SINGLE LAYER HIGH GAIN MICROSTRIP PATCH ANTENNA

M. Swapna[1] , K kethana priya[2], T Layasri[3]

[1]Assistant Professor, Department of ECE, Bhoj Reddy Engineering College for Women, Hyderabad, India
[2,3,]UG scholar students Department of ECE, Bhoj Reddy Engineering College for Women, Hyderabad, India

Abstract: A high-gain microstrip patch antenna with a single layer and one patch that is dual-polarized is shown in this letter. The design begins with a high-gain, cross-shaped microstrip patch antenna. To provide light on the workings and theoretical constraints, an antenna array model is constructed. In order to lower the sidelobe level, the middle portion of the cross-shaped patch is also deleted. The next step is to use the modified cross-shaped patch as the basis for a high gain antenna with dual polarization. To further enhance isolation, a cross-shaped strip is also included. We finish by making and measuring a prototype to demonstrate our concept. From 4.74 to 4.83 GHz, the suggested antenna has an impedance bandwidth of 1.8% and a peak realized gain of 12.47 dBi, according to the tests. Two ports are more than 24.8 dB apart in the passband. The suggested antenna only measures 1.44λ0 x 1.44λ0 × 0.024λ0 in total dimensions.

Introduction

Dual-polarized antennas have been widely used in mobile communication systems to increase channel capacity, reduce multipath fading, and reduce antenna system installation costs. Thus, numerous dual-polarized antennas are designed, for instance, cross dipoles magnetic & electric dipoles. dielectric resonator antennas and microstrip patch antennas. A microstrip patch antenna has the advantages of low profile, low loss, low cost, and easy integration with the circuit, which make it suitable for wireless communication systems. Unfortunately, the realized gains of the above designs are less than 9.5 dBi. Actually, an antenna array is an effective method to enhance the gain. However, the feeding network makes the whole system complex. Thus, a high-gain, dual-polarized microstrip patch antenna is demanding.

A conventional rectangular microstrip patch antenna is modeled by two magnetic dipoles when it works in its fundamental TM01 mode, whose gain is estimated to be about 8 dBi. Several methods appear to increase the directivity of the microstrip patch antenna. In a stacked microstrip patch antenna with four parasitic elements is designed to increase the gain. In three layers of dielectric slabs are utilized to design a high-gain microstrip patch antenna. However, the stacked structures make the above designs suffer from a high-profile. In recent years, the higher-order mode of the microstrip patch antenna has been studied to enhance the gain. The sidelobe appears when a microstrip patch antenna works in its higher-order mode. In the sidelobe is suppressed by cutting the slots to achieve a high gain with a simple structure. However, their aperture efficiency is low. In addition, shorting pins and slots are introduced to reshape the radiation pattern, which enhances the antenna gain. In TM0-odd mode is utilizedto design a high-gain antenna based on antenna array theory. Unfortunately, the unsymmetrical structure makes it unsuitable to be the radiator of a dual-polarized antenna. In the compressed higher order is refined by the shorting pins to design a wideband dual-polarized high-gain antenna. However, the peak realized gain is only 9.6 dBi. Consequently, it is still challengingto design a single-layer, dual-polarized, high-gain microstrip patch antenna.

A single-layer antenna, often referred to as a monopole or a dipole antenna, is a fundamental element in wireless communication systems, widely used due to its simplicity and effectiveness. These antennas consist of a single conducting element, typically a straight rod or wire, which serves as both the radiating element and the ground plane. The length of the antenna is determined by the operating frequency, with quarter-wavelength and half- wavelength designs being common. One of the key advantages of single-layer antennas is their omnidirectional radiation pattern, which means they radiate or receive signals equally in all directions perpendicular to the antenna axis. This property makes them ideal for applications where a uniform signal coverage is desired, such as in Wi-Fi routers, mobile phones, and RFID systems.

Single-layer antennas can be further classified based on their geometry and the type of feed mechanism. The most basic form is the monopole antenna, which is a quarter-wavelengthelement mounted over a ground plane. This configuration is widely used in applications requiring compact antennas, such as in portable devices and small communication systems. Another common type is the dipole antenna, which consists of two quarter-wavelengthelements oriented in opposite directions. This antenna is often used in applications where a stronger signal is needed, such as in TV antennas and some types of radio communication systems.

Single-layer antennas can also be designed to operate at specific frequencies, such as the microstrip patch antenna, which consists of a conducting patch on one side of a dielectric substrate, backed by a ground plane. These antennas are widely used in microwave communication systems due to their compact size and ease of integration with other components. In conclusion, single-layer antennas are a crucial component in modern wireless communication systems, providing a simple yet effective solution for a wide range of applications. Their omnidirectional radiation pattern, compact size, and ease of integration make them a popular choice for designers seeking reliable and efficient antenna solutions.

A single patch antenna is a type of antenna that consists of a single radiating patch or metallic conductor mounted on a dielectric substrate, usually a thin piece of material like FR4. It is one of the most common types of microstrip antennas due to its simplicity, low profile, ease of fabrication, and cost-effectiveness.

Literature Survey

A literature survey for a project on "A Single-Layer Single-Patch Dual Polarized High-Gain Cross-Shape Microstrip Patch Antenna" involves exploring existing research in the field of microstrip patch antennas and related topics. Researchers have extensively investigated various antenna designs to enhance performance parameters such as gain, polarization, and bandwidth. Several studies have focused on single-layer microstrip patch antennas due to their compactsize and ease of integration. The choice of a cross-shape design introduces dual polarization capabilities, allowing for improved versatility in communication systems. Research by emphasized the advantages of cross-shaped configurations in achieving dual polarization witha single patch.

Moreover, investigations into high-gain microstrip patch antennas have been prevalent, with demonstrating the significance of gain enhancement for long-range communication applications. Techniques such as feeding network optimization and substrate material selection have been explored to achieve high gain.

