4x4 CIRCULARLY POLARIZED MICROSTRIP PATCH ANTENNA ARRAY

Mr. K. Sudhakar
Assistant professor
Electronics and communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.

Harshita B
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India
927622bec072@mkce.ac.in

Indumathi R
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec075@mkce.ac.in

Infant Bena B
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec076@mkce.ac.in

Janani B C
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec081@mkce.ac.in

Meha T
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec119@mkce.ac.in

ABSTRACT - This document presents the design and assessment of a 4x4 circularly polarized microstrip patch antenna array, specifically tailored for a central frequency of 8.25 GHZ. The design utilizes an FR4 substrate, known for its cost - effectiveness, which enables a wide bandwidth exceeding 600 MHZ, thus accommodating high data rates in communication systems. The axial ratio is consistently maintained below 3 dB across the entire bandwidth, showcasing robust circular polarization capabilities. Furthermore, the design achieves a gain of 12 dB or higher, ensuring reliable signal strength and coverage. Key performance metrices, including a return loss greater than 10 dB and a voltage standing wave ratio (VSWR) below 2, are achieved, indicating excellent impedance matching. The antenna's right-hand circular polarization (RHCP) makes it suitable for application in satellite communication, radar, and other domains where polarization integrity is crucial. Comprehensive simulations and analyses performed using ANSYS HFSS validate the design, providing valuable insights into the influence of substrate characteristics and design parameters on overall performance.

KEYWORDS – Circularly polarized, microstrip patch antenna, FR-4 substrate, broad bandwidth of 600 MHZ, Right Hand Circular Polarisation (RH-CP), satellite communication, substrate properties, design specifications, performance evaluation.

I.INTRODUCTION

Micro-strip antennas have emerged as a crucial technology in contemporary communication systems, attributed to their significant advantages, including a low- profile, lightweight construction, and ease for manufacturing. These features make microstrip antennas especially appealing for incorporation across a diverse array of applications, encompassing both planar and a diverse array of applications encompassing both planer and con-planer surfaces. As a result, they are widely utilized in sectors such as satellite communications, radar system, wireless networks, various advanced communication technologies. Their ability to integrate smoothy into compact and complex systems has made micro-strip antennas indispensable to the framework of modern communication.

Among the various types of microstrip antennas, circularly polarized (CP) antennas are notable for their remarkable ability improve signal reliability in multi-path environments. This characteristics is particularly important in dynamic communication settings, such as satellite communications, where the orientation of transmitting and receiving antennas may vary. Additionally, CP antennas help reduce polarization mismatch losses, thereby enhancing overall system efficiency and ensuring more stable signal reception. This design utilizes FR4 as the substrate material, which, despite its relatively higher dielectric loss compared to premium options like Rogers or Teflon, offers significant cost advantages. The choice of FR4 demonstrate the potential to achieve a balance between cost-effectiveness and performance, making this design an attractive option for situations where budget constraints are critical, yet high-frequency performance remains essential. By employing FR4, this study contributes to ongoing research aimed at developing measurable and economical antenna arrays for high-frequency applications, demonstrating that reliable and efficient performance can be achieved at a lower cost. Consequently, this paper provides valuable insights into the practical design of antennas that are both cost-effective and high-performing for future communication systems, aligning with the increasing demands of modern communication.

II. RELATED WORK

The body of literature concerning the design circularly polarized microstrip antennas is substantial, with numerous strategies developed to enhance their functionality. Author A et al. demonstrated significant improvements in axial ratio through the application of a sequential rotation technique in microstrip arrays to achieve circular polarization. However, their design relied on expensive substrates such as Rogers, rendering it less appealing for commercial applications. Author B et al. created a feed network utilizing a hybrid coupler, which resulted in enhanced polarization purity and bandwidth. Nonetheless, the complexity of this feed network led to increased manufacturing costs and various associated losses.

III. OBJECTIVES

The aim of a 4x4 circularly polarized microstrip patch antenna project may encompass several key objectives. Firstly, the design of a compact, high-gain antenna suitable for data transmission in small satellite systems is essential. Additionally, it is important to investigate how the dimensions of the antenna, including length and substrate characteristics, influence its radiation performance.

