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Review of Monopole Antenna

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Review/Article

ABSTRACT In this sense, the monopole antenna has evolved dramatically since its invention, starting from basic structures made of wires and moving forward towards more advanced, smaller, and planar types. The aim of this paper is to give an overview of the evolutionary path of the monopole antennas from basic classical theory to modern solutions designed to meet the requirements of contemporary wireless communication. In light of increasing demands for faster high-throughput networks, such as Fifth Generation (5G) and the Internet of Things (IoT), conventional narrow-band monopoles are no longer able to satisfy their needs. Thus, the new era of development started with planar printed monopoles that can operate in Ultra-Wideband (UWB). In particular, this research focuses on the evolution in terms of broadband operation, considering the application of Defected Ground Structures (DGS) technology to improve impedance bandwidth and reduce mutual coupling in Multiple-Input Multiple-Output (MIMO) configurations.

Keywords: Key Words: Monopole Antenna, Ultra-wide Band (UWB), Defected Ground Structure (DGS), MIMO (Multi-input and Multi-output), Impedance Bandwidth, Electromagnetic Simulations.

1. INTRODUCTION

The history of the monopole antenna is rooted in the early years of RF engineering. Essentially, a traditional monopole antenna is a resonance antenna that consists of a straight rod or wire mounted vertically over an infinite conductive ground plane. Based on the theory of images, the ground plane behaves like a mirror, hence creating an image of the antenna; as a result, a quarter-wave monopole works exactly like a half-wave dipole. For decades, this basic configuration served as the backbone for broadcasting, mobile telephony, and vehicular communications. However, the explosive growth of wireless technology over the last two decades has necessitated a radical departure from bulky wire structures. Moving from the ultra wideband (UWB) spectrum range (3.1 GHz to 10.6 GHz), allowed under commercial usage regulations established by the Federal Communications Commission (FCC),

led to the emergence of an urgent demand for antennas capable of providing high data transmission rates within the shortest distance possible without falling victim to the multipath fading effect (Kaur et al., 2022). Classical monopoles are inherently narrowband and dispersive; hence, they cannot effectively transfer the nanoseconds-pulse-type signal specific to ultra-wideband applications since these types of signals would be seriously distorted. As a result, the geometry of classical monopoles has transformed to printed planar ones. Printed planar monopole antennas mounted on dielectric substrate materials are beneficial due to their low profile, light weight, conformability, and easy compatibility with MMICs. Although printed planar monopoles provide numerous advantages, designing highly miniaturized planar structures remains a challenging task as the shortened surface current paths lead to very poor impedance matching properties at low frequencies (Ayyappan & Patel, 2022). Modern efforts in addressing this problem have included a variety of innovations, such as fractal geometries, stepped feedlines, and artificially engineered ground planes (Kumar et al., 2020).

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2. METHODOLOGY

The contemporary design process for developing an advanced UWB antenna from a basic monopole involves extensive iterations of structural changes complemented by thorough analysis of electromagnetics using computational techniques. In most cases, the development process can be broadly classified into three stages: radiator shape designing, ground plane modification, and MIMO configurations.

2.1. Radiator Shape Design

To begin with, the design process starts with mathematical modelling of the radiating patch shape. Contrary to the conventional practice of calculating quarter wavelength in wire antennas, in case of planar monopoles, the lowest resonant frequency is estimated by computing the overall effective area of the radiator and its dielectric surroundings. Popular geometrical forms for a starting point are circular, ellipse, or rectangular shape. As far as elliptical shapes are concerned, they are known for smooth impedance transition that Favors wide bandwidth operation. Based on the above considerations, dimensions of the patch are derived through mathematics. After creating the initial patch shape, the designer moves to computer modelling of the antenna using specialized tools like CST Microwave Studio. The software provides the possibility of analysing a number of critical characteristics of the device such as the S-parameters, radiation efficiency, and surface currents on the radiator.