Considering the specific attributes of the proposed antenna may provide insights into the challenges and opportunities associated with single-layer, dual-polarized designs. Examining the literature will help establish a foundation for the project, allowing for a comprehensive understanding of the state-of-the-art in the field and guiding the development of the A-Single- Layer Single-Patch Dual Polarized High-Gain Cross The words antenna and aerial are used interchangeably. Occasionally the equivalent term "aerial" is used to specifically mean an elevated horizontal wire antenna. The origin of the word antenna relative to wireless apparatus is attributed to Italian radio pioneer Guglielmo Marconi. In the summer of 1895, Marconi began testing his wireless system outdoors on his father's estate near Bologna and soon began to experiment with long wire "aerials" suspended from a pole. In Italian a tent pole is known as l'antenna centrale, and the pole with the wire was simply called l'antenna. Until then wireless radiating transmitting and receiving elements were known simply as "terminals". Because of his prominence, Marconi's use of the word antenna spread among wireless researchers and enthusiasts, and later to the general public. Antenna may refer broadly to an entire assembly including support structure, enclosure in addition to the actual RF current-carrying components. A receiving antenna may include not only the passive metal receiving elements, but also an integrated preamplifier or mixer, especially at and above microwave frequencies Shape Microstrip Patch Antenna.

Concept of Antenna

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. In radio engineering, an antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver. In transmission, a radio transmitter supplies an electric current 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 ofa radio wave in order to produce an electric current at its terminals, that is applied to a receiver to be amplified. Antennas are essential components of all radio equipment.

An antenna is an array of conductors (elements), electrically connected to the receiver or transmitter. Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional, or high-gain, or "beam" antennas). An antenna may include components not connected to the transmitter, parabolic reflectors, horns, or parasitic elements, which serve to direct the radio waves into a beam or other desired radiation pattern. Strong directivity and good efficiency when transmitting are hard to achieve with antennas with dimensions that are much smaller than a half wavelength. A phased array consists of two or more simple antennas which are connected together through an electrical network. This often involves a number of parallel dipole antennas with a certain spacing. Depending on the relative phase introduced by the network, the same combination of dipole antennas can operate as a "broadside array" (directional normal to a line connecting the elements) or as an "end-fire array" (directional along the line connecting the elements). Antenna arrays may employ any basic (omnidirectional or weakly directional) antenna type, such as dipole, loop or slot antennas. These elements are often identical.

Methodology

Although the Co-axial feed model discussed in the previous section is easy to use, but it has some inherent disadvantages. Specifically, it is useful for patches of rectangular design and it impedance matching, proper grounding, and the use of appropriate coaxial cables. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below. The cavity model is a fundamental concept in antenna theory, especially in the analysis and design of resonant antennas. A cavity can be thought of as a metallic enclosure or structure that supports standing electromagnetic waves at specific resonant frequencies. These resonant frequencies depend on the dimensions and shape of the cavity, as well as the properties of the materials involved.

One of the key characteristics of a cavity is its ability to store electromagnetic energy. When an electromagnetic wave encounters a cavity, it can resonate inside the cavity, bouncing back and forth between the cavity walls. This resonance effect leads to the formation of standing waves, which have nodes and antinodes at specific locations within the cavity.

The resonance frequencies of a cavity are determined by its size and shape, as well as the boundary conditions imposed by the cavity walls. For example, a cavity with a rectangular shape will have different resonance frequencies than a cavity with a cylindrical shape. The resonance frequencies of a cavity can be calculated using mathematical techniques such as the method of moments or finite element analysis.

In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observationsfor thin substrates ($h \ll \lambda$). Since the substrate is thin, the fields in the interior region do not vary much in the z direction, i.e. normal to the patch. The electric field is z directed only, and the magnetic field has only the transverse components H_X and H_Y in the region bounded by the patch metallization and the ground.

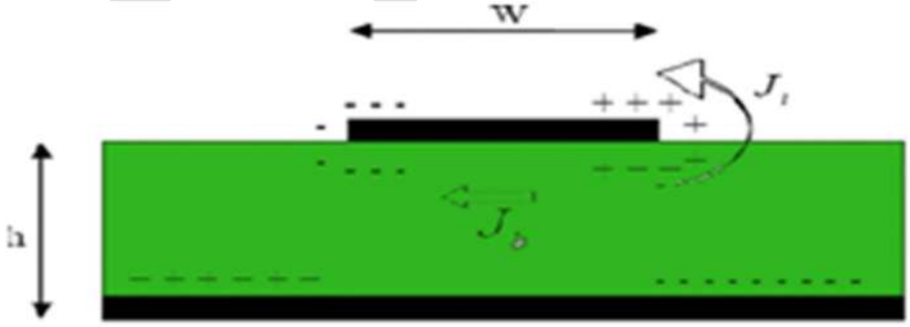


Fig 2.2 Cavity Model

When the power is provided to the Microstrip patch, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms an attractive mechanism and a repulsive mechanism as discussed by Richards. The attractive mechanism describes between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism describes between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surface of the patch.

In this model, the interior region of patch is modeled as a cavity bounded by electric walls on the top and bottom, and magnetic wall all along the periphery. The fields in the interior region do not vary because the substrate is very thin. The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Very less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces.

This implies that the magnetic fields and the electric field distribution beneath the patch would not be disturbed. However, in practice, a finite width to height ratio would be there and this would not make the tangential magnetic fields to be completely zero.

Results and Discussion

The project implements A Single-Layer Single patch Dual Polarized High Gain Cross shaped Microstrip patch Antenna are designed to operate in Reflection coefficient, Gain andRadiation pattern of antenna and 1 x 2 array antenna results are discussed below.

Output 1

Return Loss of Antenna

Return Loss is also called as Reflection Co-efficient, The reflection coefficient of an antennais 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. 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 andincident 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.

