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Design and Analysis of Planar Antenna for Radar Applications

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Abstract

This paper focuses on designing T-shaped planar antennas for Radar applications using High Frequency Structure Simulator (HFSS) software. Antenna parameters such as return loss, gain, and radiation pattern are compared to determine the optimal design for the X-Band RADAR application, ranging from 8GHz to 12GHz. Through evaluation and comparison, it is concluded that the H-shaped antenna, sized at 70601.6, exhibits the best overall performance. This antenna demonstrates an efficient gain of 6.7dB with an operating frequency of 9.02GHz. The selection of the H-shaped design over other configurations suggests its superiority in meeting the requirements of RADAR systems operating within the specified frequency range. This study underscores the significance of simulation tools like HFSS in antenna design, allowing for thorough analysis and optimization to achieve desired performance metrics. The findings contribute to advancing antenna technology for Radar applications, enhancing communication and sensing capabilities within the X-Band frequency range.

Keywords: T-shaped antenna, Planar, Radar applications, HFSS software, X-Band, Gain.

1. Introduction

An antenna is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an electric current oscillating at radio frequency (i.e. a high frequency alternating current (AC)) to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals that is applied to a receiver to be amplified.

Antennas are essential components of all equipment that uses radio. They are used in systems such as broadcasting, broadcast, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones, Bluetooth-enabled devices, wireless computer networks, baby monitors, and RFID tags on merchandise.

In some sense the first antenna dates from 1887, when Heinrich Hertz designed a brilliant set of wireless experiments to test James Clerk Maxwell's hypothesis. Hertz used a flat dipole for a transmitting antenna and a single turn loop for a receiving antenna. For the next fifty years antenna technology was based on radiating elements configured out of wires and generally supported by wooden poles.

Various studies have been conducted on automotive radar technology, focusing on different aspects such as active safety functions, antenna design, and trends in the field. While these studies provide valuable insights, they also have limitations [1]. For example, some studies may have a narrow focus on radar technology without considering other sensor technologies, which could limit the overall effectiveness of safety and comfort functions in automotive applications [2]. Additionally, specific design constraints of antenna arrays or a lack of in-depth analysis on advancements in radar technology could restrict their adaptability and practical insights [3]. Experimental validation of proposed designs in real-world scenarios is also crucial to determine their practical utility [4] and [5]

Various research papers focus on advancements in millimeter-wave technology for automotive radar sensors, including multibeam and multi-range radar systems, array antennas, vehicle millimeter long-and medium-range radar antenna arrays, substrate integrated waveguides, dual-layer transmit arrays, and broadband self-compensating phase shifters [6,7]. While these studies offer valuable insights into radar technology, some limitations include narrow frequency band focus, lack of comparative analysis, specific range applications, limited performance metrics, theoretical emphasis without practical considerations, and lack of information on scalability or adaptability [8,9]. These limitations may impact the generalizability and practical utility of the proposed radar system designs [10,11,12].

1.2. Proposed System

Marine radars are essential sensors used for detecting hazards (such as coastlines, icebergs, or other ships) and assisting the navigating in making timely decisions. Currently, several frequency bands are assigned to marine radar applications, including the S, X, and Ku bands;

in this researches, the operating frequency ranges from 9.3 to 9.4GHz. Compared with the systems using S band, the X-band system have the advantages of the compactness, flexibility, and Maneuverer ability, which benefit yachts and fishing boats.

Marine radar employs a high gain antenna which is equipped with a rotor that scans the entire horizon by transmitting the radio signals in known directions and also to receive the returning signals to detect the objects of interest. The factors such as main beam width, front to back ratio, side lobe level and polarization depends on the antenna used and also affects the performance of the radar. The undesired signals interpret falsely a target in the main beam direction thereby causing an error to be detected. Applying a horizontal polarization is necessary in order to resolve two targets in close proximity. In radar systems microstrip patch array antennas are widely applied because of their high gain, low cost, light weight and low profile in addition to which they can also accurately control radiation patterns.

The two most common type of array feeding structures are parallel-fed and series-fed structures in parallel-fed scheme, many power devices having discontinuities and also long transmission lines are essential. The presence of which aids substantial dielectric loss and spurious radiation to occur. On the other hand, short transmission lines are being used by the series fed structures which enhance the antenna efficiency. The two feeds that are commonly used in the series-fed structure are the resonate and travelling wave feeds. Resonate feed has a narrower bandwidth compared to that of a travelling wave feed. Due to the change in phase angle between two adjacent elements along the series-fed lines, the operating frequency changes which in turn the main beam angle causing the occurrence of inaccurate angle detection mainly in Frequency Modulated Continues Wave system. On the contrary, the parallel-fed structures in the middle of an array entrust the direction of the combined beam of each half array to be pointed in the broadside.