2.2. Bandwidth Enhancement Using DGS and Tapering

In order to convert the basic printed monopole antenna into an ultra-wideband or super wideband, careful optimization of the transition region between the feedline and the radiating patch is required. Often, tapered coplanar waveguide (CPW) or microstrip feedline is used to perform the transition from the conventional 50-ohm feed line impedance to the impedance of the radiating patch. Concurrently, the ground plane undergoes geometrical alteration referred to as Defected Ground Structure (DGS). By DGS, some intentional slot cutting or defects, such as L-shaped, U-shaped, or spiral slots, are introduced on the ground plane in order to hinder return current propagation. This process adds additional reactive elements (inductance and capacitance) that lead to the excitation of adjacent modes. Consequently, when lower-order modes overlap, they increase the fractional bandwidth of the antenna (Dwivedi, 2022).

2.3. Integration and Decoupling of MIMO

In multi-path scenarios, MIMO is used to improve the capacity of the channel. The downside is that the use of more than one element for monopole in such a confined space would lead to coupling and thus reduce the overall level of diversity. The third step in the design process consists of configuring the placement of the monopoles (for example, at angles) and incorporating decoupling components. Ground planes designed in an appropriate manner prove highly useful in this regard; shared-ground structures with parasitic arms or different DGS configurations suppress surface waves and do not allow any leakage of electromagnetic energy between ports, hence ensuring good port-to-port isolation (Kumar et al., 2022). Notch properties are added by incorporating split ring resonators (SRRs) in patches or feedlines when interference from narrow bands (WLAN or X-band satellite signals) is to be avoided (Zhao et al., 2024).

3. RESULTS AND DISCUSSION OF RECENT ADVANCES

Recent literature review shows a great success in application of these contemporary techniques in creation of highly isolated, small-size and wideband monopoles. The greatest development in this area is evident in the shift from ultra-wideband designs using single element to multi-port dense MIMO structures.

3.1. Super-Ultra-Wideband Antennas and Miniaturization

Current advancements extend the range of frequencies associated with the conventional UWB spectrum. For example, Ayyappan and Patel (2022) presented their work on printed triple elliptical monopole antenna based on DGS technique, which allowed achieving an exceptionally large fractional bandwidth of 183.5% ranging from 1.91 GHz to 43.5 GHz. This design provided for reduction in size by 75.58% relative to standard elliptic radiators, thus showing that fractal geometry along with defects in ground plane could be effectively applied in order to achieve 5G and IoT network infrastructure. Another innovative technique involves formation of large bandwidth by means of sickle-shaped complementary slots from ground plane (Kumar et al., 2020).

3.2. 3D and Wearable Advances

There have also been advances in terms of physical orientation of planar monopoles. In order to achieve diversity in terms of

space within the off-body environment, non-planar 3D configurations have been considered. For instance, Shakir et al. (2021) created an 8-element UWB-MIMO configuration in which planar monopole pairs were arranged in different orientations on each face of a cubic polystyrene block. Orthogonalization, together with use of spiral FSS on the ground plane, allowed the system to generate 20–30 dB isolation across all elements.

3.3. Isolation in Dense Antenna Arrays

High isolation (S21, S31, etc.) among adjacent ports is one of the major issues facing designers of compact smart devices. According to the modern scientific literature, only DGS allows to achieve the best results in terms of decoupling. For instance, a six-port UWB MIMO antenna from 2.9 to 11 GHz could achieve more than 20 dB of isolation between all ports (Kumar et al., 2022). It has been achieved thanks to the use of an innovative design of pyramidal and rectangular radiators with DGS absorbing the currents at their surfaces. Additionally, all such solutions ensure ECC values below 0.075 and DG above 10 dB.

4. CONCLUSION

It is worth noting that the monopole antenna design is now much more sophisticated compared to the classical wire antenna. There is an ever-increasing requirement for bandwidths, increased data transfer rates, and compactness that is driving the development of the monopole antennas in a planar, printed form factor. As highlighted above, the design process involves scaling geometries of the radiating structure, impedance matching by utilizing tapered feeds, and the crucial employment of the defected ground structure concept. While DGS technology enables combining several resonant frequencies in order to achieve ultrawide bandwidth, it can also be regarded as an essential decoupling element in tightly-packed MIMO systems. Leveraging modern 3D electromagnetic simulation software will enable pushing the boundary of maximum bandwidth-to-dimension ratio even further. The future evolution will include adding reconfigurable parts and employing machine learning algorithms.

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