Antenna designers often aim to achieve a good match between the antenna and the transmissionline 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.

return loss is a measure in relative terms of the power of the signal reflected by a discontinuityin a transmission line or optical fibre. This discontinuity can be caused by a mismatch betweenthe termination or load connected to the line and the characteristic impedance of the line.

It is usually expressed as a ratio in decibels (dB) where RL(dB) is the return loss in dB, Pi is the incident power and Pr is the reflected power. A Return loss is related to both standing wave ratio (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss.

From a certain perspective 'Return Loss' is a misnomer. The usual function of a transmission line is to convey power from a source to a load with minimal loss. If a transmission line is correctly matched to a load, the reflected power will be zero, no power will be lost due to reflection, and 'Return Loss' will be infinite. Conversely if the line is terminated in an open circuit, the reflected power will be equal to the incident power; all of the incident power will be lost in the sense that none of it will be transferred to a load, and RL will be zero. Thus the numerical values of RL tend in the opposite sense to that expected of a 'loss'.

Where Return loss,

$$RL(\mathrm{dB}) = 10\log_{10}\frac{P_\mathrm{i}}{P_\mathrm{r}}$$

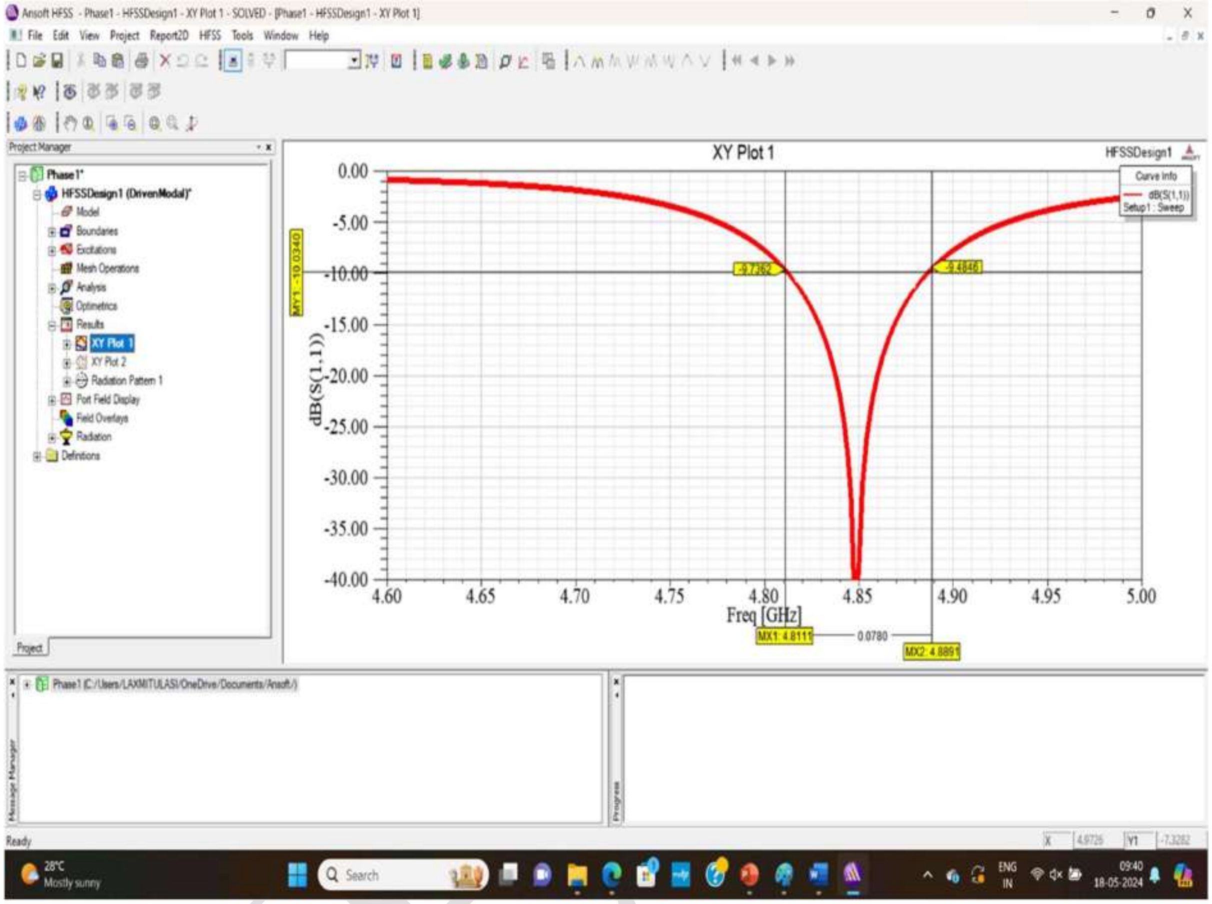


Fig 6.1 Reflection coefficient graph of antenna

The characteristics of graph explains about X axis has Frequency in GHz that was done in output 1 – 4.811 to 4.8891 GHz of frequency with a Bandwidth of 0.0780. Y axis has Powerof the signal at return loss is -9.7362 to -9.4846 dB. The curve has a sharp dip forming an inverted peak around 4.85 GHz, which could indicate a resonance frequency or a significant feature in the frequency response data.