2. Proposed T Shaped Antenna Design

Antennas play a crucial role in modern communication systems, serving as the interface between electronic devices and the electromagnetic spectrum. The T-shaped antenna design represents a versatile and widely used configuration due to its simplicity, compactness, and broadband capabilities. In this proposed design, we will explore the key features, design considerations, and potential applications of a T-shaped antenna.

The T-shaped antenna structure consists of a horizontal radiator, resembling the horizontal bar of the letter 'T', connected to a vertical feed line, resembling the vertical stem of the letter 'T'. This configuration offers several advantages, including omnidirectional radiation patterns, ease of fabrication, and suitability for integration into various devices and systems.

One of the primary design considerations for a T-shaped antenna is its resonant frequency and impedance matching. By adjusting the dimensions of the horizontal and vertical elements, engineers can tune the antenna to resonate at specific frequencies, making it suitable for a wide range of applications, including wireless communication, RFID systems, and radar systems.

The size of the T-shaped antenna is typically determined by the desired operating frequency. For example, antennas operating in the GHz range will have smaller dimensions compared to those operating in the MHz range. Additionally, the material properties of the antenna substrate, such as dielectric constant and loss tangent, can influence its performance and efficiency.

To achieve broadband operation, designers may incorporate additional features such as parasitic elements, impedance matching networks, or multiple resonant modes. These techniques help broaden the frequency bandwidth of the antenna while maintaining acceptable radiation characteristics across the operating range.

The T-shaped antenna design offers flexibility in terms of mounting options and orientation. It can be implemented in various configurations, including monopole, dipole, or inverted-L, depending on the specific requirements of the application. Furthermore, its compact size makes it suitable for integration into compact electronic devices such as smartphones, IoT sensors, and wearable gadgets.

In terms of performance, the T-shaped antenna exhibits omnidirectional radiation patterns in the azimuth plane, making it suitable for applications requiring uniform coverage in all directions. However, the elevation pattern may vary depending on the height and orientation of the antenna above the ground plane. Proper placement and ground plane design are essential to optimize performance and minimize interference.

The proposed T-shaped antenna design holds promise for a wide range of applications in wireless communication, IoT, RFID, and radar systems. Its simplicity, compactness, and broadband capabilities make it an attractive choice for engineers and designers seeking reliable and efficient antenna solutions. By carefully optimizing the dimensions, materials, and operating parameters, the T-shaped antenna can fulfill the demanding requirements of modern wireless communication systems while offering versatility and cost-effectiveness.

Figure 1 shows the geometry of the proposed T shaped antenna capable for dual-band operational characteristics. In our present design structure, the antenna is etched on both sides of Rogers RO3003(tm) substrate with relative dielectric constant 3, thickness 1.6 mm, and a total area Ls*Ws is 70*60 mm^2.

