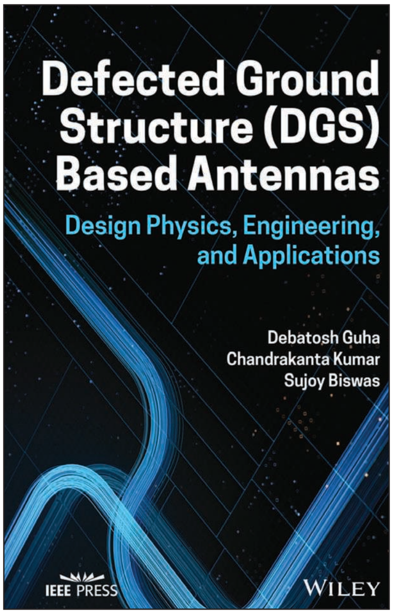
Defected Ground Structure (DGS) Based Antennas: Design Physics, Engineering, and Applications

Reviewed by Armando Fernández-Prieto



Title: *Defected Ground Structure (DGS) Based Antennas: Design Physics, Engineering, and Applications*
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This book takes you on an exciting journey into the world of antennas designed with defected ground structures (DGSs). It covers a wide range of interesting and timely topics. The authors, Prof. Debatosh Guha, Prof. Chandrakanta Kumar, and Prof. Sujoy Biswas, who are globally recognized experts in the field of antennas, have compiled a comprehensive collection of subjects. These topics span from the foundational elements of DGSs, involving the modeling, examination, and creation of DGS equivalent circuits, to discussions on DGSs for printed antenna feeds, control of unwanted modes under a microstrip patch to reduce cross-polarized radiation, and mutual coupling in arrays and multiple-input, multiple-output (MIMO) designs. The applications of DGSs extend not only to printed antennas but also to planar inverted-F and dielectric resonator antennas.

In Chapter 1, the authors deliver a thorough introduction to DGSs, offering an extensive review. They delve into the physics behind DGSs and their evolution from photonic bandgap and electromagnetic bandgap structures (EBGs) in a sophisticated yet accessible manner. They accurately conclude that DGSs are a simplified case of 2D EBGs printed on the ground plane. The chapter provides a comprehensive classification of various geometries used in implementing DGSs in printed circuits, starting with the initial comb-like structure. The evolution of geometries from the comb-like structure is analyzed, showcasing more sophisticated and compact designs with improved performance. Detailed descriptions are given for frequency-tunable DGSs, uniform periodic DGSs, nonuniform periodic DGSs, and asymmetric DGSs. Finally, the chapter explores the wide range of applications for DGSs in microwave circuits, both passive and active, tracing their evolution from filter design to their use in planar antennas.

Chapter 2 is dedicated to the circuit modeling of DGSs in planar technology and their application in planar antenna design with DGS integration. The primary focus is on three main methodologies for modeling DGSs: lumped *LC*/*RLC* circuits, distributed transmission line circuits, and the quasi-static approximation. Based on these methodologies, the authors propose equivalent circuits for DGSs with different geometries, such as dumbbell, spiral, interdigital or open-square DGSs. Furthermore, DGSs with aperiodic rejection bands are also studied in this chapter. In all cases, losses are considered in the equivalent circuit models when necessary. The chapter closes by discussing the suitability of the various circuit modeling techniques for DGSs, emphasizing that the specific application and the DGS placement relative to the antenna's transmission lines determine the most appropriate technique.

In Chapter 3, the authors conduct a comprehensive discussion on the significant potential of DGSs in enhancing the response and performance of printed antennas. The authors specifically focus on the utilization of DGSs in both the transmission lines feeding the antennas and the antennas themselves. Regarding feeding, the chapter includes detailed

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demonstrations illustrating how DGSs can enhance antenna matching and suppress higher order harmonics up to the fourth order. Exploring applications in the antennas, they explore areas such as the design of filtering antennas, the enhancement of isolation between different ports, the expansion of the operating bandwidth of patch antennas, and strategies for achieving high levels of miniaturization through the design of more compact antennas. While the issue of reducing cross polarization in linearly polarized antennas is mentioned in this chapter, it is extensively discussed in the next chapter.

In Chapter 4, the authors commence with a rigorous study of resonant modes in patch antennas of various geometries (rectangular, circular, triangular, etc.), clearly identifying, for each case, the dominant mode causing copolar radiation and the modes responsible for cross-polarization radiation. In all cases, except for the circular and square patches, these modes are essentially higher order modes. In the case of the circular and square patches, the orthogonal component of the dominant mode must also be considered as a source of cross polarization. The chapter provides a brief overview of different techniques used to reduce cross-polarization levels in the orthogonal plane or H-plane for planar antennas, most of them based on perturbing higher order modes without affecting the fundamental radiating mode. Some practical aspects to be considered when integrating DGS antennas, such as SMA connection and the presence of metallic support for the antennas, are also discussed.

Chapter 5 discusses the sources of cross-polarization radiation in linearly polarized microstrip antennas in detail, addressing both the main planes (especially the H-plane) and the diagonal planes, which were not considered in Chapter 4. Additionally, the discussion is conducted for various patch geometries and feeding techniques. In all cases, the importance of the near-field transverse electric and magnetic fields in generating cross-polarization radiation is apparent. These fields are closely related to the surface electric currents flowing on both the microstrip patch and the ground plane. This insight suggests the use of DGSs to enhance the currents responsible for the radiation of the main mode while simultaneously disturbing, to the extent possible, the currents responsible for cross-polarization radiation. Thus, the authors demonstrate that the use of DGSs allows for the design of microstrip antennas with low cross polarization in both the main and diagonal planes.

