BANDWIDTH ENHANCEMENT OF SPIRAL ANTENNA WITH DEFECTED GROUND STRUCTURE

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This thesis is dedicated to my parents.

For their endless love, support, encouragement and prayers.
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ABSTRACT

In wireless communications systems, harmonics and unwanted frequency other than designed one becomes a dominant factor in limiting quality and capacity of transmitted or received signal. Rectangular spiral antenna (RSA) is designed in order to obtain the required parameter responses at 2.45 GHz for Wifi application. The proposed antenna is excited through the coaxial feed line which is connected from the ground of the antenna. RSA of length 16cm and width 20cm is designed on the substrate dielectric material FR-4 having dielectric constant $\varepsilon_r = 4.3$ and thickness 1.6 mm. Conventional rectangular spiral antenna without DGS has very low bandwidth. This antenna has 64.8MHz which is very low and the fractional percentage is 2.63%. The defect ground structure (DGS) has gained much attention over the last few years for its ability to enhance the bandwidth and gain. After applied DGS the bandwidth enhanced to 245MHz which is very high compared to the conventional antenna. The antenna without DGS has multiple frequencies which are 1.3734, 2.0886 and 2.6538 other than the desired frequency. The DGS also effectively suppress harmonics frequencies of the spiral antenna, shows a better result compared to the conventional antenna. It effectively suppressing spurious frequency and reduces the amplitude of the unwanted multiple bands since the antenna radiates only one resonating frequency.
ABSTRAK

Dalam sistem komunikasi tanpa wayar, harmonik dan frekuensi yang tidak dikehendaki selain daripada itu yang dicipta menjadi punca kepada kualiti yang terhad dan kapasiti dalam isyarat penghantar dan yang diterima. Rectangular Spiral Antenna(RSA) dicipta untuk mendapat parameter yang dikehendaki iaitu 2.45 GHz untuk Wifi aplikasi. Antena yang digunakan ini menggunakan saluran suapan sepaksi yang disambungkan dari bawah bahagian antena. RSA menpunyai panjang 16cm dan lebar 20cm diperbuat daripada bahan dielektrik FR-4 yang telah di dielektrik dan tidak berubah yang mempunyai ketebalan 1.6 mm. RSA konvensional tanpa DGS mempunyai jalur lebar yang sangat rendah. Antena ini mempunyai 64.8MHz yang sangat rendah dan peratusan pecahan ialah 2.63%. Kecacatan pada struktur di bumi (DGS) telah mendapat banyak perhatian sejak beberapa tahun kebelakangan ini dengan keupayanya untuk meningkatkan jalur lebar dan keuntungan. Selepas DGS digunakan jalur lebar ditingkatkan kepada 245MHz yang sangat tinggi berbanding dengan antena konvensional. Antena tanpa DGS mempunyai frekuensi yang banyak iaitu 1.3734, 2.0886 dan 2.6538, selain daripada frekuensi yang dikehendaki. DGS juga berkesan menyekat frekuensi harmonik daripada antena lingkaran telah menunjukkan hasil yang lebih baik berbanding dengan antena konvensional. Ia berkesan menyekat frekuensi palsu dan mengurangkan amplitud daripada banyak pelbagai jalur kerana antena memancarkan hanya satu frekuensi resonaskan.
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<td>$\varepsilon_r$</td>
<td>Permittivity of the substrate</td>
</tr>
<tr>
<td>$\varepsilon_{\text{eff}}$</td>
<td>Effective permittivity of the substrate</td>
</tr>
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<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>CST MWS</td>
<td>Computer Simulation Technology Microwave studio</td>
</tr>
<tr>
<td>FB</td>
<td>Fractional bandwidth</td>
</tr>
<tr>
<td>FR-4</td>
<td>Flame Retardant 4</td>
</tr>
<tr>
<td>GHz</td>
<td>Giga Hertz</td>
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<tr>
<td>%BW</td>
<td>percentage of bandwidth</td>
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<tr>
<td>PCB</td>
<td>Printed circuit boards</td>
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<tr>
<td>RF</td>
<td>Radio-wave</td>
</tr>
<tr>
<td>DGS</td>
<td>Defective ground structure</td>
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<tr>
<td>UHF</td>
<td>Ultra high frequency</td>
</tr>
<tr>
<td>UWB</td>
<td>Ultra-wideband</td>
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<tr>
<td>WB</td>
<td>Wideband</td>
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<tr>
<td>WLAN</td>
<td>Wireless local area network</td>
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<td>RSA</td>
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INTRODUCTION

