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A SINGLE-LAYER SINGLE-PATCH DUAL-POLARIZED HIGH-GAIN CROSS-SHAPED MICROSTRIP PATCH ANTENNA

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Abstract: This letter introduces a microstrip patch antenna with a single layer and a single patch. The antenna is dual-polarized and has a high-gain design. The design starts with a microstrip patch antenna in the form of a cross, with the characteristic of high gain. A model of an antenna array is developed to provide an understanding of its mechanism and the theoretical constraints. Additionally, the central portion of the patch in the form of a cross is eliminated in order to decrease the degree of sidelobes. Subsequently, a high-gain antenna with dual polarization is developed using the modified cross-shaped patch as its foundation. Furthermore, a strip in the form of a cross is used to enhance isolation. Ultimately, a prototype is constructed and assessed to validate our concept. The tests indicate that the suggested antenna has an impedance bandwidth of 1.8% from 4.74 to 4.83 GHz, with a maximum realized gain of 12.47 dBi at 4.77 GHz. The isolation between the two ports exceeds 24.8 dB inside the passband. The suggested antenna has a compact size, measuring 1.44λ0 × 1.44λ0 × 0.024λ0.

Introduction

Dual-polarized antennas are extensively used in mobile communication systems to enhance channel capacity, mitigate multipath fading, and lower antenna system installation expenses. Therefore, a multitude of dual-polarized antennas are created, such as cross dipoles with both magnetic and electric dipoles. Dielectric resonator antennas and microstrip patch antennas. The microstrip patch antenna has many benefits including a compact design, little signal loss, cost-effectiveness, and seamless integration with circuitry, making it highly ideal for wireless communication systems. Regrettably, the actual increases achieved by the aforementioned solutions fall short of 9.5 dBi. Indeed, an antenna array is a very efficient technique for amplifying the gain. Nevertheless, the feeding network adds complexity to the whole system. Therefore, there is a significant need for a microstrip patch antenna that has excellent gain and is dual-polarized.

When operating in its basic TM01 mode, a standard rectangular microstrip patch antenna may be represented by two magnetic dipoles. The estimated gain of this antenna is around 8 dBi. Multiple techniques have been seen to enhance the directivity of the microstrip patch antenna. A stacked microstrip patch antenna is constructed with four parasitic components to enhance the gain. A high-gain microstrip patch antenna is designed using three layers of dielectric slabs. Nevertheless, the layered structures of the aforementioned designs result in a prominent or conspicuous appearance. Recently, researchers have investigated the higher-order mode of the microstrip patch antenna to improve its gain. The presence of a sidelobe is seen when a microstrip patch antenna operates in its higher-order mode. The suppression of sidelobes is achieved by reducing the slots, resulting in a high gain and a simple structure. Nevertheless, their aperture efficiency is suboptimal. Furthermore, the inclusion of shorting pins and slots serves to modify the radiation pattern, so amplifying the antenna gain. The TM0-odd mode is used to create a high-gain antenna using antenna array theory. Regrettably, the asymmetrical construction renders it unsuitable for use as the radiator of a dual-polarized antenna. The shorting pins are used to modify the compressed higher order in order to create a wideband dual-polarized high-gain antenna. Nevertheless, the maximum achieved increase is just 9.6 decibels isotropic (dBi). Designing a single-layer, dual-polarized, high-gain microstrip patch antenna remains a difficult task.

Review of existing literature

The literature survey for the project titled "A Single-Layer Single-Patch Dual Polarized High-Gain Cross-Shape Microstrip Patch Antenna" entails examining previous studies conducted on microstrip patch antennas and related subjects. Scientists have thoroughly examined several antenna designs in order to improve performance characteristics like as gain, polarization, and bandwidth.

Multiple investigations have concentrated on microstrip patch antennas with a single layer because of their small dimensions and easy integration. The use of a cross-shaped design enables the incorporation of dual polarization capabilities, hence enhancing the adaptability of communication systems. Research has highlighted the benefits of using cross-shaped structures to achieve dual polarization using only one patch.

Furthermore, there have been several studies conducted on high-gain microstrip patch antennas, which have shown the need of increasing gain for long-distance communication purposes. Methods such as optimizing the feeding network and selecting the appropriate substrate material have been investigated in order to get a high level of gain.