Gain of Antenna

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 antennain 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 relativeto 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 receivedsignals 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. 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). Gain is a parameter which measures the degree of directivity of the antenna's radiation pattern. A high-gain antenna will radiate most of its power in a particular direction, while a low-gain antenna will radiate over a wide angle.the antenna gain, or power gain of an antenna is defined as the ratio of the intensity (power per unit surface area) I radiated by the antenna in the direction of its maximum output, at an arbitrary distance, divided by the intensity Iso radiated at the same distance by a hypotheticalisotropic antenna which radiates equal power in all directions. This dimensionless ratio is usually expressed logarithmically in decibels, these units are called decibels-isotropic (dBi).High-gain antennas have the advantage of longer range and better signal quality, but must be aimed carefully at the other antenna. An example of a high-gain antenna is a parabolic dish such as a satellite television antenna. Low-gain antennas have shorter range, but the orientation of the antenna is relatively unimportant. An example of a low-gain antenna is the whip antenna found on portable radios and cordless phones. Antenna gain should not be confused with amplifier gain, a separate parameter measuring the increase in signal powerdue to an amplifying device placed at the front-end of the system, such as a low-noise amplifier.

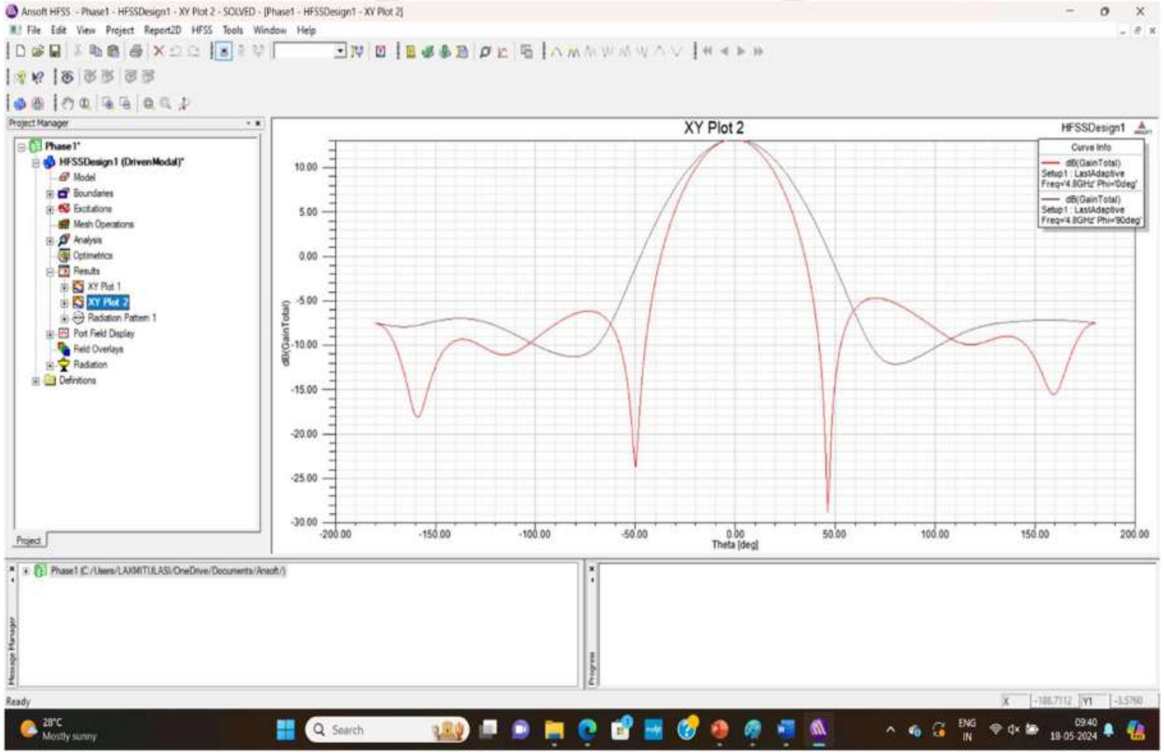


Fig 6.2 2D Gain plot of antenna

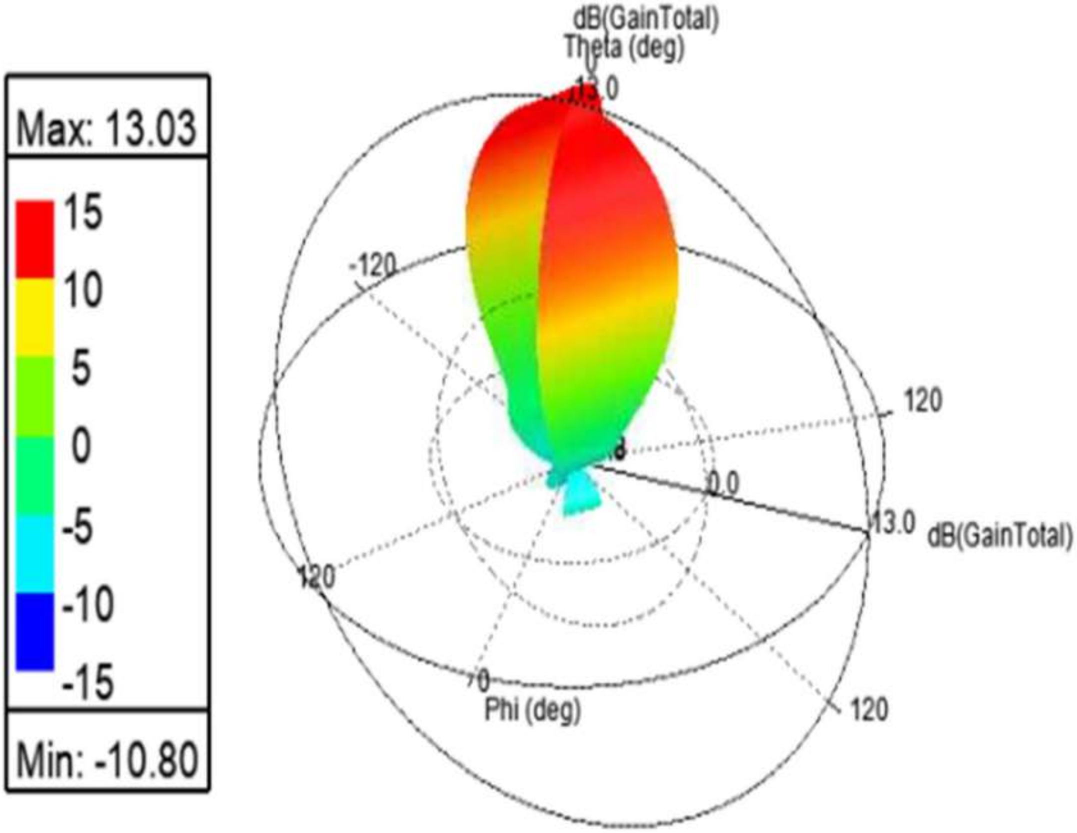


Fig 6.3 3D Gain plot of antenna

The red line on the graph goes up and down, creating peaks and valleys. This shows that the gain changes depending on the angle. At some angles, the gain is very high (peaks), and at others, it's lower (valleys).The Gain of the XY Plot X axis has Theta [deg] v/s Y axis has GainTotal in decibels [dB]. The frequency of the signal is 4.8GHz the only difference is Phi has0 deg and 90 deg. In these arrays are not added so noise is low. So that Total Gain was obtained.

Output 2

The antenna is fed by two ports, the S-parameters analysed are S11, S22 and S12, as shownin the below figure. From the figure, it is clear that the antenna works between the frequencies4.81-4.88 GHz, and the mutual coupling (S21) is less than -40dB within the operating frequency range. The bandwidth of the antenna is 0.07 GHz.

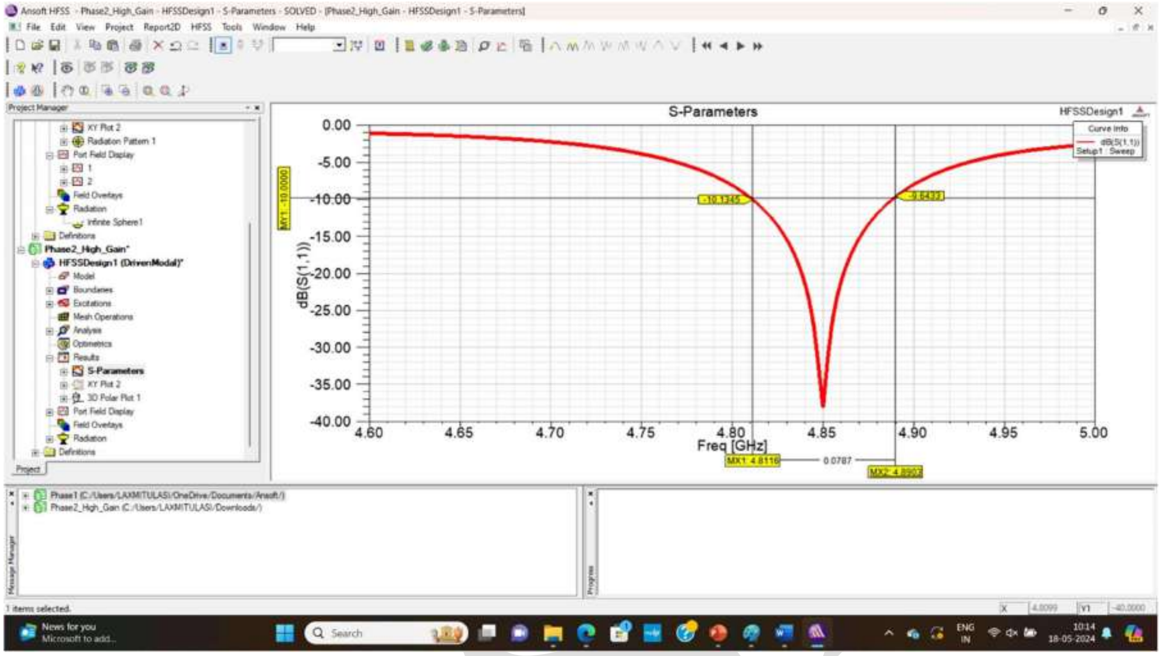
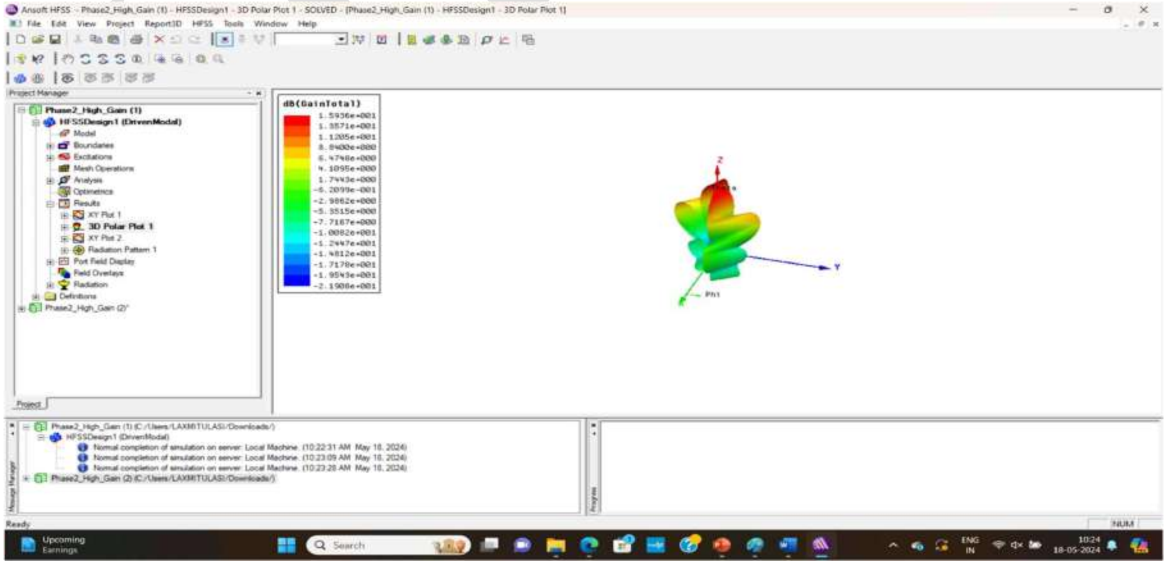


Fig 6.5 Reflection coefficient graph of 1x2 array antenna

The antenna is fed by two ports, the S-parameters analysed are S11, S22 and S12, as shownin the below figure. From the figure, it is clear that the antenna works between the frequencies4.81-4.89 GHz, and the mutual coupling (S21) is less than -40dB within the operating frequency range. The bandwidth of the antenna is 0.08 GHz.