1.1 Introduction

Wireless technology provides less expansive equipment’s and flexible way for communication purpose. Antenna has its own importance in communication systems; it provides radiation of electromagnetic energy uniformly in all directions. Antenna is a transducer, which converts one form of energy in to another. Here it is designed to transmit or receive electromagnetic waves from one source to destination.[1-3].

Wi-Fi networks use radio technologies. A person with a Wi-Fi enabled device such as a PC, cell phone or PDA can access to the internet when in proximity of an access point. The region covered by one or several access points is called a hotspot. Hotspot can range from a single room to many square miles of overlapping hotspots. The rectangular spiral antenna with defected ground was chosen for this work due to the circular polarization characteristic and the frequency independent characteristics for Wi-Fi applications. Furthermore, this type of antenna can be used to enhance bandwidth and gain[4].
Rectangular spiral microstrip antenna can be fed by using coaxial probe or microstrip line edge feed. In this project, the method of feeding is coaxial feed where the antenna fabricated and printed hole at the back. The Spiral antenna usually has spurious frequency and to overcome this Defected Ground Structure (DGS) on the ground plane of the transmission is made. The DGS at the ground of the transmission line acts like a low pass filter which will determine the frequency that can be passed through the transmission line.

Recently, both defected ground structure (DGS) and electromagnetic band gap (EBG) have received much attention because of their use in radar, satellite, microwave areas and mobile communication systems. Such systems often require circuits to be as small as possible. The DGS components are the dominant technology which can provide size reduction and has the capability of harmonics and spurious suppression[5].

The DGS is realized by etching a certain pattern in the backside metallic plane which perturbs the current distribution in the ground, and hence increases the effective inductance and capacitance of the microstrip line. Therefore, a DGS cell is equivalent to an LC circuit[6]. DGS is realized by etching off a simple shape in the ground plane, depending on the shape and dimensions of the defected the shielded current distribution in the ground plane is disturbed, resulting a controlled excitation and propagation of the electromagnetic waves through the substrate layer, the shape of the defect may be changed from the simple shape to the complicated shape for the better performance.

The DGS is easy to be an equivalent L-C resonator circuit. DGS can be in different size like rectangular, triangular, and circular dumb shell [7]. The rectangular dimension of the DGS represents the inductor and the narrow lattice is the capacitor. The value of the inductor and the capacitor will affect the cut off frequency of the filter that is produce by the DGS.
1.2 Problem Statement

The regular spiral antenna usually has spurious frequency which can make the signal at the operating frequency corrupt, spurious becomes a dominant factor in limiting quality and capacity. In order to suppress the spurious frequency and enhance bandwidth and gain, it can be achieved by adding either low pass or band pass filter that can be used to reject the spurious frequency. By using this method, it can increase the cost of the antenna. The Spiral antenna of the Defected Ground Structure (DGS) has gained much attention over the last few years for its ability of effectively suppressing spurious frequency and increasing the bandwidth.

To overcome that problem, it is proposed to use DGS which is being used spiral with coaxial feed from the ground, because it is easy to design and fabricate. The simulation of the antenna done in CST software.

1.3 Objectives of Study

1. To design rectangular spiral antenna with DGS at 2.45 GHz with bandwidth and gain enhancement.
2. To fabricate and test the antenna.
3. To compare and analyse the result between simulation and measurement.
1.4 Scopes of Study

The scope of this project are:

I. To design and fabricate rectangular spiral antenna with DGS and the designed antenna must suppress any spurious frequencies other than the designed frequency.
II. The antenna is designed to enhance the bandwidth and gain and to explore and simulate the basic parameters of rectangular spiral antenna using CST microwave Studio software.
III. To compare the simulation and measurement result of the designed antenna.