Examining the distinct characteristics of the suggested antenna may provide valuable understanding of the difficulties and possibilities linked to single-layer, dual-polarized designs. Analyzing the literature will provide a basis for the project, enabling a thorough comprehension of the latest advancements in the area and directing the creation of the A-Single-Layer Single-Patch Dual Polarized High-Gain Cross-Shape Microstrip Patch Antenna.

Antenna Design

Antenna Configuration

To achieve a compact, efficient, and versatile antenna solution for various wireless communication applications. The configuration of the proposed antenna, which is printed on one side of an F4BME220 dielectric lamina ($\varepsilon r = 2.2$ and $\tan \delta = 0.0007$) with a thickness of $t = 1.5$ mm. The other side of the dielectric lamina is the ground plane. It consists of a cross-shaped patch with four square slots at the center. As shown in Fig. , Parts A and B are connected by a strip, as are Parts C and D. On the other hand, Parts C and D are connected by another strip, Parts A and B. The above results mean that the proposed antenna has a single-layer and a single-patch. In addition, two 50 Ω SMAs are utilized to excite each polarization of the antenna. The inner part of the SMA is connected to the patch, and the outer part is soldered to the ground plane.

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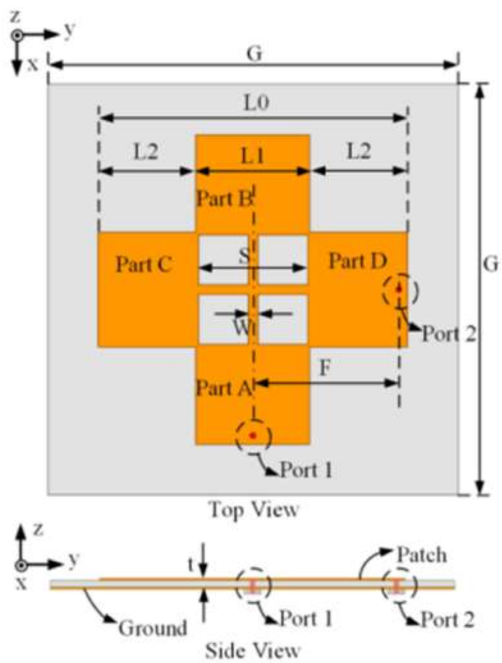

Fig. 1. Configuration of the proposed dual-polarized antenna: L0 = 68, L1 = 25, L2 = 21.5, S = 24, W = 2, F = 32, G = 90, and t = 1.5 (unit: mm).

Figure 3.1: Configuration of antenna

A higher-order mode is utilized to achieve a higher-directivity microstrip patch antenna, compared with the fundamental mode. First, a conventional cross-shaped microstrip patch antenna is considered, which is called Ant. A, The simulated S-parameter reveals that Ant. A resonates at 4.84 GHz. The current in Part 1 is similar to that of the TM03 mode of a conventional rectangular microstrip patch antenna. The current in Part 2 is similar to that of the TM01 mode of a conventional rectangular microstrip patch antenna. However, the current in Part 2 and the center part is anti-phased, which is different from that of a conventional TM03 mode rectangular microstrip patch antenna. Thus, it can be inferred that the radiation mechanism is different. Here, the cross-shaped patch is divided into five parts. Each part is similar to that of the TM01 mode. It is well known that the sidelobe is caused due to the anti-phase current in the higher-order mode, like TM03, TM05 mode, etc. For Ant. A, the current in the center part is anti-phased, compared with the current in the other parts.

S-parameter is also called Reflection Co-efficient of 4.81 GHz to 4.88GHz and -10dB is accepted above this -10dB it will not work and Bandwidth of the Antenna 4.88-4.81=0.07GHz,Bandwidth is the Range of frequencies and In this using Narrow Bandwidth which has less Bandwidth used to increase High-Gain, Initially, the design process starts with a square shaped patch design and convert it into a cross shaped patch by combining four square patches. The cross shaped patch is fed by a coaxial pin.

SL.No.	Parameters	Values
1	Patch dimension (L*W)	68*2 mm^2
2	Feed length (L)	21.5mm

3	Feed width (W)	2mm
4	Relative Permittivity (ε_r)	2.2
5	Substrate Material	F4BME220
6	Loss tangent (tanδ)	0.0007
7	Gain	13dB
8	Thickness(t)	1.5mm

HFSS Software

It is a powerful tool that can be used to predict the behaviour of various electronic components, such as antennas, filters, connectors, and printed circuit boards, at high frequencies. This allows engineers to optimize their designs for better performance and to avoid potential problems, such as electromagnetic interference (EMI).