Gain of antenna

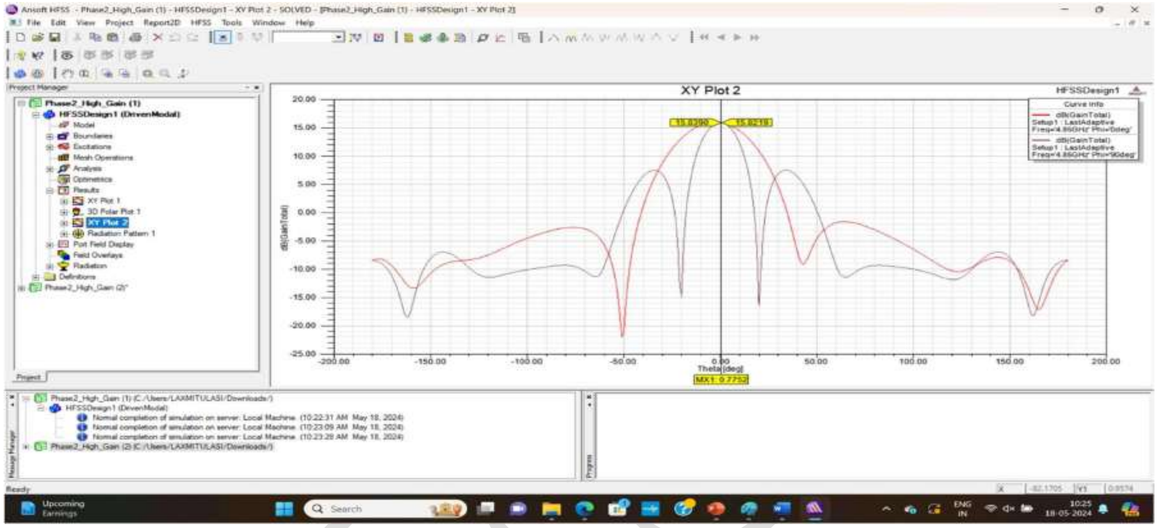
Antenna gain is often expressed in decibels relative to isotropic (dBi) or relative to a dipole (dBd). If the gain is given in dBd, it is compared to the gain of a half-wave dipole antenna.



Phase2_High_Gain (1) (C:/Users/LAXMITULASI/Downloads/)
HFSSDesign1 (DrivenModal)
Normal completion of simulation on server: Local Machine. (10:22:31 AM May 18, 2024)
Normal completion of simulation on server: Local Machine. (10:23:09 AM May 18, 2024)
Normal completion of simulation on server: Local Machine. (10:23:28 AM May 18, 2024)
Phase2_High_Gain (2) (C:/Users/LAXMITULASI/Downloads/)

Fig 6.6 3D Gain plot of antenna at 4.85 GHz

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 receivedsignals in a specific direction, such as in long-distance communication, radar systems, orsatellite 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.



Phase2_High_Gain (1) (C:/Users/LAXMITULASI/Downloads/)
HFSSDesign1 (DrivenModal)
Normal completion of simulation on server: Local Machine. (10:22:31 AM May 18, 2024)
Normal completion of simulation on server: Local Machine. (10:23:09 AM May 18, 2024)
Normal completion of simulation on server: Local Machine. (10:23:29 AM May 18, 2024)
Phase2_High_Gain (2) (C:/Users/LAXMITULASI/Downloads/)

Fig 6.7 2D gain plot antenna at 0 Deg 15.8dB

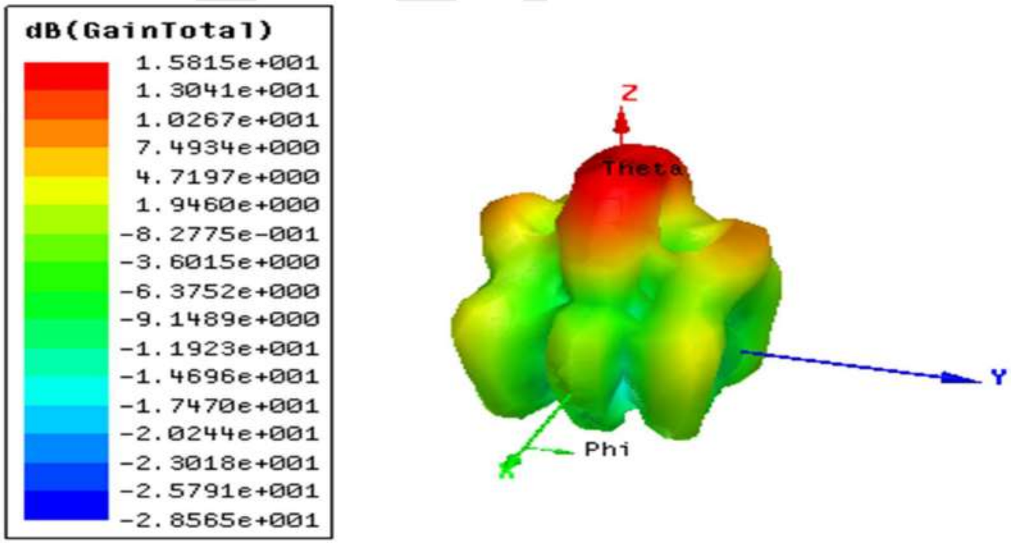


Fig 6.8 Gain of Array antenna

Antenna gain is a crucial parameter in the design and selection of antennas for various communication and radar systems.The maximum gain of the 1x2 array antenna is 15.8 db

Radiation pattern of an antenna

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.