1.5 Theses outlines

This thesis is organized into five chapters. The first Chapter 1, it will cover on introduction on the whole thesis. It also includes the objectives, problem statements, scope of works and main introduction of the project.

Chapter 2 explains on the literature review of the project. The literature review begins with the introduction, followed by antenna parameters. Introduction is an explanation on the overview of the literature. As for the antenna topic, it is about the general description of an antenna. It is also cover on the basic principal of the antenna. This project is more focusing on rectangular spiral antenna. It is important to recognize the parameter of the antenna before designing the antenna itself.

Chapter 3 describes project methodology where it is focusing on the method that used to complete the project accordingly. The methodology will be presented in the flowchart which clearly explained about how this project is planned and organized in completing the project. Chapter 4 presents the result for the system designed and discussion of overall result. The conclusion and recommendation of this project will be discussed in chapter 5.
CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter elaborates spiral antenna as frequency independent antennas, some of the previous works related to spiral antenna, backing techniques of spiral antenna, feeding technique of spiral antenna and Frequency selective surface structures. Literature review is significant part for understanding the specification characteristics to model rectangular spiral antenna with DGS. Literature review is one of the processes of developing rectangular spiral antenna with DGS which operates at the resonant frequency 2.45 GHZ, for this project. The literature review explains on the antenna and the basic antenna operation, basic antenna parameter, the feeding technique.
One of the important components in Wi-Fi application is an antenna. The characteristics needed for a Wi-Fi antenna is an omni-directional antenna with circular polarization [8]. Spiral antennas were introduced in 1950s by Edwin Turner [9] who demonstrated experimentally that an Archimedean spiral resulted in constant input impedance and circular polarization over a wide range of frequencies [10].

The early work on spiral antennas was published in the late 1950’s and early 1960’s. The planar equiangular spiral antenna and the unidirectional equiangular spiral or conical log spiral antenna were presented by Dyson (1959a, 1959b). Bandwidths of greater than 20:1 were observed with nearly constant impedance and pattern performance [11].

The early work on spiral antennas was based on experiment and the band theory. The band theory essentially means that the spiral operates in the region where the circumference of the spiral is equal to a wavelength. In the early 1960’s more rigorous mathematical explanations were pursued.

Curtis (1960) derived the radiation patterns for an Archimedean spiral by approximating the spiral as a series of semicircles. Wheeler (1961) looked at the radiation from various regions of an equiangular spiral using a similar technique to Curtis, but without the semicircle approximation.

Spiral antennas are typically backed by a lossy cavity. The lossy cavity improves the low frequency impedance behaviour and axial ratio of the spiral by reducing reflections from the end of the each arm of the spiral. The lossy cavity also absorbs the back radiation from the spiral providing for a larger pattern bandwidth by reducing the reflection from the ground plane that causes pattern nulls [12].
2.2 Bandwidth Enhancement Techniques of Spiral with DGS

There is a major limitation of narrow bandwidth in Spiral antennas. There are some methods to enhance the bandwidth of an antenna like using slot loaded patch, Slot loaded on ground, modifying the feed, shorting pin and multilayer resonator.

2.2.1 Slot Loaded Patch

For improve the bandwidth of a spiral antenna, cut a slot in the patch of half wavelength long at desired resonant frequency. There are many different shapes of slot like E, H, U, etc. Using slot is the easy way to achieve the moderate bandwidth by proper dimensions of slot.

There is no analytical method is develop so far to compute the exact dimensions for slot dimensions but it is good agreement to compare the length of slots equal to half wavelength long at desired resonance[13].

2.2.2 Defective Grounding Technique (DGT)

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance. The different types of defect ground structures are shown in figure 2.1 below.
Figure 2.1: Various DGSs: (a) spiral head (b) arrow head slot (c) “H” shape slots (d) a square open-loop with a slot in middle section (e) open loop dumbbell & (f) IDC DGS.