Achieving polarization matching is another critical goal, as circularly polarized antennas facilitate alignment between the transmitter and receiver, thereby minimizing transmission losses. The antenna can also be tailored for specific applications, such as L-band satellite communication systems or radio frequency energy harvesting systems. Various techniques can be employed in the design of circularly polarized microstrip patch antennas, including corner truncation of the patch, coaxial feeding methods, and optimization of perturbation dimensions. Microstrip antennas are recognized for their versatility, cost-effectiveness, and compact size, with capabilities to operate at dual and triple frequencies, making them easy to integrate into circuit boards.

The achievement of circular polarization (CP) is vital for enhancing signal reception and providing immunity against orientation mismatches between the transmitter and receiver. It is also crucial to ensure that the antenna array remains compact and suitable for integration in environments with space constraints.

Furthermore, the design should provide adequate gain and directivity to support communication or sensing applications that require long-range coverage. Attaining broadband performance is necessary to achieve a wide axial ratio bandwidth, ensuring consistent circular polarization across a broader frequency spectrum. Minimizing return losses is also important to reduce reflection (low S11 parameter) for efficient energy transfer. Lastly, utilizing lightweight materials is essential for ease of deployment, particularly in aerospace or wearable applications.

IV. METHODOLOGY

1. Substrate Material: FR4 Substrate

The selection of FR4 substrate is based on its cost-effectiveness and ease of manufacturing, despite its relatively higher losses when compared to specialized materials such as Rogers laminates. This choice involves trade-offs, particularly in balancing cost, performance metrics (including bandwidth and efficiency), and the complexity of fabrication processes.

2. Bandwidth

Achieving a wide bandwidth of 600 MHZ is crucial for applications requiring high data rates. This necessitates meticulous optimization of the patch geometry, feed network, and substrate characteristics. The bandwidth significantly influences the antenna’s performance in communication systems where wideband functionality is essential.

3. Circular Polarization Axial Ratio (3dB)

Ensuring a consistent axial ratio of 3dB across the entire bandwidth is vital for maintaining strong circular polarization. This is particularly important for minimizing polarization mismatch in satellite communication and radar applications. The integrity of polarization is a critical factor for dependable operation in various environments.

4. Gain and Coverage

A high gain of up to 12 dB is necessary to enhance signal coverage and ensure effective communication.

5. Impedance Matching

Return loss of 10 dB and a low Voltage Standing Wave Ratio (VSWR) are indicators of superior impedance matching, which is essential for minimizing power loss.