Ansys HFSS (high-frequency structure simulator), is a commercial finite element method solver for electromagnetic (EM) structures from Ansys that offers multiple state-of-the-art solver technologies. Each solver in ANSYS HFSS is an automated solution processor for which the user dictates the geometry, properties of the material and the required range of solution frequencies.

Engineers use Ansys HFSS primarily to design and simulate high-speed, high-frequency electronics in radar systems, communication systems, satellites, ADAS, microchips, printed circuit boards, IoT products, and other digital devices and RF devices. The solver has also been used to simulate the electromagnetic behavior of objects such as automobiles and aircraft. ANSYS HFSS allows system and circuit designers to simulate EM issues such as losses due to attenuation, coupling, radiation and reflection.

The benefits of simulating a circuit's high frequency behavior with high accuracy on a computer reduces the final testing and verification effort of the system as well as mitigating the necessity of building costly multiple prototypes, saving both time and money in product development.

HFSS captures and simulates objects in 3D, accounting for materials composition and shapes/geometries of each object. HFSS is one of several commercial tools used for antenna design, and the design of complex radio frequency elements including filters, transmission lines, and packaging.

The HFSS Antenna course explores antenna-related HFSS topics such as radiating boundaries, including how well they absorb energy from different angles, and hybrid regions which connect different antenna simulations together. HFSS Antenna covers both finite element analysis (FEA) volumetric simulation as well as integral equation (IE) simulation and how they can connect a reflector antenna dish simulation to a horn antenna simulation feeding the dish. HFSS Antenna practices impedance matching antenna with circuit elements and explores examples of finite array design analysis with unit cells and Floquet modes.

Features of HFFS

3D EM simulation: HFSS can simulate the behaviour of electromagnetic fields in 3D, which is essential for accurately predicting the performance of complex electronic devices.

Multiple solver technologies: HFSS includes a variety of solver technologies, such as finite element method (FEM), integral equation (IE), and asymptotic solvers, which can be used to solve different types of EM problems.

Wide range of materials: HFSS can be used to simulate the behaviour of a wide range of materials, including metals, dielectrics, and magnetic materials.

Parametric design: HFSS allows engineers to define their designs parametrically, which means that they can easily change the dimensions and properties of their designs and see how these changes affect the performance of their devices.

Post-processing tools: HFSS includes a variety of post-processing tools that allow engineers to visualize and analyse the results of their simulations.

4.2 ANSOFT HFSS EM SIMULATION

The performance of electronic devices depends on electromagnetic (EM) behaviour. ANSYS $HFSS^{TM}$ simulation results delivers the most accurate answer possible with the least amount of user involvement.

HFSS is essential for designing high frequency and/or high speed components used in modern electronics devices. Understanding the EM environment is critical to accurately predict how a component-or subsystem or end product performs in the field. HFSS address the entire range of EM problems, including losses due to reflection, attenuation, radiation and coupling.

The power behind HFSS occurs in the mathematics of the finite element method (FEM) and the integral, proven automatic adaptive meshing technique. This provides a mesh that is conformal to the 3D structure and appropriate for the electromagnetic problem solving. With HFSS, the physics defines the mesh; the mesh does not define the physics. As a result, designer can focus on design issues rather than to spend significant time determining and creating the best mesh.

HFSS results yield information critical to our engineering designs. Typical results include scattering parameters (S, Y, Z), visualization of 3D electromagnetic fileds.

Results and Discussions

Return Loss

Return Loss is also called as Reflection Co-efficient, The reflection coefficient of an antenna is a measure of how well the antenna is matched to the transmission line or the medium through which it is propagating electromagnetic waves. It is denoted by the symbol Γ| (gamma). The reflection coefficient can also be expressed in terms of magnitude and phase. The magnitude represents the ratio of the amplitude of the reflected wave to the amplitude of the incident wave, while the phase represents the phase shift between the reflected and incident waves.

A reflection coefficient of 0 indicates a perfect match, meaning that all the power is absorbed by the load, and none is reflected back. A reflection coefficient of 1 (or -1 in magnitude) indicates total reflection, meaning that all the incident power is reflected and none is absorbed by the load.

Antenna designers often aim to achieve a good match between the antenna and the transmission line or medium to maximize power transfer and minimize signal loss. This is important for efficient operation and performance of the antenna system.