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For applications that require high gain values, beam scanning, or very specific beam shapes, the use of antenna arrays becomes essential. Antenna arrays take up much more space than a single antenna would, and they also present a series of issues associated with both the array of antennas and the feeding system of the array. All of these matters are discussed in detail in Chapter 6. In this chapter, the authors analyze how the use of DGSs allows, among other things, a significant reduction in cross-polarized radiation originating in all planes (E, H, and diagonals) due to both the type of feeding (coaxial or microstrip) and the discontinuities present in the feeding network of the array. The results are illustrated with a series of specific applications, such as millimeter-wave imaging or enhancement of the scanning range in metasurface arrays, among others. Another significant issue presented by antenna arrays is the mutual coupling among elements of the array. This subject is precisely addressed in Chapter 7.

In general, the mutual coupling among elements within the same antenna array typically leads to a degradation in the array's performance. Some of the issues associated with this coupling include a decrease in gain, an increase in sidelobe levels, or the generation of grating lobes, among others. For this reason, in Chapter 7, the authors undertake a comprehensive study of the mutual coupling among elements in linearly polarized antenna arrays. They explore how the implementation of DGSs enables a significant reduction in mutual coupling. The three main mechanisms giving rise to mutual coupling among array elements are analyzed: radiation coupling, surface wave coupling, and coupling due to currents in the ground plane. In all cases, DGSs prove to be tremendously efficient in reducing mutual coupling as demonstrated when used in certain critical applications, such as reducing scan blindness in large arrays, increasing the scan range in phased arrays, or enhancing the performance of antennas used in 5G, MIMO, and millimeter-wave applications.

Chapter 8 focuses on the use of DGSs in antennas with circular polarization. It begins with a thorough discussion of various methods for generating circular polarization in planar antennas and presents the main challenges associated with this polarization. In circularly polarized antennas, the axial ratio must be as close to one as possible across the entire bandwidth. Additionally, the bandwidth for which the axial ratio is close to one should, as much as possible, coincide with the antenna's impedance bandwidth. This condition, defining the antenna's operating bandwidth, can be achieved through the intelligent use of DGSs. Therefore, this chapter extensively studies the use of these structures in various types of planar antennas, not only to provide two orthogonal polarizations—a necessary condition for achieving circular polarization—but also to increase the operating bandwidth of the antennas. Furthermore, the chapter also analyzes the possibility of using reconfigurable DGSs to achieve antennas that can switch from left-handed circular polarization to right-handed circular polarization. The chapter also proposes solutions for broadband antennas implemented on thick substrates. Such substrates lead to high levels of cross polarization and significant deviations in the antenna beam. The use of DGSs helps to mitigate these two problems considerably. The chapter concludes by exploring how incorporating DGSs into substrate-integrated waveguide antennas with circular polarization, fed with two ports, enhances the isolation between these two ports.

Finally, in Chapter 9, the authors delve into the utilization of monopole antennas loaded with DGSs for ultrawideband and multiband applications. Monopole antennas often experience impedance matching degradation and radiation pattern nonuniformity when implemented with reduced ground planes. Additionally, since the bandwidth for these antennas is very wide, they can interfere with other narrower bands or channels commonly used, such as a wireless local area network, WiMAX, or X-band. This chapter provides intelligent solutions to these issues using DGSs: introducing notches to avoid interference with other bands; controlling the radiation pattern of monopole antennas due to their ability to provide a large impedance bandwidth with a compact ground plane; and achieving multiband operation by introducing resonances that allow the division of the ultrawideband transmission channel of the antenna into different smaller bands with controllable bandwidths and center frequencies.

The book also provides a large collection of references organized by topic and a lot of images of real structures with their respective electromagnetic responses, which facilitate a better understanding of the concepts being discussed. This book serves as an immensely valuable resource for readers. In essence, it stands as an excellent reference for diverse facets of antennas based on DGSs. Not only is this book an informative source, but it also serves as inspiration for those looking to venture into this exciting research field. I am confident that you will find great value in having your own copy.

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papers, books, and sports (item “9” in Figure 2). I will ponder about the quest for understanding why we are in this vast universe going back to about 13.7 billion years ago and perhaps even more if we consider a multiuniverse scenario. May Maxwell’s equations guide you and lead you to uncover more mysteries of nature, all for the betterment of humanity and our planet Earth (item “14” in Figure 2). Finally, and most importantly, give your utmost attention to your health and well-being, as this is the only commodity that you truly own throughout your life (item “15” in Figure 2). Try to exercise my 15 life lessons and I promise you good things will happen (Figure 2)!

SUPPLEMENTARY MATERIAL

This article has supplementary downloadable material available at http://doi.org/10.1109/MAP.2023.3334680.

You are also encouraged to watch the video, “Interview posted on YouTube: Legends of Electromagnetics: Prof. Yahya Rahmat-Samii.”

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I thank Prof. Kathie Melde, my former Ph.D. student, and Prof. Stuart Long, a longtime colleague, for organizing the special session during my 50 years of research and educational activities at my 75th birthday. Many thanks to my family, all my students, collaborators, and colleagues who, throughout my career, have empowered me to enjoy what I do and hopefully keep on doing it. I am also grateful to Dr. C. J. Reddy for inviting me to contribute this article to his magazine column.

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