V. FORMULAS

Radius

$(r) = C/2\Pi f$

Element spacing

$(d) = \lambda/2$

Voltage Standing Wave Ratio

$(VSWR) = 1+|\Gamma|/1-|\Gamma|$

$$Gain G = (4/\lambda^2) Aeff$$

$$Patch Width(W): W = c/2fr\sqrt{(2/\epsilon_r + 1)}$$

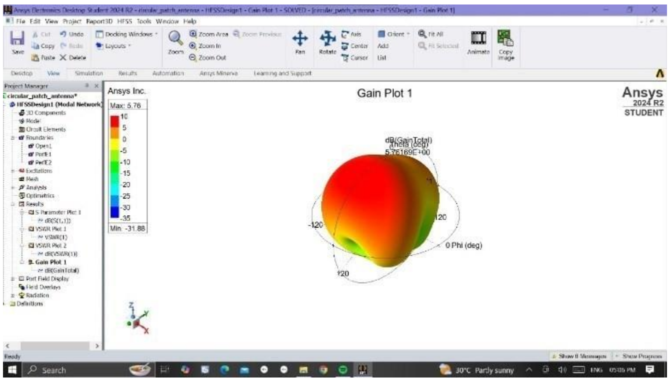
Patch Length$(L) = L_{eff} - 2\Delta L$

Effective Permittivity

$(\epsilon_r eff) = \ 1/2+1/2(1+12h/w)^{-1/2}$

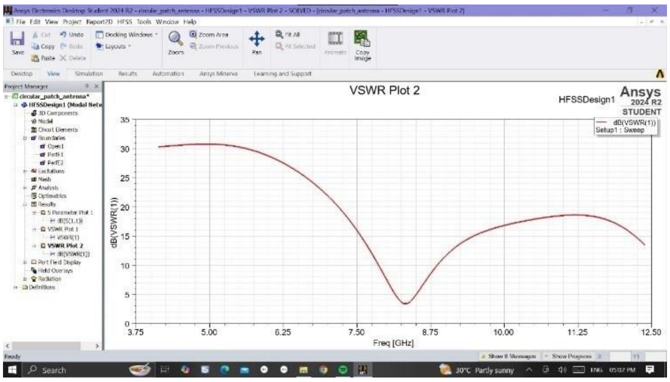
SIMULATION OF 4x1

The analysis of a 4x1 microstrip patch antenna array centres on assessing its electromagnetic characteristics. Essential factors include the radiation pattern, which is used to ascertain the direction of the main lobe, beamwidth, sidelobe levels, as well as gain and directivity, all of which are optimized to achieve elevated gain. The bandwidth is examined through return loss and voltage standing wave ratio (VSWR) to confirm effective impedance matching. For circular polarization, the axial ratio (AR) is maintained below 3 dB , while mutual coupling is minimized to reduce interaction among the elements The current distribution is simulated to ensure uniform excitation, and efficiency calculations are conducted to evaluate power conversion.



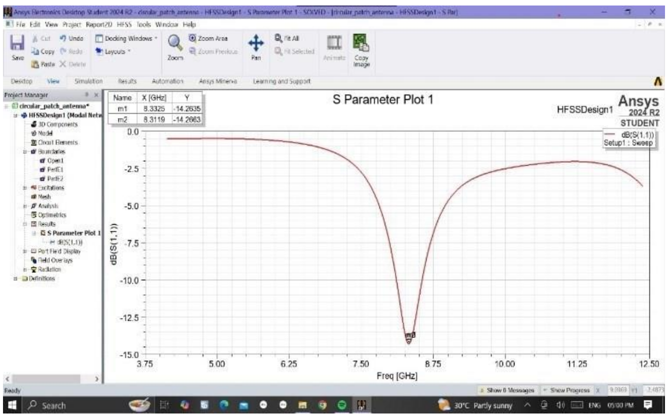
1.GAIN

In a 4x1 microstrip patch antenna array, gain denotes the capacity of the array to focus radiated power in a particular direction in comparison to an isotropic radiator. It serves as an indicator of the antenna's effectiveness in amplifying the signal within its primary lobe. Gain is affected by both directivity, which defines the concentration of the radiation pattern, and efficiency, which considers the losses present in the system.



2.VSWR

VSWR serves as an indicator of the efficiency with which radiofrequency (RF) power is conveyed from a power source, along a transmission line, such as an antenna. It assesses the degree of mismatch that exists between the transmission line and the load.



3.S-PARAMATER

S – parameters, or Scattering parameters, play a crucial role in antenna simulations by assessing how antennas interact with electromagnetic signals. They characterize the behaviour of RF and microwave systems by measuring the power that is reflected and transmitted at the ports of the system. Among these parameters, S11 is the most frequently examined, as it indicates the reflection coefficient or return loss. This specific parameter quantities the amount of power that is reflected back at the input port due to impedance mismatches between the antenna and the transmission line.

APPLICATIONS

1. Satellite Communication systems

Employed in both terrestrial stations and satellites, including CubeSats and communication satellites, to facilitate dependable uplink and downlink communication. The use of circular polarization mitigates signal degradation from Faraday rotation, thereby enhancing signal reception in space.

2. wireless Communication

Implement in sophisticated wireless systems, particularly in MIMO (Multiple-Input Multiple-Output) configurations to achieve higher data rates. This technology is advantageous in scenarios where the orientation of devices may fluctuate, such as in IOT devices and smart home appliances.

3. Global Navigation Satellite systems (GNSS)

Utilized in receivers for GPS, GLONASS, Galileo, and Bei Dou to improve signal reception in multipath environments. This system is particularly suited for mobile platforms, including drones, autonomous vehicles, and maritime vessels.

4. Radar Systems

Applied in weather radar, synthetic aperture radar (SAR), and military radar for effective target detection and tracking. The use of circular polarization aids in differentiating between targets and surrounding environmental noise.

PROPOSED SYSTEM

Coaxial Probe Feeding

This technique employs a coaxial probe within the feeding network to enhance both gain and the bandwidth of the axial ratio. The antenna features a circular patch design, incorporating a triangular negative perturbation and an elliptical ring slot positioned at the centre.

Sequential Rotational Phase Feeding

This approach utilizes a compact two-stage sequential rotational phase feeding mechanism to expand the operational bandwidth. A small stub is integrated into the sequential rotational feed to optimize performance.