Since the antenna is fed by two ports, the S-parameters analysed are S11, S22 and S12, as shown in the below figure. From the figure, it is clear that the antenna works between the frequencies 4.81-4.88 GHz, and the mutual coupling (S21) is less than -40dB within the operating frequency range. The bandwidth of the antenna is 0.07 GHz.

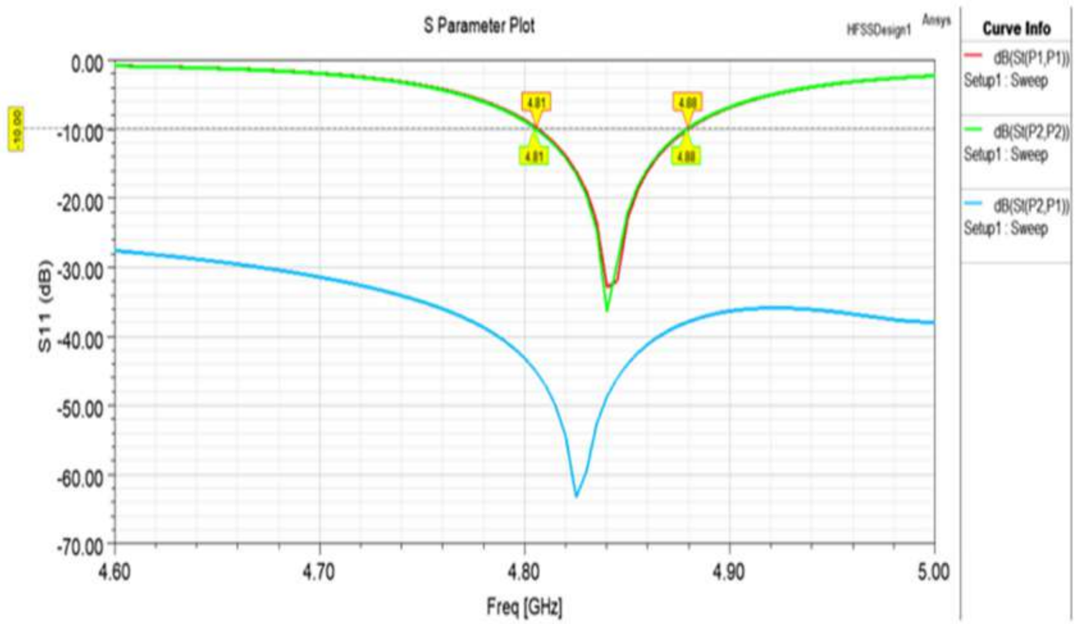

Fig 5.1: reflection coefficient graph of antenna

Gain

The gain of an antenna is a measure of its ability to direct or concentrate electromagnetic radiation in a particular direction. In simple terms, it quantifies the effectiveness of an antenna in focusing its radiated power in a specific direction compared to an isotropic radiator (an idealized point source that radiates uniformly in all directions). The gain is expressed as a ratio and is usually measured in decibels (dB).

Antenna gain is often expressed in decibels relative to isotropic (dBi) or relative to a dipole (dBd). If the gain is given in dBd, it is compared to the gain of a half-wave dipole antenna.

High gain is desirable in applications where it is necessary to focus the transmitted or received signals in a specific direction, such as in long-distance communication, radar systems, or satellite communication. However, it's important to note that antenna gain is always a trade-off, as increasing gain in one direction often results in a decrease in gain in other directions. Antenna gain is a crucial parameter in the design and selection of antennas for various communication and radar systems.The maximum gain of the proposed antenna is 13 dB.