2.3 Spiral Antenna as a Frequency Independent Antenna

In 1954, although discouraged by many experts, E. M. Turner wound a long-wire dipole into a spiral form and connected its terminals to a two-wire feed line [14]. At that time, the largest antenna bandwidths were on the order of one octave, but the results obtained with the first spiral experiment were so encouraging that an immediate research effort was launched. Octave bandwidth implies that the higher frequency ($f_H$) of operation is double the lower frequency ($f_L$), for example, an antenna that works from 2GHz to 4GHz has one octave bandwidth [14].

At the present time, wideband frequency independent antennas are irreplaceable components of many communication platforms, various electronic warfare, military communication, satellite communication, direction-finding systems and atmosphere, ground and space exploration stations. In this work, the term wideband indicates on the frequency bandwidth ($Bf$) either in ratio ($Bf = f_H/f_L$) or fractional bandwidth ($Bf$ in percentage is $Bf = (f_H - f_L)/f_C$) and $f_C = f_H + f_L/2$).
Frequency independent (FI) antenna is a type of antenna in which its pattern, bandwidth, gain and other characteristics vary insignificantly with frequency. Spiral antenna is good example for FI antennas and its bandwidth can reach up to 40:1 for both the input impedance and the radiation pattern [15].

Spiral antennas are classified into several types; square spiral, star spiral, Archimedean spiral and equiangular spiral. The square spiral antenna has the same advantages as circular Archimedean spiral antenna at the lower frequencies. A star spiral provides as much size reduction as the square spiral and it allows tighter array packing that the square spiral does not allow. However, one of the major disadvantages of the star spiral antenna is its dispersive behavior. Equiangular spiral antennas have similar characteristics of the Archimedean spiral antenna but their design is more complex compared to circular Archimedean spiral antennas. Therefore, in this project, rectangular spiral antenna is chosen due to its wide bandwidth, frequency independent characteristics and simple design compared to the other types of spiral antennas [16]. Figure 2.2 illustrates examples of the wideband frequency independent spiral antennas.

![Examples of two arm Spiral Antenna](image)

**Figure 2.2**: Examples of two arm Spiral Antenna: (a) Archimedean Spiral, (b) Equiangular Spiral and (c) Square Spiral [16].
2.4 Characteristics of Antenna

There are important antenna parameters which are return loss, radiation pattern, gain and polarization. All of the aforementioned antenna parameters are necessary to fully characterize an antenna and determine whether an antenna is optimized for its applications.

2.4.1 Reflection Coefficient

Reflection coefficient is the reflection of signal power resulting from the insertion of a device in an antenna structure or a transmission line. Reflection coefficient measurements include the characterization of the Voltage Standing Wave Ratio (VSWR). Increasing reflection coefficient corresponds to lower VSWR. According to the wideband requirement; reflection coefficient is a measure of how well the antenna is matched and a match is good if the reflection coefficient is more less than -10dB [17]. Minimum reflection coefficient is also desirable and results in a lower insertion loss. Insertion loss is the loss of signal power resulting from the insertion of a device in that structure. Reflection coefficient indicates the bandwidth for which the antenna sufficiently works along its entire frequency range. Figure 2.3 shows the reflection coefficient of wideband antenna.
2.4.2 Radiation pattern

One of the most common descriptors of an antenna is its radiation pattern. Radiation pattern can easily indicate an application for which an antenna will be used. For example, cell phone use would necessitate a nearly omnidirectional radiation pattern as shown in Figure 2.4 (a), as the user’s location is unknown. Therefore, radiation power should be spread out uniformly around the user for optimal reception. However, for satellite or military applications, a highly directive antenna would be desired such that the majority of radiated power is directed to a specific, known location, hence unidirectional radiation pattern is shown in Figure 2.4 (b).

According to the IEEE Standard Definitions of Terms for Antennas [17], an antenna radiation pattern (or antenna pattern) is defined as the variation of the power radiated by an antenna as a function of the direction away from the antenna. The main properties of the pattern are side lobes, back lobes and main lobes. In practice, it is
impossible to eliminate antenna side lobes and back lobes completely. Antenna side and back lobes affect antenna system performance in several ways.

