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The Effect of Defective Ground Structure on Antenna Performance: A Review

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Abstract

This paper presents a detailed analysis of the impact of Defected Ground Structures (DGS) on the performance of microstrip patch antennas. Microstrip patch antenna is a hot topic of research for antenna design engineers. While microstrip patch antennas offer numerous advantages in terms of its small size, low cost, low profile and their ease of fabrication, their inherent limitations in gain, bandwidth, and power handling make them less suitable for some high-performance or broadband applications. DGS is a defect created intentionally to improve the performance of the antenna. Each DGS configuration exhibits distinct characteristics, with its geometry and dimensions significantly influencing the overall performance of the antenna.

Keywords: *DGS, Microstrip Patch Antenna, Slot, Polarization, Miniature*

1. Introduction

Microstrip patch antennas are gaining increasing popularity in modern wireless communication systems. An antenna functions as a transducer, converting electrical signals into radio frequency (RF) signals at the transmitter and vice versa at the receiver. Among various types, microstrip antennas are especially favoured for their compact form factor, low production cost, and ease of integration with microwave circuitry. However, these advantages come with drawbacks such as limited bandwidth, low gain, and reduced efficiency. To overcome these limitations, advanced techniques like defected ground structures (DGS) and electromagnetic bandgap (EBG) structures have been introduced. DGS, in particular, is highly effective in enhancing antenna performance by enabling miniaturization, harmonic suppression, improved gain and bandwidth, reduced mutual coupling and cross-polarization, and better return loss. This technique involves etching deliberate patterns in the ground plane, which disrupts the current distribution and modifies the ground's electrical characteristics. By adjusting the dimensions and location of these patterns, one can control the equivalent inductance and capacitance—thereby tuning the antenna's resonant frequency to specific application needs. Microstrip antennas incorporating defected ground structures (DGS) are gaining popularity due to their straightforward design and the convenience of implementing them on microstrip substrates [1]. Fallahpour et al. [2] offers a comprehensive overview of antenna miniaturization techniques based on topology and materials, highlighting methods such as the defected ground structure under topology-based approaches.

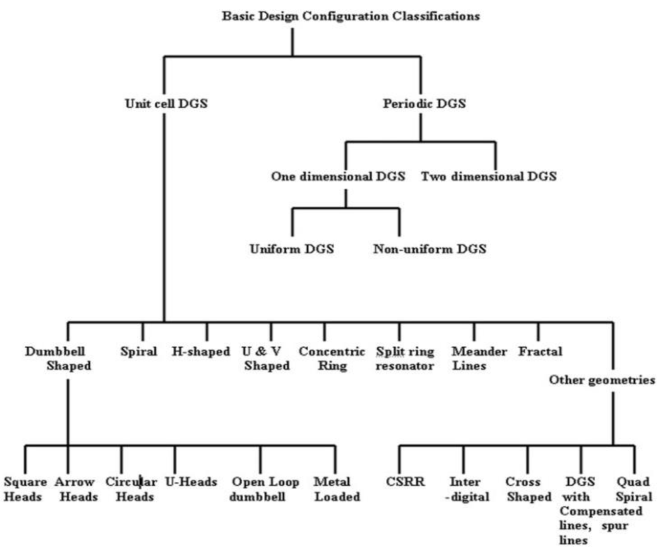

Figure 1 Flow Chart of Various DGS Configurations [5]

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Altering the ground plane leads to discontinuities that reroute the current of the primary radiator along the conductive surface, thereby extending the electrical length of the ground plane [2-3]. Defected Ground Structures (DGS) are created by etching specific patterns into the ground plane. These defects disrupt the current distribution in the ground plane, based on their shape and size, which influences the excitation and propagation of electromagnetic waves through the substrate. Modifying the defect from a simple to a more complex shape can enhance the antenna performance [4]. DGS can be classified as shown in figure1 below. Figure 2 shows the various DGS geometries: dumbbell-shaped, circular head dumbbell, arrow head dumbbell, U-shaped, H-shaped, square heads connected with U-slots, square slots connected with narrow slot at edge, cross-shaped, inter-digital, Fractal, open loop dumbbell, L-shaped, meander lines, U-head dumbbell, double equilateral U, V-shaped, split-ring resonators, concentric ring shaped, half-circle, and spiral-shaped have been reported [5]. The dumbbell shaped DGS is the first form of DGS. The structure includes two rectangular defected regions and a connecting slot, which introduce equivalent inductance (L) and capacitance (C), respectively. As a result, this forms a parallel L-C circuit as shown in figure 3, that produces resonance at a specific frequency [6].

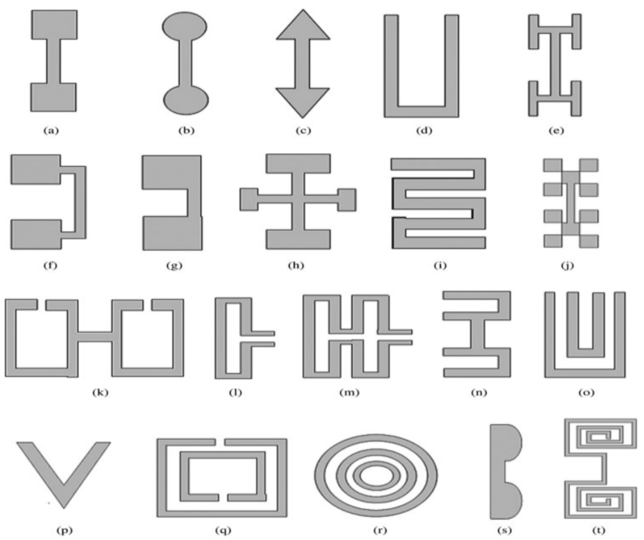

Figure 2 Different DGS Geometries [5]

