, can be minimized or evaded by utilizing an appropriate substrate of low permittivity of our choice. Below are six different classes of dielectric material that are selected for substrates.

1) Cerámica – Alúmina (ε_r = 9.5, tan δ = 0.0003)
   a. This category of dielectric has extremely low loss tangent but brittle in nature.
   b. It is used in high frequency usages and also has exceptional resistance against chemical processing.
   c. For alumina, temperature range is equal to 1600ºC and
2) Synthetic type materials – Teflon (ε_r = 2.08, tan δ = 0.0004)
   a. This dielectric material acquires properties of a very good electric constant but with a soft melting point and poor adhesion.
   b. The dimensional steadiness for the substrate has comparatively poor but when reinforcement is done with glass of ceramic it will recover the dimensional stability to fairly well for exploiting it with various applications.
3) Composite materials – Duroid (ε_r = 2.2 / 6.0 / 10.8, tan δ = 0.0017)
   a. This composite material has a combination of synthetic and fiberglass materials that are cited above. These materials have

properties with good electrical and physical and exceptional dimensional steadiness and is more widely used.

4) Ferromagnetic type - Ferrite (ε_r = 9 – 16, tan δ = 0.001)

   a. This category of the dielectric material is influenced by an electrical field that propagate.

   b. The frequency at which antenna resonate will be influenced upon the biasing and hence the designs of magnetically tuneable antenna are possible.

5) Semiconductor – Silicon (ε_r = 11.9, tan δ = 0.0004)

   a. This category of dielectric material that is incorporated within microwave circuit, but only small portions are available. Hence it is not appropriate for antenna applications.

6) Fiberglass FR-4 – Woven fiberglass (ε_r = 4.3, tan δ = 0.002)

   a. Material here is relatively of low in cost, for such a low loss tangent. Nevertheless, woven fibres be likely to be anisotropic and this is undesirable in many designs.

There are abundant substrates that is used for design of MSA, with their dielectric constants within range of $2.2 \leq \varepsilon_r \leq 12$. The low dielectric constant ε_r is about 2.2 to 3.3, the medium around 4.3 to 9 and the high approximately above 9.3 to 12. Normally, dense substrates with lesser dielectric constants are regularly used for antenna designs as it offers improved efficiency, with respect to larger bandwidth and slackly bound fields for emission into space, disadvantage is it leads to large size antenna.

To overcome disadvantage from larger size antenna, slender substrates with greater dielectric constants would result in smaller antenna size. By compromising on less efficient and narrow bandwidth. Therefore, there must be a design compromise between size of antenna and better antenna performance.

1.5. Feeding Techniques

Feeding methods shows an extremely important role in performance of antenna and stability of design. Various feeding methods are discussed below. These procedures are classified into two categories:

- Contacting method: Microstrip line, probe of Coaxial
- Non-contacting method: Aperture Coupled and Proximity Coupled

1.5.1. Contact Feed:

In this technique, radio frequency power is fed in a straight line to the radiating patch by means of a connecting component like microstrip line or coaxial wire. In the non-contacting arrangement, electromagnetic field engages coupling to conveying power sandwiched between the transmission line and radiating patch. The four most important feed techniques which are used in antenna design such as microstrip line, coaxial probe both classified under contacting schemes, aperture coupling and proximity coupling both classified under non-contacting schemes [8][9].

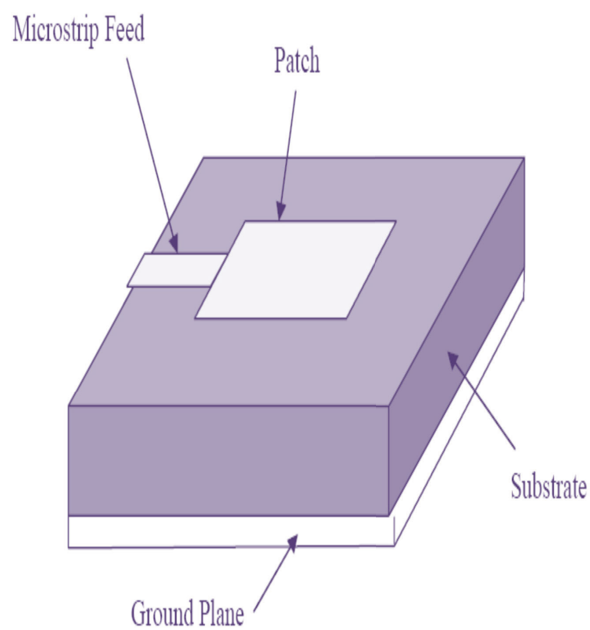
1.5.1.1. Microstrip Line Feed

A conducting strip is used to connect to the edge of the patch element as revealed in Figure 1.4 (a). The conducting strip connected is much lesser in width as likened to the patch and this method of feed arrangement has always been the advantage as feed can be imprinted on the similar kind of substrate to deliver a planar structure. One of the significant features of MSA is the diversity of feeding technique appropriate to them. It's always needs to have a good impedance match requirement among the transmission line and patch can be obtained without any supplementary matching elements be contingent profoundly on feeding techniques used. There are four most prevalent structures which are used to feed microstrip antenna. They are Microstrip line, Coaxial probe, Aperture coupled and Proximity coupled. Microstrip line and coaxial cable are contacting arrangement while aperture coupling and proximity coupling are the non-contacting arrangement.