3. Structure of T Shaped Antenna

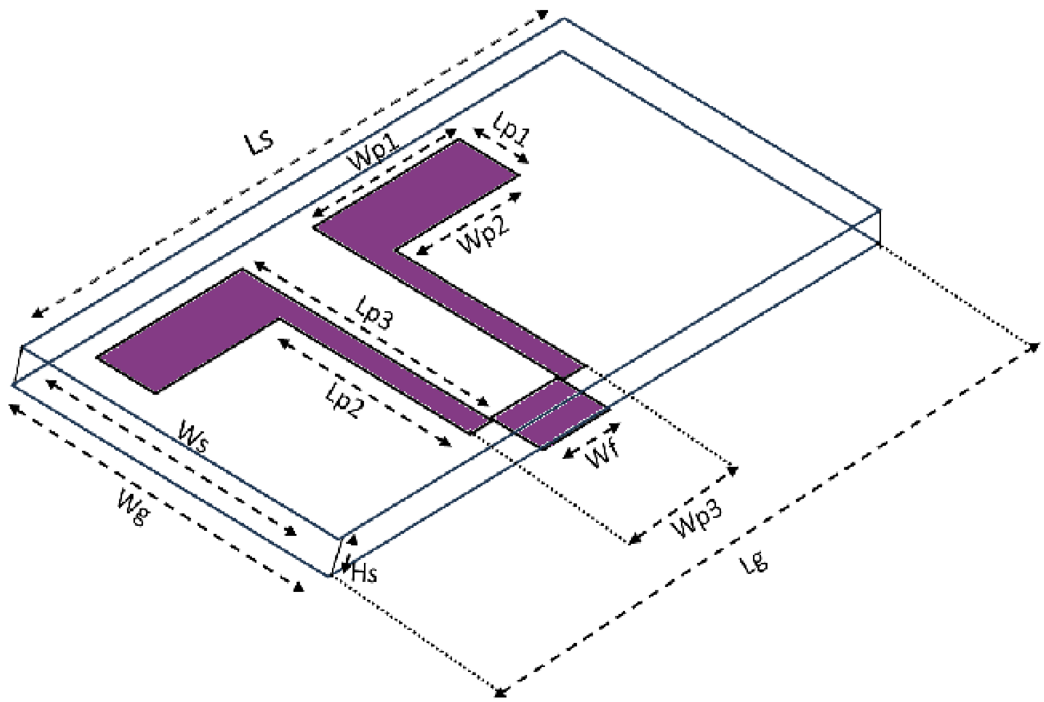

Figure.1. Schematic representation of T-shaped Antenna

Various parameters related to the dimensions of patches, substrate, ground, and feedline in a scientific research context. The width and length of three different patches, labeled as Wp1, Wp2, Wp3, Lp1, Lp2, and Lp3, are provided in millimeters. The width of patch 1 is 23 mm, patch 2 is 21 mm, and patch 3 is 9 mm. The length of patch 1 is 11 mm, patch 2 is 33.75 mm, and patch 3 is 44.5 mm. Additionally, the dimensions of the substrate are given as Ls (length), Ws (width), and Hs (height) with values of 70 mm, 60 mm, and 1.6 mm, respectively. The ground dimensions are specified as Lg (length) and Wg (width) with values of 70 mm and 60 mm. The feedline dimensions are denoted as Lf (length) and Wf (width) with values of 26.25 mm and 5 mm. These parameters are crucial for the design and analysis of the electromagnetic properties of the structure under investigation, providing a basis for further experimental and theoretical investigations in the field of electromagnetic engineering.

4. Results and Discussion

4.1. Simulation Results of T Shaped Antenna return Loss

Figure 2 shows the graphical representation of the return loss for T-Shaped antenna. It attains the return loss as -27.02 dB at 10.63 GHz.

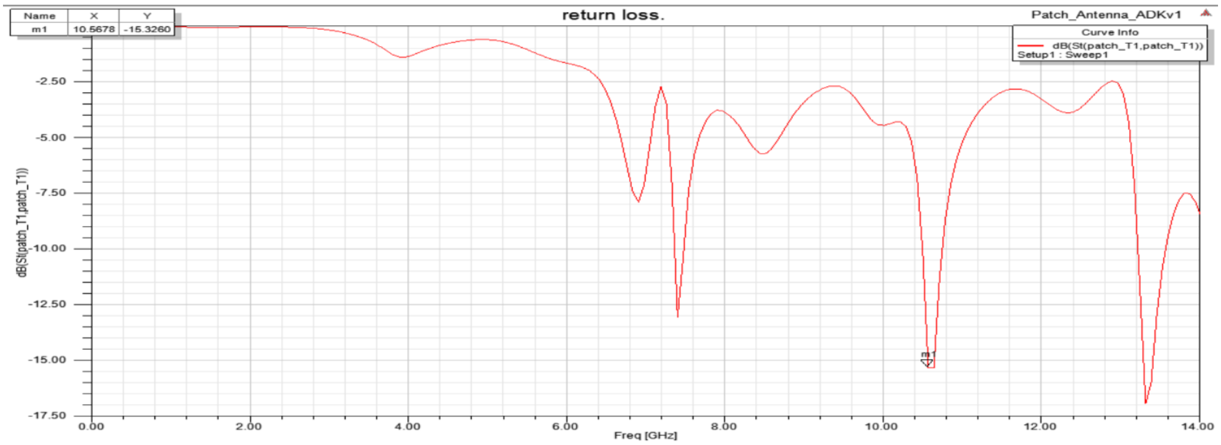

Figure.2. The graphical representation of the return loss for T-Shaped antenna

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. Figure 5 shows the 3D representation of the gain for T-Shaped antenna. It attains the gain as 6.7 dB. The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle and the azimuth angle. Figure 6 shows that 2D representation of T-Shaped antenna and it is an Omni directional.

5. Conclusion and Future Work

Our comparative analysis of the T shaped antennas we meticulously examined their structural properties and performance metrics, focusing specifically on return loss and gain characteristics. After thorough evaluation, we arrived at a conclusive determination that the T -shaped antenna exhibits superior gain compared to its T -shaped counterparts. This finding is pivotal as gain directly influences the effectiveness and range of signal transmission and reception in antenna systems. Moreover, beyond its high gain, the T-shaped antenna demonstrates several other advantageous attributes like it has very high performance, coupled with its low profile, simplicity, cost-effectiveness, and adaptability to multi-frequency applications, positions the T-shaped antenna as a promising solution for radar communication systems and beyond.

Moving forward, towards the future research and development in X-Band radar antennas presents that, exploring advanced materials and manufacturing techniques could enhance antenna performance and efficiency, particularly in terms of bandwidth and radiation pattern control. Additionally, investigating innovative antenna geometries and configurations beyond the T shapes may unlock further improvements in gain, bandwidth, and radiation characteristics.

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