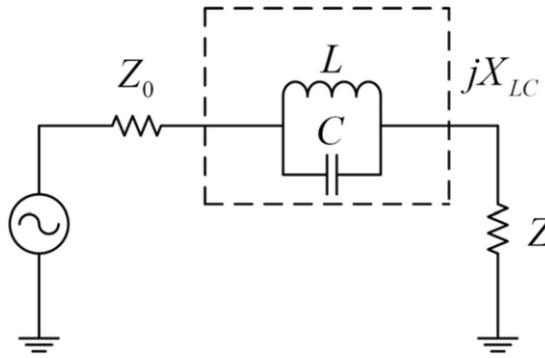

Figure 3 LC Equivalent Circuit of Dumbbell Shaped DGS [6]

Therase et. al. proposed a compact microstrip antenna incorporating novel Circular Ring Resonator (CRR) defected ground structure [1]. The antenna designed for X-band applications is fabricated on FR-4 substrate with inset feed modified square ring as the radiating layer and two concentric circular conductive copper rings as Defected Ground Structure (DGS). In [7] author presented detailed comparison of different compact MSA designs, achieved by etching various slot shapes on the ground plane (using DGS), and contrasts them with designs where slots are etched on the radiating patch. Of all the designs studied, the bowtie-shaped slot on the ground plane delivers the best performance, achieving a 30-dB reduction in cross-polarization levels and a 21% decrease in operating frequency. The authors also proposed that etching slots on the ground plane, rather than on the patch, leads to improved outcomes in terms of reduced operating frequency and lower cross-polarization levels.

By using defected ground structure, a miniature rectangular patch antenna is designed [8]. The ground plane of the antenna is embedded with pi-shaped slot and three annular rings results in shifting the antenna resonance from 13 GHz to 2.4 GHz. In [9] for antenna miniaturization DGS structure in the form of six concentric rings and a rectangular slot is used to shift the resonant frequency of patch antenna from 10 GHz to 3.5 GHz. With DGS the antenna will operate at 3.5 GHz for WIMAX applications. Microstrip patch antenna for dual frequency operation incorporating defected ground structure for improved gain and bandwidth is presented for C-band and X-band wireless applications [10]. The antenna exhibits resonance at two frequencies: 6.1 GHz and 8.9 GHz, delivering gains of 3 dB and 10 dB at these respective frequencies. With the proposed defect the antenna is able to achieve 95 % bandwidth enhancement at 8.9 GHz. The bandwidth and gain of the antenna are improved by incorporating four dumble-shaped DGS structures below the microstrip feed line [11]. A circular shaped patch antenna is implemented on FR-4 substrate and four dumble-shaped slots are loaded underneath the feed line for UWB applications. To reduce cross-polarized (XP) radiation of a microstrip patch antenna a defected ground structure is proposed [12]. The circular patch antenna featuring a defect in the ground plane effectively reduces cross-polarization levels, while maintaining the antenna's other characteristics unchanged. Rectangular microstrip patch antenna integrated with DGS to improve polarisation purity (co- to cross-polarised isolation) in radiated fields is proposed [13]. Author demonstrated the possibility of achieving high polarisation purity with improved bandwidth.

A rectangular-shaped Defected Ground Structure (DGS) was implemented on microstrip array antennas comprising two, four, and eight elements, fabricated on glass epoxy substrates [14]. The study demonstrated that increasing the number of array elements integrated with DGS led to enhanced bandwidth performance. A miniaturized microstrip patch antenna array designed for the S band at 2.2 GHz is introduced in [15], utilizing a Defected Ground Structure (DGS) to enhance performance. RT-Duroid substrate is used for the fabrication of the antenna prototype. Antenna miniaturization of 83% in comparison to conventional patch antenna is achieved, as the resonance frequency has been shifted from 5.2 GHz to 2.2 GHz. For reduction in mutual coupling between elements in microstrip antenna array structure a novel T-shape DGS is proposed [16]. The main advantage of the proposed DGS is its compact structure in comparison to the conventional DGS. With T-shape DGS mutual coupling reduction is achieved in case of both the E-plane and H-plane. In [17] author proposed use of defected ground structure for controlling higher order harmonics in microstrip antenna array for S band application. A pair of dumbbell-shaped defected ground structures (DGS) has been incorporated beneath the feed point, to eliminate the higher order harmonics. A MIMO antenna incorporating DGS is designed for operation at terahertz (THz) frequency range [18]. The improved isolation performance of the quad-port MIMO antenna is achieved through the implementation of a Defected Ground Structure (DGS) functioning as a band-stop filter. This configuration effectively decouples the electromagnetic field between the stimulated antenna and the terminated one. The antenna demonstrates strong isolation characteristics, maintaining levels above 20 dB across the 2.8 to 10.4 THz frequency range. Additionally, within the 1.7 to 2.7 THz band, it achieves isolation greater than 10 dB. A MIMO antenna with two elements operating at 5.8 GHz, DGS in the form of a zigzag grove is inserted into the center of the two elements to reduce the mutual coupling is presented [19]. The mutual coupling is reduced by 28.8 db.

Conclusion

The effect of defected ground structure on the performance of microstrip patch antenna is presented. The defected ground structures are having various shapes and sizes and have resonant behavior. It affects the antenna parameters like frequency, bandwidth, reflection coefficient, cross polarization, gain. Over time, a range of Defected Ground Structure (DGS) designs have been developed to enhance performance specifically aiming for wide bandwidth, miniature size, gain, cross polarization reduction, and many more. The integration of DGS introduces an additional degree of design flexibility in microwave antenna designing and its various applications.

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