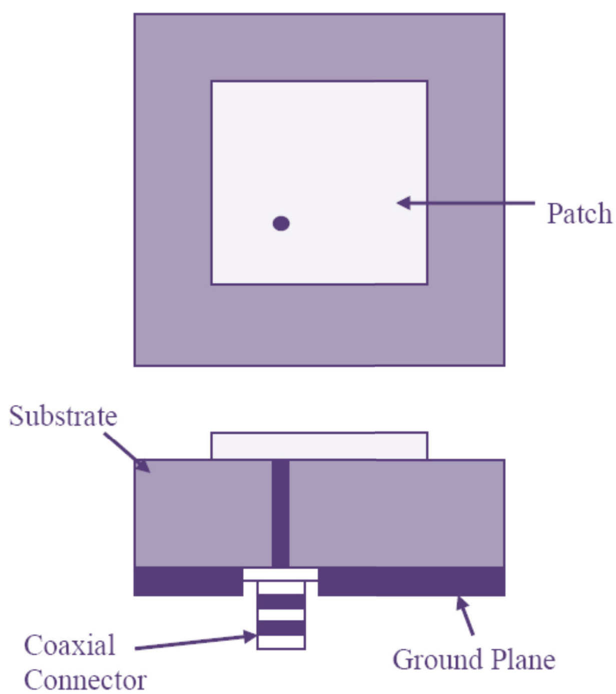
The need of inset into patch is to obtain match in impedance with feed, which eradicates the need for any additional matching element. This is achieved by suitably monitoring the inset position. Hence this it is easy-going feeding scheme since it provides easiness of substrate to ground plane. However, as the height of the dielectric substrate rises, surface waves and spurious radiation also upsurges which obstructs the bandwidth [32].

1.5.1.2. Coaxial Feed

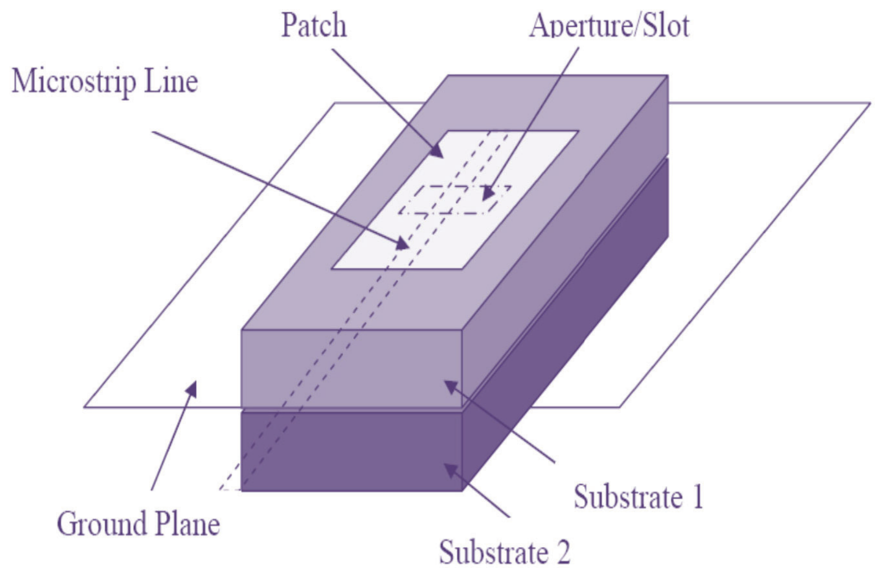
The Coaxial feed is an extremely acquainted technique used as feeding method for MSA from Figure 1.4 (b), it can be seen that the internal conductor wire of the coaxial connector spreads across the dielectric material and is soldered from bottom to radiating patch element, while ground plane is connected by outer conductor. The foremost use of this type of feeding arrangement is positioning can be at any desired location on the patch in regulation to match with its input impedance. These methods of feed undergo from numerous shortcomings.



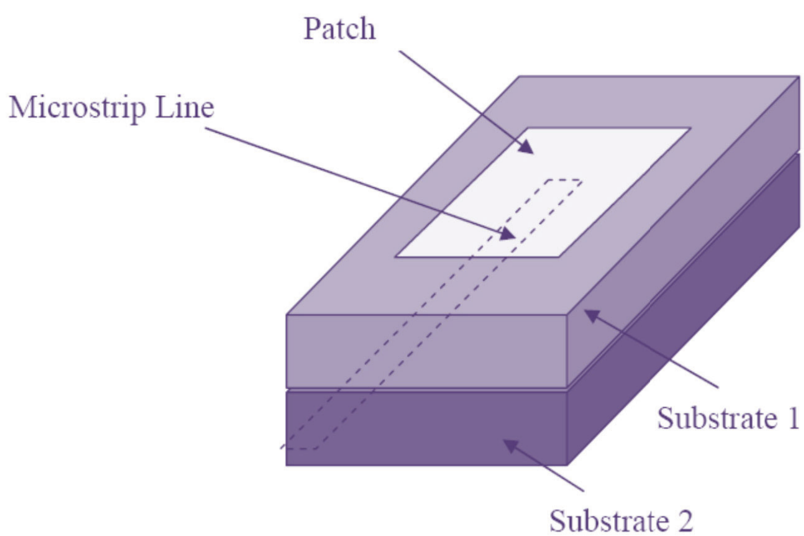
(a)Microstrip Feed Line



(b) Coaxial Feed line



(c) Aperture Coupled Feed method



(d) Proximity Coupled Feed method

Figure 1.4: Microstrip antenna feeding methods

1.5.2. Non-Contacting Feed:

The method which have been considered below, solve these problems related with contact feeding method but has to be cooperated with size of antenna.

1.5.2.1. Aperture Coupled Feed

In this category of feed technique, aperture coupled feed arrangement comprises of a radiating patch on upper substrate board which has non-conducting back side. The upper exterior of the lower substrate acts as conducting ground plane and it has an electrically minor aperture or slot cut in it. The radiating patch is excited through this aperture or slot, from feed line present on the backside of the lower substrate. The quantity of coupling starting the feed line to the patch is regulated by the shape, position and size of the aperture. Meanwhile the ground plane acts as a separator between the patch and the feed line, most of spurious radiation is eliminated. Conventionally, a higher value of dielectric material is considered for the underneath substrate and a thick with low dielectric constant value material is used on upper substrate to improve radiation pattern from the patch element.