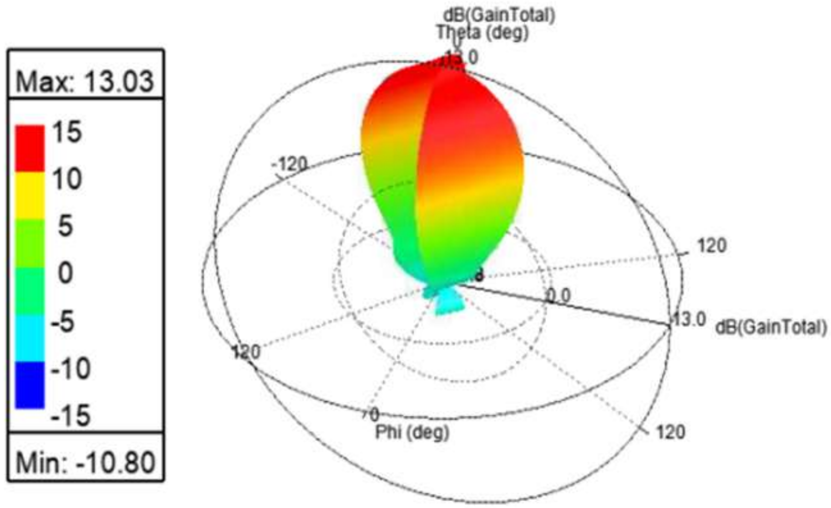

Fig 5.2: 3D gain plot of antenna at 4.85 GHz

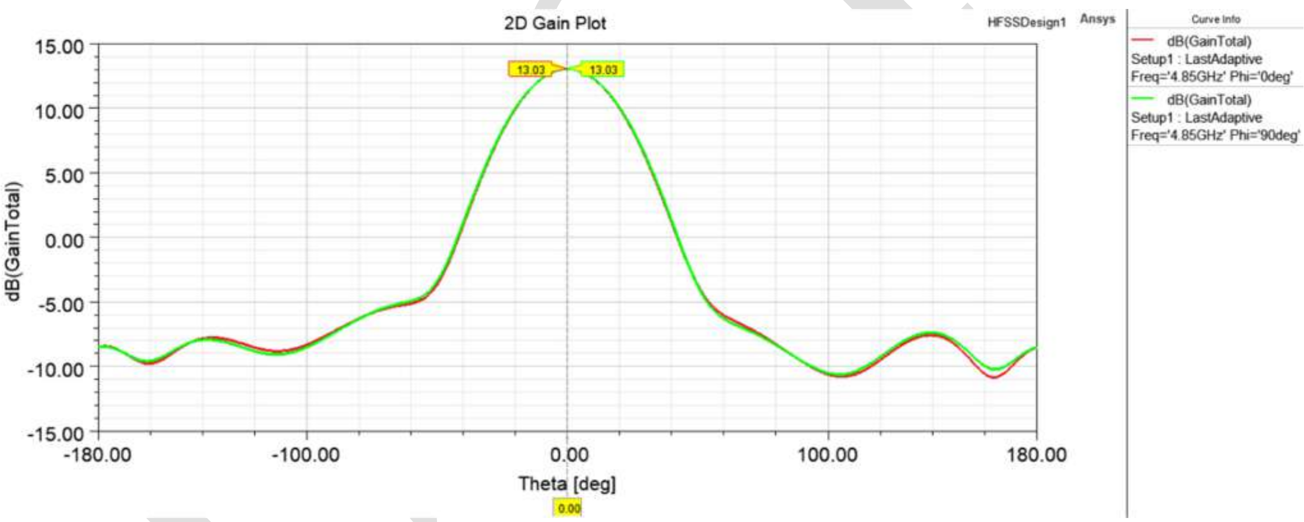

Fig 5.3: 2D Gain plot of antenna

Radiation pattern

The radiation pattern of an antenna is a graphical representation or a mathematical description of how the antenna radiates or receives electromagnetic waves in three-dimensional space. It illustrates the distribution of radiated power as a function of direction, showing how the antenna's performance varies in different azimuthal and elevation angles.

There are two main types of radiation patterns: azimuthal (horizontal) and elevation (vertical). The combination of these patterns provides a comprehensive view of the antenna's behaviour in all directions. The radiation patterns of the antenna shows unidirectional patterns.

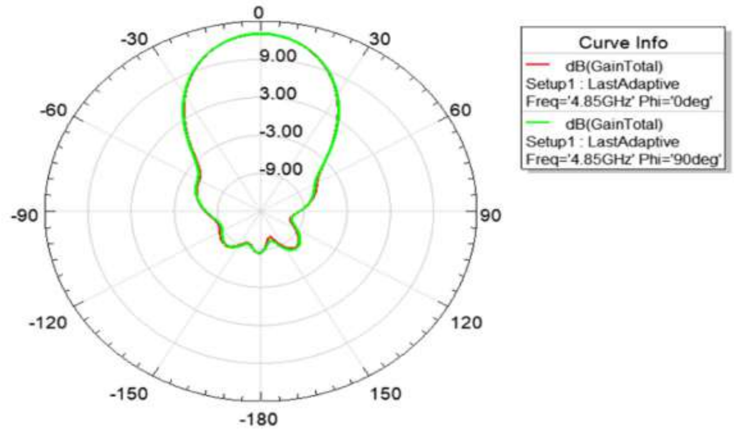

Fig: Radiation Pattern of anten

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