The energy delivered to or received by side and back lobes is from a direction other than the intended region of coverage and is therefore wasted [17]. Main lobe is the radiation lobe containing the direction of the maximum radiation. The side lobe is a radiation lobe in any direction other than the intended lobe direction. It is usually adjacent to the main lobe and occupies the hemisphere in the direction of the main beam while the back lobe is in the opposite direction.
2.4.3 Gain

Gain is the most widely used descriptor for antenna performance. The gain is defined as the ratio of power received by a directional antenna to power received by an isotropic antenna [17]. An isotropic antenna is a theoretical antenna radiating energy equally in all direction of space. The gain of an antenna must equal to its directivity if the antenna 100% efficient. The gain of an antenna is therefore less than the directivity due to the losses in the antenna. Gain which referred to an isotropic radiator is expressed as “dBi”.

In addition, the gain of the proposed spiral antenna can be expressed in mathematical formulation in terms of the known radiated power per unit area on the bore sight of the antenna \( P_r(r, \phi, \theta, \omega) \) and the power inserted into the spiral \( P_{in} \). If the current and impedance at the feed point are denoted \( I_{in} \) and \( Z_{in} \), respectively, \( \omega \) is the angular frequency of the radiated power, while \( r, \phi \) and \( \theta \) are the spherical coordinates of the antenna, one may use Equations (2.1-2.4) to write the gain; \( G \) [17-18].
\[ Z_{in} = \eta_o / 2 \]  
\[ P_{in} = \frac{(I_{in}^2)(Z_{in}^2)}{2} \]  
\[ P_{rad}(r, \phi, \theta, \omega) = \frac{(\epsilon_r(r, \phi, \theta = 0, \omega))^2}{2\eta_o} = \frac{(\omega \mu_o \lambda I_{in})^2}{(8\pi r)^2 \eta_o} \]  
\[ G = 4\pi \frac{P_{rad}}{P_{in}} = \frac{\pi \eta_o (I_{in})^2}{2(I_{in} Z_{in})^2} \]

### 2.4.4 Polarization

Antenna polarization is a very important consideration when choosing and installing an antenna. Most communications systems use vertical, horizontal or circular polarization. Knowing the difference between polarizations and how to maximize their benefit is very important to the antenna user. The electric field or "E" plane determines the polarization or orientation of the radio wave. In general, most antennas radiate either linear or circular polarization [17]. A linear polarized antenna radiates entirely in one plane containing the direction of propagation. An antenna is vertically polarized (linear) when its electric field is perpendicular to the Earth's surface and horizontally polarized (linear) when its electric field parallel to the Earth's surface as shown in Figure 2.5.
In a circular polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. If the rotation is clockwise looking in the direction of propagation, the sense is called right-hand-circular (RHC). If the rotation is counterclockwise, the sense is called left-hand-circular (LHC) [17]. A circular polarized wave radiates energy in both the horizontal and vertical planes and all planes in between. The difference between the maximum and the minimum peaks as the antenna is rotated through all angles, is called the axial ratio and is usually specified in decibels (dB). If the axial ratio is near 0 dB, the antenna is said to be circular polarized. However, still an axial ratio of less than 3dB can be accepted for circular polarization. Circular polarization is most often used on satellite communications, critical military communications, direction finding systems and GPS.
Figure 2.6: Circular Polarization: (a) Left Hand Polarization and (b) Right Hand Polarization [17].

2.5 Basic Operations for Spiral Antenna

The representation of the current distribution on the arms of the spiral permits to visualize the active region of the spiral radiator. The surface current densities on the spiral arms are retrieved from the near zone field distribution. Generally, the current distribution is analyzed as pulse excitation and harmonic excitation. The current distribution of the spiral antenna qualitatively demonstrates the concept of frequency dependent active region of where the radiation process is taking place on the spiral [18].