1.5.2.2. Proximity Coupled Feed

This feed arrangement has two layers of substrates, with radiating patch on upper substrate whose back side has no conducting plane. The microstrip line feed method is etched on the lower substrate which is backed by conducting ground plane. The source feed line is positioned between the patch and ground plane. As revealed in Figure 1.4 (d), two different dielectric substrates are utilized in this case with top substrate having graduating patch. The main advantage of this feed technique is that it eradicates spurious feed radiation and delivers very high bandwidth (as high as 13 %) when compared with conventional methods. The major shortcoming of this feeding scheme is that problematic condition in fabricating because of the two dielectric layers which need appropriate alignment to each other. Also, there is an increase in thickness of antenna taken as a whole [8][9]. Assessment of all feeding techniques is as given below.

Table 1.3: Comparisons of different feed techniques.

Types of Feed	**Microstrip Line Feed**	**Co-axial/Probe Feed**	**Aperture Coupled Feed**	**Proximity Coupled Feed**
Easy fabrication	Easy	Need of Soldering and drilling network	Alignments required	Alignments needed
Impedance Matching	Much Easy	Need to locate	Easier	Easy
Reliability of antennas	Better performance	Very poor due to Soldering damage	Good stability	Good
Spurious	More	More	Less	Moderate
Bandwidth	2-5%	2-5%	2-5%	12%

1.6. Modelling Techniques

Many methods have been developed over the past years for a wide variety of applications in RF engineering. These methods or techniques can be divided into: i) Time Domain (TD) such as Finite Different Time Domain (FDTD) and ii) Frequency Domain (FD) such as Moment of Methods (MOM) and iii) Finite Element Method (FEM). Many different commercial software has been established using one of these methods, and it is therefore not necessary any longer to write a new code but just utilize any of them to aid the modelling of the RF design. In this section, the foundation principles on which these methods are based are briefly introduced [32] [34].

1.6.1. The Method of Moment (MoM)

It is a numerical method of solving electromagnetic problems or volume integral equation in the frequency domain. MoM can be utilized to resolve problems in numerous areas of engineering and sciences including electromagnetic. MoM is used to solve electromagnetic problem. Numerical Electromagnetic Code is the most recognized of the codes using MoM to solve problems that can be defined as sets of one or more wires. Although, it is an adaptable and thoroughly simple method, it has need of large amounts of computation. The MoM method is broadly used to solve electromagnetic scattering and problems related to radiation. This technique is based on reducing the operator equations forwarding a system of linear equations that is written in matrix form. The MoM applied to wire antennas for instance, is used by the marketable software IE3D. Accuracy of results is considered an advantage using this method as it uses essentially exact equations and delivers a direct numerical explanation of these equations.

1.6.2. Finite-Difference Time-Domain (FDTD)

The Finite Difference Time Domain is a method that is broadly used to stimulate several electromagnetic problems. The literature on FDTD is extensive and has remained in use for various microwave analysis such as, antenna designs, propagation, filter design, and many other microwave analyses. However, FDTD is not appropriate for electrically huge system but is good for system involving pulses. This method did not gain considerable attention despite its usefulness to handle electromagnetic problems until the computing costs became low The FDTD algorithm iteratively calculates the field values in the problem space that is discretized into unit cells. Each unit cell is assigned with three orthogonal electric and three orthogonal magnetic fields

1.6.3. Finite Element Method (FEM)

It is a mathematical technique used for finding estimated explanations using partial differential equations (PDE) in addition to integral equations. The solution is based on reducing the differential equation totally or interpreting PDE by estimating system of common differential equations, then are numerically integrated using Euler's method which is a standard technique such as the Runge-Kutta. FEM is a technique solves frequency domain boundary regarded of electromagnetic difficulties using a variational form. There are normally two types of analysis that are used in FEM 2-D and 3-D canonical elements of differing shape. While 2-D conserves straightforwardness and allows itself to be run from a normal computer, it however, tends to give less accurate results. Three-dimensional canonical element, however, gives more accurate results by working effectively on faster computers. The FEM is repeatedly used for frequency domain for computing the frequency field distribution in complex, restricted regions such as cavities and waveguides.

1.7. Defected Ground Structure (DGS)

1.7.1. Introduction

Since decades around has remained a significant development and enhancement in the antenna research. Towards the accomplishment of high data-rates and low signal power in antennas. The Research and Development of Microwave Engineering is being concentrating on to development of antennas to encounter the demands. Many of research journals and lots of paper has been published and implemented in the line of development of novel antennas. In this thesis, we are presenting a basic understanding and review of DGS embedded antennas towards modern developments and providing the consecutive development in the MSA's using DGS [35] [37].

1.7.2. Evolution of DGS

Since the contemporary studies on Photonic Band Gap (PBG) structures in electromagnetic needle to the idea of DGS. PBGs is utilized in Electromagnetic (EM) applications and also in different application and investigations centred on PBGs or now represented as Electromagnetic Band Gap (EBG) structures, these are basic non-natural periodic structures display the properties of a bandpass filter i.e. preventing EM wave from propagating across them over a series of frequencies which is fundamentally termed as "stop-band" and "pass-band" there is a band gap caused by the EBG [35] [37] structure. Many studies on PBGs developed popular in microwaves and millimetre waves application, various geometry evolved through a series of investigations and a concise assessment of basic EBG structure precedents to DGS. The structure having periodic composition with metallic, available dielectric or metalloid dielectric elements with lattice repetition of *p=n /2,* being the guide wavelength, are originate to exhibit EBG behaviour.