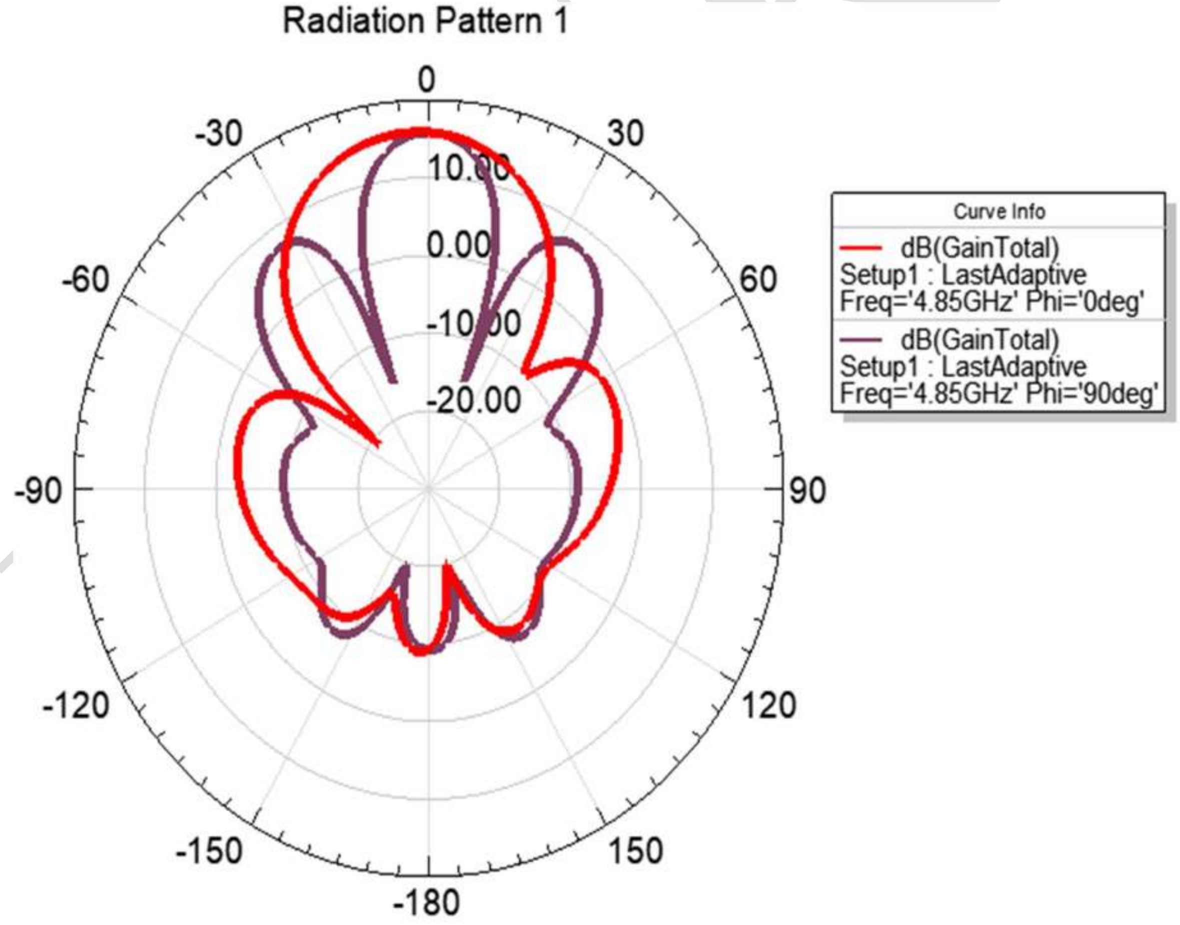


Fig 6.9 Radiation Pattern of Array antenna

The radiation patterns of the Array antenna shows unidirectional patterns in Phi 0 Deg and 90 Deg and radiation has side lobes and main lobe red line

Conclusion

Conclusion and Future scope

The project aimed to design and analyze a single-layer single-patch dual-polarized high-gain cross-shaped microstrip antenna. The antenna design process involved meticulous attention to detail, considering various factors such as impedance matching, radiation pattern, and gain optimization. Through rigorous simulation and testing, the antenna demonstrated promising performance characteristics suitable for applications requiring high gain and dual- polarization capabilities.

The design process commenced with thorough research into existing microstrip antenna designs, identifying key features and parameters crucial for achieving high performance. The cross-shaped geometry was chosen for its ability to provide dual-polarization while maintaining simplicity in construction. By carefully selecting dimensions and optimizing the layout, the antenna was tailored to operate at the desired frequency with enhanced gain and efficiency.

Simulation tools such as CST Microwave Studio were employed to model and analyze the antenna's performance under different operating conditions. Parametric studies wereconducted to investigate the effects of various design parameters on the antenna's characteristics, allowing for fine-tuning to meet the project requirements. Impedance matching networks were incorporated to ensure maximum power transfer and minimize reflection losses, resulting in improved overall performance.

The fabricated prototype underwent rigorous testing to validate its simulated performance. Measurements were taken for parameters such as return loss, radiation pattern, and gain, comparing the results against simulation data to verify the accuracy of the design. Any discrepancies were meticulously analyzed, leading to iterative refinements in the design to achieve closer alignment between simulation and experimental results.The antenna's dual- polarization capability was a key feature, enabling it to transmit and receive signals with orthogonal polarizations simultaneously. This characteristic is advantageous in applications requiring diversity reception or polarization diversity, enhancing the system's robustness against signal fading and interference. Moreover, the high-gain nature of the antenna makes it suitable for long-range communication systems, satellite communication, and radar applications where increased signal strength is essential.