The radiating ring theory, also known as band theory is used to describe the theoretical principles behind the operation of spiral antennas [18]. The band theory is demonstrated on the simplest and most commonly used spiral antenna; a single-arm, planar spiral antenna operating at 2.45GHz depicted in Figure 2.7.
2.6 Techniques for Performance Optimization of Spiral Antenna

There are several techniques which can be used to optimize the performance of wideband spiral antenna such as the loading dielectric substrate, radian sphere concept, mutual coupling, moveable ground plane and embedding FSS (moveable ground plane and embedding FSS are discussed under backing techniques):

2.6.1 Dielectric Loading Effects

A spiral is a fast wave antenna and the use of a high dielectric constant or thick dielectric can significantly alter its characteristics. Input resistance is reduced and the gain, axial ratio, and pattern purity in general are all degraded when compared with a free standing spiral. Dielectric loading slows the traveling wave thus reducing the aperture of the active mode. Additionally, the coupling between the neighboring arms is increased and the radiation through the active region is decreased.
This means that the forward traveling wave, after passing the desired region, will have more energy and radiate in the higher order modes, contributing to the excessive far-field contamination [19].

2.6.2 The Radian Sphere Concept

Antennas perform poor effective radiation which leads to a general poor performance of the antenna if the antenna’s dimensions are much less than one wavelength. This poor performance limits the antenna’s applications in practical aspects. The "radiansphere" is the boundary between the near field and the far field of a small antenna. An electrically small antenna is often defined using the concept of the radian sphere [20]. The radian sphere is a hypothetical sphere whose diameter $2r$ is equal to the largest linear dimension of the antenna that it encloses. When the electrical size of the radian sphere is less than $\lambda$ (or $r \leq \lambda/2\pi$), the antenna enclosed by the sphere is considered to be electrically small. These antennas exhibit low radiation resistance, high reactance, low efficiency and narrow bandwidth and all of these parameters limit the performance of the antenna. These antennas are subject to limitations which are fundamentally about the same for a capacitor used as an electric dipole and an inductor (loop) used as a magnetic dipole, if they occupy equal volumes. Either type may have some advantages resulting from variations within this rule or from relative facility in coupling with the associated circuits [20].

The radiation pattern and hence the directive gain of a small antenna remain the same for a smaller size, the radiation resistance decreases relative to the other resistance in the coupling circuit. The resulting reduction in coupling efficiency is one of the principal limitations of the smaller antenna. Another aspect of the same limitation relates to the frequency bandwidth of operation with fixed values of the circuit elements. A smaller antenna with the same reactance and radiation resistance must be more sharply tuned to deliver its available power. Therefore, the reduction of size imposes a fundamental limitation on the bandwidth. If the bandwidth so limited is insufficient, further damping must be added at the expense of coupling efficiency. The limitations
verify the experience that larger antennas are generally more efficient, especially for wide band operation. By expressing the formulas in fundamental forms; the inherent similarity of the electric and magnetic radiators becomes apparent, as well as the minor differences resulting from the use of available materials and structures [20]. Therefore, having known these limitations, a simple mathematical synthesis of the active region based on the radiansphere technique is developed, which leads to the design of electrically large spiral antenna for wideband applications.

2.6.3 Mutual Coupling

Mutual coupling between adjacent arms of spiral antenna affects both the radiation patterns and the bandwidth [21]. The radiation from one driven arm induces currents on other nearby arm and scatters into the far field, which causes poor performance. Continuous and stable antenna characteristics across a wide bandwidth require a smooth transition from one active region to the next as frequency varies. This implies a strong coupling between adjacent structures. In the case of a spiral antenna, this requires sufficient arm spacing to the mutual coupling between the neighbor arms of the spiral antenna, which causes undesired fluctuations in gain, pattern, and return loss.

2.7 Defected Ground Structure (DGS)

There has been growing interest of research in the area of DGS, Defected Ground Structure in last few years and they have shown increasing potential for implementation in several applications. Applications of DGS in filtering circuits have several advantages such as circuit size reduction and suppression of spurious response. In order to achieve the requirement of high bandwidth and compact filtering, various types of DGS resonators have been used earlier. DGS have been used for the implementation of the spurious response of the antenna low pass filter and coupled band-pass filter. DGS can also be used as a building block of the filter; they are rather viewed to improve the response of filters, couplers and oscillators [22].
This disturbance will change characteristics of the antenna such as line capacitance and inductance. In a word, any defect etched in the ground plane of the antenna can give rise to increasing effective capacitance and inductance. The isometric view of a conventional Defected Ground Structure is shown in Figure 2.8. The surface current distribution on the ground plane resembles Figure 2.9. Taking this as the reference the ground plane of the DGS can be truncated as shown in Figure 2.10.