These competences are broadly grouped into three groups: three dimensional (3D); two-dimensional (2D); and one-dimensional (1D). A 2D planar EBG structure, shown in Figure 1.5, is actually a recurring pattern of circular unit cell engraved out on ground plane of a printed transmission line. In year 1999, group of research team approached to simplify the geometry and eliminated periodic nature of the configuration. They simply considered a single cell of dumbbell shape for obtaining significant stop band in both C and X-bands for a Microstrip line and in their preliminary paper, it was called as “PBG unit structure.” In their succeeding article, the identical structure was characterized as “Defected Ground Structure” (DGS). Therefore, a DGS can be considered as a simplified alternative of printed EBG structure on a ground plane [37].

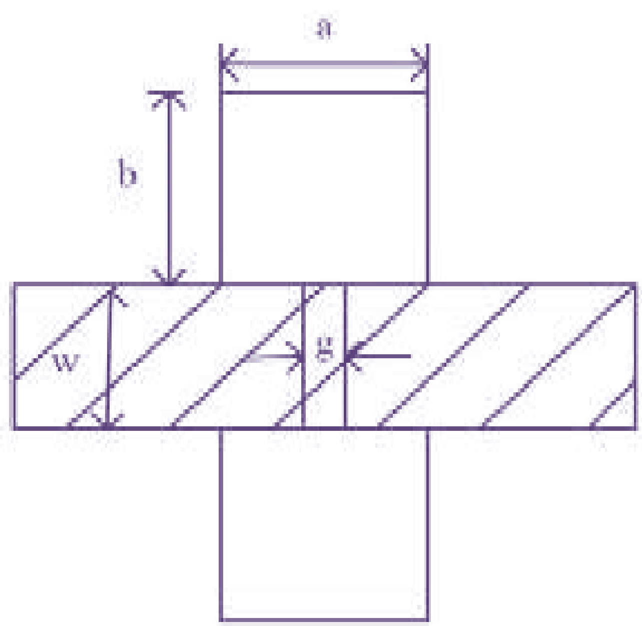


Figure 1.5: The dumbbell DGS with width a and length b connected with another block by slot width g, with strip line of w width.

1.7.3. Basics of DGS and Working

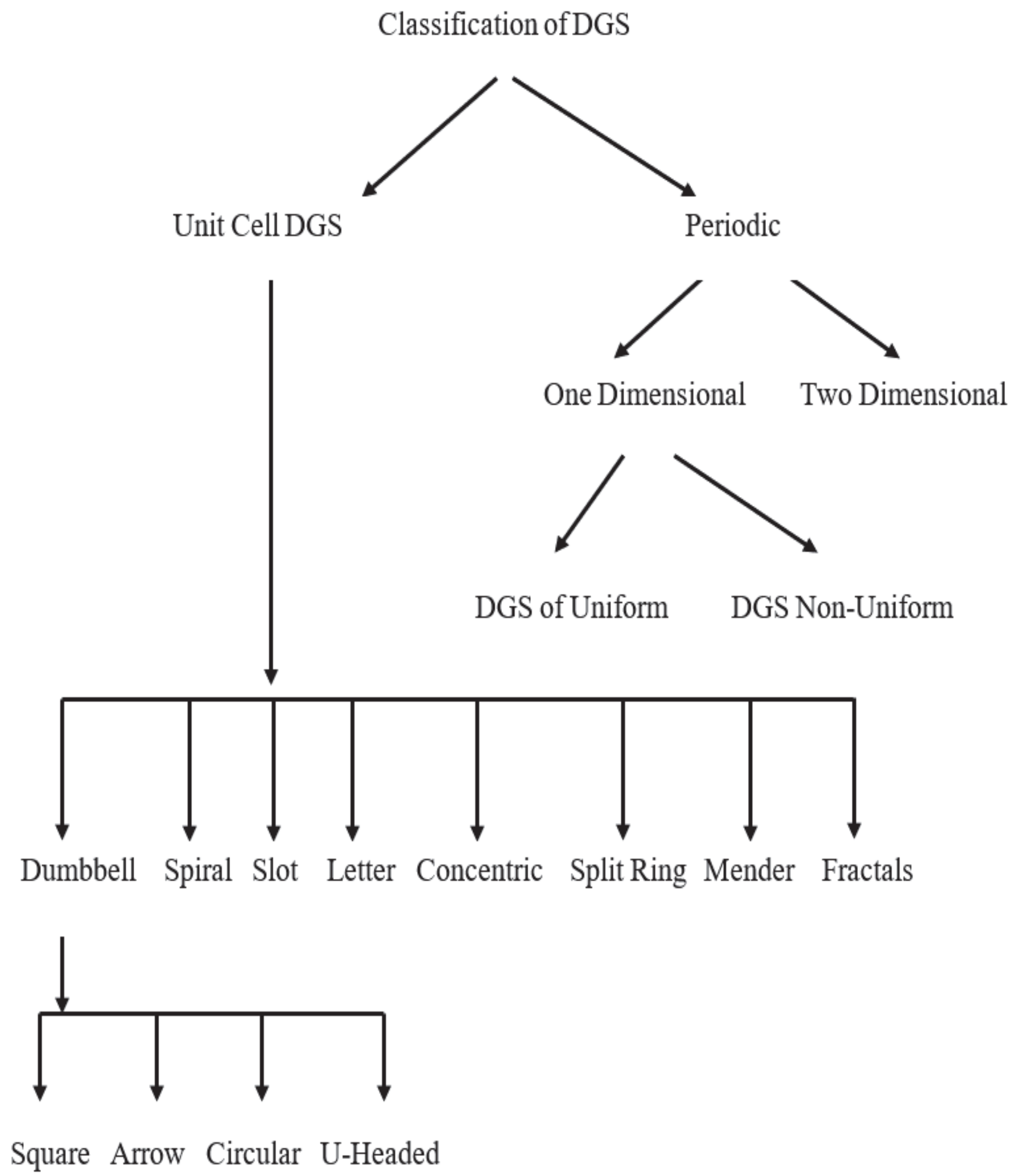
Defected ground, as the name imply it's the intentionally created mistake on ground plane of microstrip antenna, with a predefined specific geometry and shape which is engraved out as a single defect or periodic configuration to create a characteristic of band stopping wave propagation characteristics through the substrate over certain range of frequencies. Hence DGS can be designated as a single cell EBG.