In addition to performance considerations, practical aspects such as fabrication complexity and cost-effectiveness were also taken into account during the design process. The single- layer configuration simplified manufacturing and reduced production costs, making the antenna more accessible for widespread deployment in various applications.

Overall, the project successfully achieved its objectives of designing and analyzing a single- layer single-patch dual-polarized high-gain cross-shaped microstrip antenna. Through a systematic approach encompassing theoretical analysis, simulation, fabrication, and testing, the antenna demonstrated excellent performance characteristics suitable for a wide range of applications. Future work may focus on further optimization for specific frequency bands or integration into practical systems to explore its full potential in real-world scenarios.

The project embarked on the design and evaluation of a 1x2 array antenna utilizing two patch elements, aiming to harness the benefits of array configurations for enhanced performance in communication and radar systems.

This endeavor sought to leverage the advantages of array antennas, such as increased gain, directivity, and beamforming capabilities, while employing a compact and cost-effective design using two patch elements. Through meticulous design iterations, simulation studies, fabrication, and testing, the project culminated in the development of an antenna array with remarkable characteristics suitable for a diverse array of applications.

References

[1] M. A. Jensen and J. W. Wallace, “A review of antennas and propagation for MIMO wireless communication,” IEEE Trans. Antennas Propag., vol. 52, no. 11, pp. 2810–2824, Nov. 2004.

[2] D.-L. Wen, D.-Z. Zheng, and Q.-X. Chu, “A wideband differentially fed dual-polarized antenna with stable radiation pattern for base stations,” IEEE Trans. Antennas Propag., vol. 65, no. 5, pp. 2248–2255, May 2017.

[3] Y. Cui, X. Gao, H. Fu, Q.-X. Chu, and R. Li, “Broadband dual-polarized dual-dipole planar antennas: Analysis, design, and application for base stations,” IEEE Antennas Propag. Mag., vol. 59, no. 6, pp. 77–87, Dec. 2017.

[4] D. Wang, G. Wang, D. Lu, N. Yang, and Q. Zhang, “Design of wideband base station antenna by involving fragment-type structures on dipole arms,” IEEE Trans. Antennas Propag., vol. 70, no. 7, pp. 5953–5958, Jul. 2022.

[5] B. Q. Wu and K.-M. Luk, “A broadband dual-polarized magnetoelectric dipole antenna with simple feeds,” IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 60–63, 2009.

[6] Q. Xue, S. W. Liao, and J. H. Xu, “A differentially-driven dual-polarized magneto-electric dipole antenna,” IEEE Trans. Antennas Propag., vol. 61, no. 1, pp. 425–430, Jan. 2013.

[7] S.-G. Zhou, Z.-H. Peng, G.-L. Huang, and C.-Y.-D. Sim, “Design of a novel wideband and dual polarized magnetoelectric dipole antenna,” IEEE Trans. Antennas Propag., vol. 65, no. 5, pp. 2645–2649, Mar. 2017.

[8] Y. X. Guo and K. M. Luk, “Dual-polarized dielectric resonator antennas,” IEEE Trans. Antennas Propag., vol. 51, no. 5, pp. 1120–1124, May 2003.

[9] Y. M. Pan, P. F. Hu, K. W. Leung, and X. Y. Zhang, “Compact single-/dualpolarized filtering dielectric resonator antennas,” IEEE Trans. Antennas Propag., vol. 66, no. 9, pp. 4474–4484, Sep. 2018.

[10] H. Tang, C. Tong, and J. Chen, “Differential dual-polarized filtering dielectric resonator antenna,” IEEE Trans. Antennas Propag., vol. 66, no. 8, pp. 4298–4302, Aug. 2018.

[11] K. D. M. Pozar and D. H. Schaubert, Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays. Hoboken, NJ, USA:Wiley, 1995.

[12] Z. Tang, J. Liu, Y.-M. Cai, J. Wang, and Y. Yin, "A wideband differentially fed dual- polarized stacked patch antenna with tuned slot excitations," IEEE Trans. Antennas Propag., vol. 66, no. 4, pp. 2055–2060, Apr. 2018.

[13] Q. Li, S. W. Cheung, and C. Zhou, "A low-profile dual-polarized patch antenna with stable radiation pattern using ground-slot groups and metallic ground wall," IEEE Trans. Antennas Propag., vol. 65, no. 10, pp. 5061–5068, Oct. 2017.

[14] D. Sun, Z. Zhang, X. Yan, and X. Jiang, "Design of broadband dualpolarized patch antenna with backed square annular cavity," IEEE Trans. Antennas Propag., vol. 64, no. 1,pp. 43–52, Jan. 2016.

[15] Y. Li, Z. Zhao, Z. Tang, and Y. Yin, "Differentially fed, dual-band dual-polarized filtering antenna with high selectivity for 5G sub-6 GHz base station applications," IEEE Trans. Antennas Propag., vol. 68, no. 4, pp. 3231–3236, Apr. 2020.

[16] A. Afshani and K.Wu, "Dual-polarized patch antenna excited concurrently by a dual- mode substrate integrated waveguide," IEEE Trans. Antennas Propag., vol. 70, no. 3, pp. 2322–2327, Mar. 2022.

[17] A. Vallecchi and G. B. Gentili, "Design of dual-polarized series-fed microstrip arrays with low losses and high polarization purity," IEEE Trans. Antennas Propag., vol. 53, no. 5, pp. 1791–1798, May 2005.

[18] Y. Wang and Z. Du, "Dual-polarized slot-coupled microstrip antenna array with stable active element pattern," IEEE Trans. Antennas Propag., vol. 63, no. 9, pp. 4239–4244, Sep. 2015.