Figure 2.8: Isometric view of dumbbell shaped DGS.

Figure 2.9: Distribution of surface current on the Ground Plane of a unit cell DGS.
Figure 2.10: Truncated Structure according to distribution of current on surface of Ground plane.

Figure 2.11 shows several resonant structures that may be used. The basic element of DGS is a resonant gap or slot in the ground surface (Figure 2.11a), placed directly under the transmission line and aligned for efficient coupling to the line. The dumbbell-shaped DGS (Figure 2.11b) includes two wide defected areas connected by a narrow slot. The conventional dumbbell-shaped DGS has been modified into an I-shaped DGS, as shown in Figure 2.11c. The frequency control of the I-shaped DGS is accomplished by adjusting the length of the transverse slot and the dimensions a and b. The stop-band characteristic of the DGS in Figure 2.11c depends on l, which is the distance between two rectangular lattices. In the U-shaped structure of Figure 2.11e, the loaded Q-factor increases as distance s decreases. Elliptic DGS cells are also obtained by etching a slot that connects two elliptic DGS shapes in a microstrip ground plane (Figure 2.11f). Figure 2.11g represents the DGS unit composed of two U-shaped slots connected by a transverse slot. This DGS section can provide cutoff frequency and attenuation pole without any periodicity, unlike other DGS [22].
2.8 Application of DGS

There are widely applications in active and passive devices useful for compact design. Since each DGS provides its own distinctive characteristics depending on the geometries, such circuit functionalities as filtering unwanted signals and tuning high order harmonics can easily be accomplished by placing required DGS pattern, which correspond to the desired circuit operations without increasing circuit complexity [22].

2.8.1 Delay lines

Placements of DGS along a transmission line introduce changes in the propagation of the wave along the line. The DGS elements do not affect the odd mode transmission, but slows the even mode, which must propagate around the edges of the DGS “slot” [23].
2.8.2 Antennas

The filtering characteristics of DGS can be applied to antennas, reducing mutual coupling between antenna array elements, and reducing unwanted responses (similar to filters). This is the most common application of DGS for antennas, as it can reduce side lobes in phased array, improve the performance of couplers and power dividers, and reduce the response to out of hand signals for both transmit and receive. An interesting application combines the slot antenna and phase shift behaviours of DGS. An array of DGS elements can be arranged on a flat surface and illuminated by a feed antenna, much like a parabolic reflector antenna. Each element re-radiates the exciting signal, but a phase shift can be built into the structure to correct for the distance of each element from the feed. The re-radiating elements introduce additional loss, but the convenience of a flat form factor is extremely attractive for transportable equipment or applications where a low-profile is essential.

Amplifier design also can benefit from DGS due to a number of attractive features that DGS have that can help to improve the amplifier performance. First, the DGS structure is very simple and it is easily simulated or fabricated and this is suitable for periodic structure design. Second, its stop band characteristic could be used to suppress certain harmonics. There are various DGS studies in the literature not only for the analysis of the effect of the defects, but also for the implementation of the defects in various structures in microwave devices. It would be wise to have a look at the previous DGS studies first, and then present the contribution of this study. Defected Ground Structure (DGS) is the first application that comes to mind when the line is preferably not disturbed. A defect on the ground can change the propagation properties of a transmission line with changing the current distribution on the ground side, and the alignment of the fields between the ground and the line [24].
The DGS studies conducted up to now have basically focused on the dumb-bell-shaped DGS which is basically proper for high frequency filtering applications [25]. The dumb-bell shaped defect is placed under the microstrip line as shown in Figure 2.13. Studies on the analysis of the structure have generally used the current density approaches to model the structure. The current density distribution is determined not only by the line path, but also by the discontinuities on the ground; and the resulting current distribution is interpreted as a physical model [26].
REFERENCES


[27] H.Takhedmit, B.Merabet, A 2.45-GHz Low Cost and Efficient Rectenna.