The DGS structures are echoing in character. Conventionally, in planar microstrip circuits, a DGS is always placed underneath a microstrip line, this defect disturbs the electromagnetic fields around slot. This surrounded electric fields provide the Capacitive effect (C), whereas the surface currents produced around a defect cause an Inductive effect (L). This, in progression, results in resonant nature of DGS There are various shapes and size with varying frequency reactions and also its equivalent circuit parameters [37]. The presence of DGS in printed transmission line essentially disturbs the current spreading on ground plane and thus moderates the change in equivalent line parameter in the region of defect. Thus, it effects the source wave characteristics and exhibits following properties [37].

1. Band gap properties obtained due to EBG structure.
2. A slow wave effect, which increases compacting, in printed antenna circuit.

1.7.4. DGS Classification

Basically, DGS can be generally organized into two categories depending on configurations and size detailed classification is given below [37].



1.7.4.1.Single unit cell DGS

The DGS basic geometries described till now comprises ingenuous shapes such as rectangular and circular dumbbell, spiral, “U”, “V”, “H”, Concentric and Split ring, Meander shape, Fractals shape, some of ingenuous and commonly used shapes are shown the below Figure 1.6.

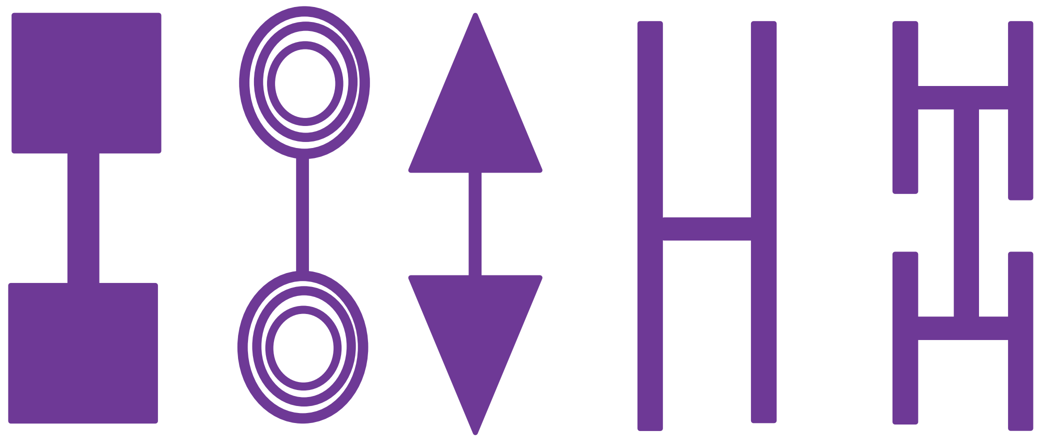


Figure 1.6: Different Shape of DGS

1.7.4.2. Periodic DGS

The recurrence of unit cell in a periodic fashion, gives much improved result and deeper characteristics in antenna design, DGS which are moulded by the periodic replication of single cells is considered as periodic DGS, Periodic repeated structures such as PBG and DGS for transmission lines is been characterized in wide interest for their widespread requirement in antennas and also in microwave circuits. Transmission lines having a periodic structure is having restricted passband and stopband as applicable to lowpass filters. The increased slow wave significance and its additional components are important properties of repeated structures as that can be recognized and gives advantage to compact circuit using these above properties. Periodic means reappearance of the physics structure. By cascading DGS significant cells on ground plane the complexity and BW of the stop-band for projected DGS circuit are motivated to be subject to the number of periods. Periodic DGS consideration is about selecting the shape of unit DGS, and the spacing between two DGS units and also the allocation of the different DGS.

1.7.5. Modelling of DGS

An appropriate and efficient design approach is necessary to model single or unit cell DGS, with appropriate modelling technique we can acquire both the mathematical base and model to design any DGS structure. Since by creating defect it changes the current distribution on ground plane of MSA, by contributing rise to corresponding inductance and capacitance. Consequently, DGS works like resonating L-C circuit coupled to microstrip line. When a source signal is transferred across a DGS embedded microstrip line, vigorous coupling appears within the transmission line and the DGS structure about the frequency wherever DGS resonates. If signal sent covers the frequency at which DGS resonate, and furthermost all the signal is stored in its equivalent parallel LC circuit. Basically, modelling is categorised into three different categories: (a) Transmission line modelling; (b) LC and RLC circuit modelling; and (c) Quasi-static modelling [37].

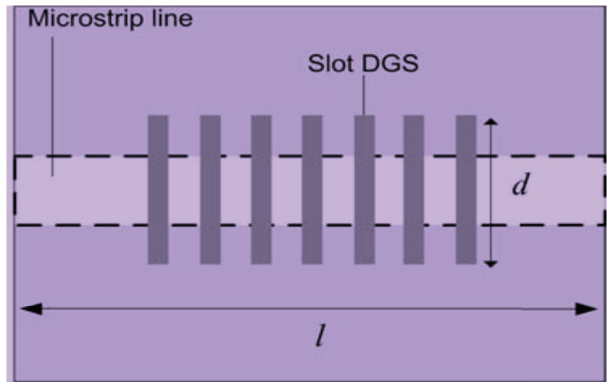
1.7.5.1. Transmission Line

In transmission line exhibiting, the slots resonate at different frequencies given by

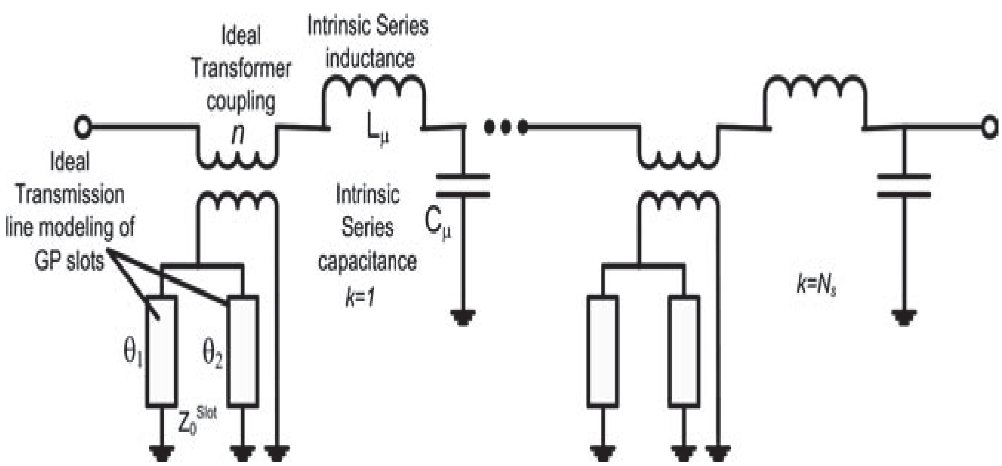
$$f \cong m \frac{c_0}{2d\sqrt{\varepsilon_{eff}^{slot}}} \tag{1.1}$$

where, m=1,2,3,4. The slots are modelled in transmission line having characteristic impedance Z_0^{slot} besides electrical length $\theta = \theta_1 + \theta_2 = \beta_m^{slot} d$ Here $\theta_1 = \theta_2$ if the arrangement of the microstrip line is symmetric with respect to d [28]. The coupling linking the slots and microstrip line is represented by an ideal transformer through a turn ratio.

$$n \cong \sqrt{\frac{Z_0^{\mu strip}}{Z_0^{slot}}} \qquad (1.2)$$



(a)



(b)

Figure 1.7: (a)Top view schematic of simple 7-cell uniform periodic slot DGS based on a transmission line model. (b) equivalent circuit of slot DGS

1.7.5.2. LC and RLC Equivalent circuit modelling

In Transmission line model needs to assess the impedance which is analytically depends on frequency, consequently more general approach of demonstrating a DGS in terms of equivalent parallel LC or RLC circuit has been discovered. The essential element of DGS is an echoing gap or slot in the ground metal, placed straightforwardly under a transmission line and associated for effective coupling to transmission line. Each depends on occupied area, equivalent L-C ratio, with coupling constant, higher-order reactions, and additional electrical parameters. Designer will select the structure which works finest for the particular application. The corresponding equivalent circuit of DGS is generally a parallel circuit of resonance in series with transmission line to which it is coupled as revealed in Figure 3.4. The I/P and O/P impedances are of transmission line section, while the relevant values of L, C and R are controlled by the physical dimensions values of the DGS structure and its location on ground relative to the transmission line properties.

The values of L, C and R is controlled by the dimensions and location relative to the "through" transmission line. The variety of structures arises from distinctive requirements or bandwidth (Q) and centre frequency, as well as practical interests such as a size/shape that does not overlap other fractions of the circuit, or a structure which can be easily truncated to the frequency. The reactance of equivalent circuit is given Figure 3.4. The equivalent Resistance, Inductance, and Capacitance values are acquired from the expression [28] [29].

$$C = \frac{\omega_c}{2Z_O(\omega_O^2 - \omega_c^2)} \tag{1.3}$$

$$L = \frac{1}{4\pi^2 f_O^2 C} \tag{1.4}$$

where ω_0 is resonance angular frequency and the L & C values are given by:

z_o is input impedance

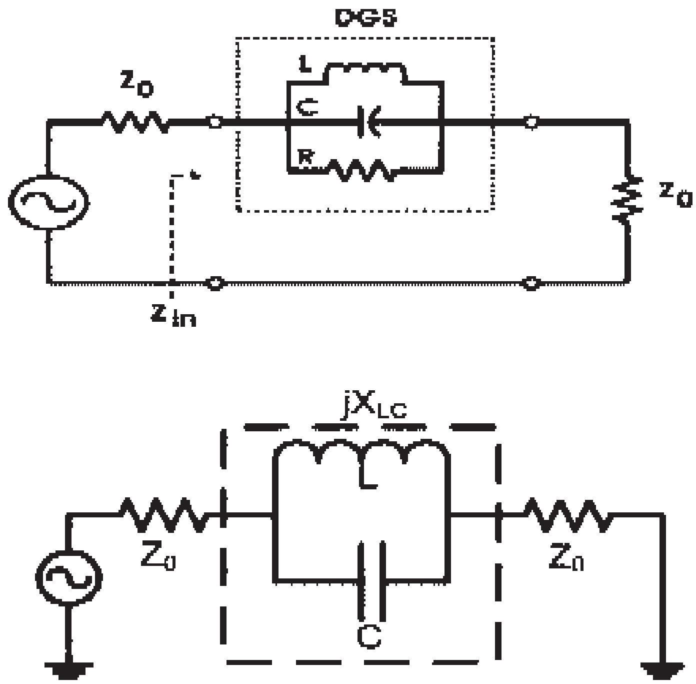


Figure 1.8: Equivalent circuit of a DGS element

1.7.5.3. Quasi-static modelling

This is another efficient technique to model a DGS. The quasi-static approach uses an equivalent circuit in view of the physical dimensions of defects in the very opening [37]. The basic steps to be followed are shown in Figure 1.9. This technique is appropriate to comparatively simpler geometries where each DGS segment could be represented by its equivalent circuit component. To understand the process, we again consider with an example of dumbbell-shaped DGS shown in Figure 1.10, the nature of the current dispersal on ground plane surrounding the defect is to be analysed first. This indicates an equivalent current ribbon with different segments having altered widths. The width of the strip is estimated from simulated bunching of current lines.

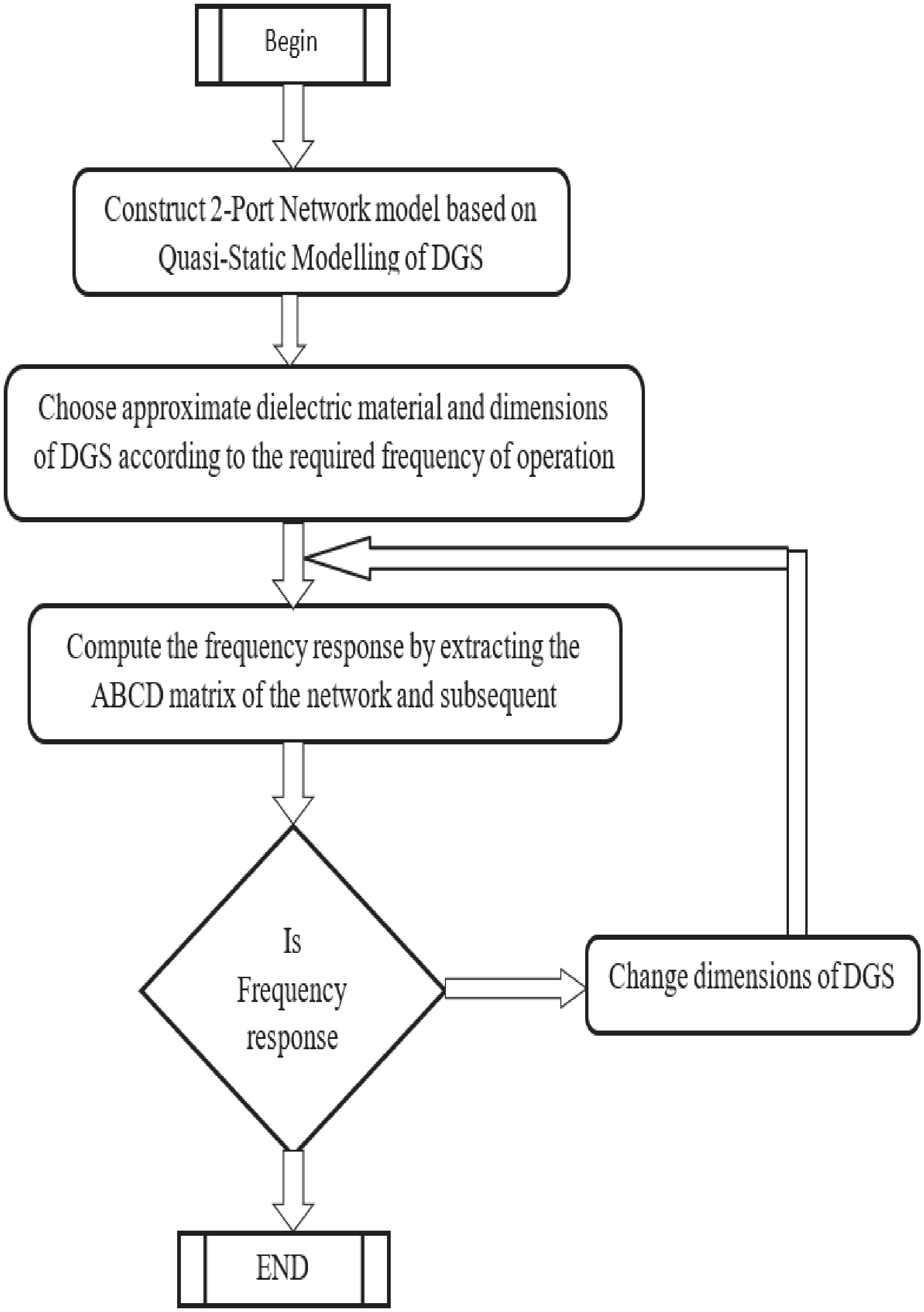
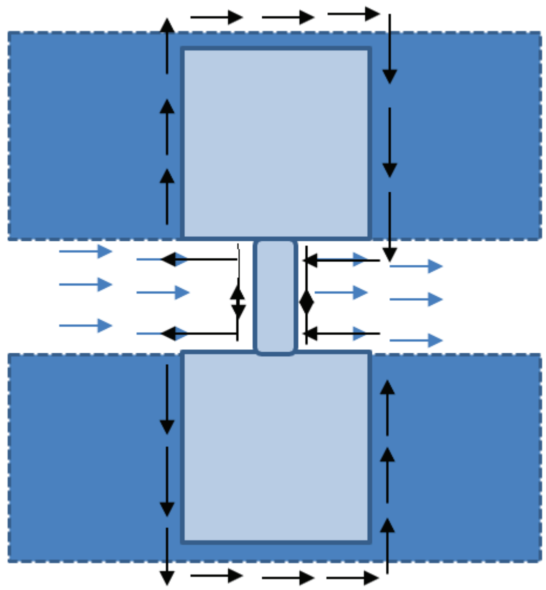
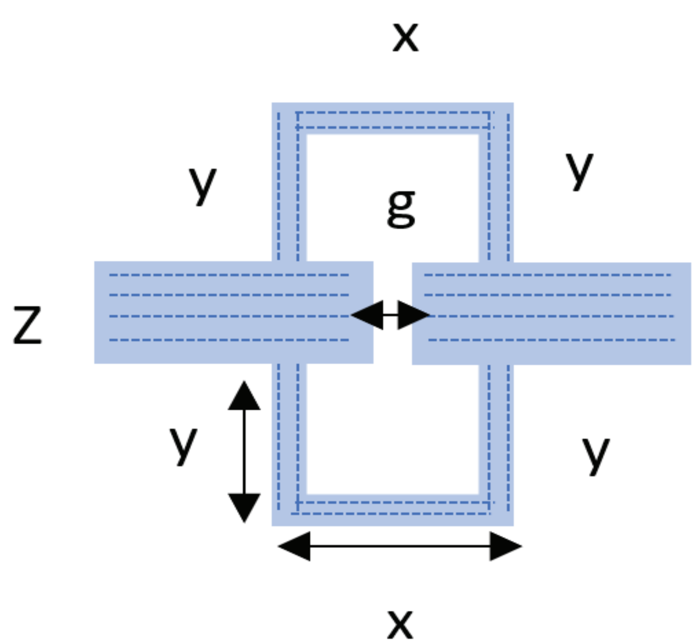


Figure 1.9: Steps followed for design of DGS using quasi-static modelling



(a)



(b)

Figure1.10: (a) Schematic of perturbed current distribution around the periphery of the defect obtained using commercial EM simulators; (b) Schematic showing the equivalent current ribbon.

It can be detected that the strip model reveals it as a combination of two microstrip cross-junctions and the flow of current across the slot created on ground plane of antenna. It is detected that the current flows in form of loop to provide variation in the parameters of antenna [37].

1.7.6. DGS Advantages and Disadvantages

Advantages:

- It is typically careful to approximate an infinite, flawlessly -conducting current sink.
- Requirement of additional complexity in design can be avoided, if various DGS elements are used to correct stop band performance.
- Improves performance.
- It reduces side lobes in arrays antennas.
- It enhances the functioning of couplers and power dividers.
- It reduces the interaction to signals.
- low-profile.
- The DGS elements do not affect the odd mode transmission, but slows the even mode, which necessity for propagating around the edges of the DGS “Slot”.
- Interval lines and phase shifters can be streamlined in many conditions by using DGS.
- The typical capacitive-loaded microstrip line occasionally used for slow-wave applications can be enhanced with the insertion of DGS resonator structures.
- Decreases mutual coupling in antenna array elements by adding DGS.

- Reduce unwanted responses of resonating frequency.
- Higher order disturbance in directional couplers and also in power combiner or dividers circuits are removed.
- DGS allows the designer to place a notch almost anywhere on ground plane.
- The narrow bandwidth can be obtained by specified designs.
- Have compactness in size and free of spurious pass band response.
- Have better harmonic elimination ability when compared with conventional design.
- The DGS has a self-resonant frequency created by slots.
- The structures are simple to design and fabricate.
- The stopband is very wider and deeper.

Disadvantages

- If you initiate slots, back lobes may present due to which some of the energy will be disseminated in back lobe which in turn decreases the gain in desired direction.
- Ground plane is a flawless electrify conductor with magnitude of reflection equal to 1 and the phase equal to -180. When by introducing slots on ground plane this magnitude and its phase gets change, so this ground is not related for the applications that need this property.
- By reducing ground plan, back lobs will increase, it also increases SAR value.
- It reduces front to back ratio.
- The important shortcoming of the DGS technique is it radiates in back circuits. Though much of its instance energy at the resonant frequency is

redirected back down the transmission line. Radiation within surrounded microwave circuits can be problematic to incorporate in simulation. Boundary conditions are typically established for absorbing (no reflections), which rationalises calculations, but excludes the structures around the circuit being examined. In some cases, size of the inclusion will make the problem too large to achieve a solution in a realistic time, and details of the physical structure may take a very long to determine and enter into the software. EM simulation is positively accurate.

- Circuit as a subject, with ambiguity of radiation effects, the construction and cautious evaluation of a prototype is strongly recommended. A knowledgeable designer may be talented to create a basic model of the insertion for more precise simulation, but measurement remains important for confirmation. A less significant shortcoming is that DGS structures upsurge the area of circuit.
- Structures are very problematic to model because of its too many design parameters also cause radiation from the periodic defects in microwave and millimetre wave communication systems.
- An engraved defect on ground plane interrupts shield current distribution over ground plane. The disruption in shield current distribution change the complete prpoperties of a transmission line in terms of capacitance and inductance.

1.7.7. DGS Applications

In this we have seen how the evolution of DGS has taken place from EBG and PBG. Basic DGS classification as well as different geometries along with their S parameters have been examined. Different types of modelling techniques of DGS have been studied and found that quasi-static modelling is more practical as its equivalent value of inductance and capacitance have a direct association with DGS dimensions and thus permit one to design a DGS with the assistance of theoretical calculations. Since its inception, the DGS has been widespread mainly for printed circuit boards. Initial DGS was applied for microstrip antennas developed for the filter applications associated with the microstrip feed line. DGS embedded patch antenna was primary examined in 2005 to progress the radiation properties in single element [35] [37]. After that, during the next five years, the DGS has been explored in diverse shapes and forms. There are wide applications in active and passive devices useful for compacted design. Since each DGS structures provide its particular distinctive descriptions depending on the particular geometries, such circuit functionalities for filtering undesirable signals and alteration of higher order harmonics can effortlessly be accomplished by means of insertion required DGS patterns on ground plane, which correspond to required circuit operations by not increasing circuit complexity. Hence DGS is been more popular particularly in printed circuit board applications. A detailed brief review work on basics of DGS is published in Recent science publication, London International Journal.[1]

[1] International Journal of Electrical and Electronics and Telecommunication Engineering (IJEETE), **"Microstrip Antenna with Defected Ground Structure: A Review"** Recent science publication, London ISSN: 2051-3240. Vol. 46 Issue-1, February 2015 pp. 1492-1496 Impact factor 2.221. (peer Reviewed)