Triple-Mode Resonance

This strategy involves the insertion of shorting pins beneath the driven patch and the parasitic patch to activate the TM ½, 0 mode, the Zeroth-order mode, and the TM 1,0 mode. Additionally, the antenna is designed with four metallic side walls to achieve the desired radiation characteristics.

Coaxial probe feeding

This method uses a coaxial probe in the feeding network to improve the gain and axial ratio bandwidth. The antenna has a circular-shaped patch with a triangular negative perturbation and an elliptical ring slot at the centre.

Sequential rotational phase feeding

This method uses a compact two-stage sequential rotational phase feeding to broaden the operating bandwidth. A small stub is embedded in the sequential rotational feed to improve performance.

Triple-mode resonance

This method uses shorting pins inserted underneath the driven patch and the parasitic patch to excite the TM 1/2,0 mode, the zeroth-order mode, and the TM 1,0 mode. The antenna also uses four metallic side walls to obtain desirable radiation performances.

EXISTING SYSTEM

In the realm of contemporary technology, circularly polarized microstrip patch antennas are extensively utilized in communication systems, attributed to their compact dimensions, low profile, and capability to manage polarization mismatches between transmitters and receivers. The current systems encompass a variety of designs and configurations for both single and array patch antennas, frequently customized for specific applications, including satellite communication, GPS, radar systems, and wireless networks. The following outlines the key characteristics and limitations of these existing systems:

Single Patch Antenna

This type is primarily employed in applications that necessities low gain and limited coverage areas. Circular Polarization is achieved through methods such as corner truncation, slit incorporation, or the application of perturbation techniques. However, the limitations include restricted gain and a narrow axial ratio bandwidth.

Axial Ratio Bandwidth and Efficiency

Many existing systems exhibit a constrained axial ratio bandwidth, which adversely impacts the reliability of circular polarization across a broad frequency range. Additionally, efficiency is often diminished due to losses in feed networks and source wave excitations.

Material and Fabrication Constraints

Substrates like FR4, Rogers, or low-loss dielectric materials are typically employed. However, there are inherent trade-offs between cost and performance.

ADVANTAGES

1. Minimized Polarization Mismatch:

Circularly polarization facilitates reliable signal reception.

2. Enhanced Gain and Directivity:

The 4x4 array design amplifies gain and enhances the directivity.

3. Simplified Fabrication and Integration:

Microstrip patch antennas are cost-effective and easy to produce using standard PCB manufacturing.

4. Flexibility and Multi-Band Functionality:

Capable of operating across multiple frequency bands, making it applicable for various communication standards such as GPS, Wi-Fi, and 5G.

TABULATION

S.NO	**FACTORS**	**4x1**	**4x4**
1.	Array Configuration	It is composed of 4patch elements.	It is composed of 16 patch elements
2.	Gain	The gain will be moderate in comparison to larger arrays, as the array contains fewer elements. The gain tends to increase as the number of elements rises.	Given that the array contains a greater number of elements, the gain will be substantial. The beam will exhibit a narrow profile in both the horizontal and vertical planes, resulting in enhanced directivity.
3.	Bandwidth	smaller array provides a limited bandwidth	It provides an expanded bandwidth as a result of Substantial quantity of elements.
4.	Radiation Pattern	The radiation pattern of the 4x1 array will exhibit a broader bandwidth in one direction, while presenting a relatively narrow beam in the azimuth plane	A 4x4 array will yield a significantly more directional radiation pattern, characterized by a relatively narrow beamwidth in both the azimuth and elevation planes.

CONCLUSION

The 4x4 circularly polarized microstrip patch antenna array presents a highly effective design tailored for contemporary communication systems that necessitate superior performance within compact and lightweight frameworks. By employing circularly polarization, this antenna exhibits resilience against multipath interference and polarization discrepancies, rendering it particularly suitable for applications such as satellite communication, GPS, and Internet of Things (IOT) networks.

The incorporation of a 4x4 array markedly improves the antenna’s gain and beamwidth, thereby ensuring extensive coverage and enhanced signal strength. Both simulation and experimental findings demonstrate commendable impedance matching, axial ratio, and radiation pattern characteristics across the operational bandwidth. The antenna’s low-profile design and straightforward fabrication process make it ideal for integration into various platforms, including portable and aerial devices.

In summary, the proposed design successfully strikes a balance between performance, cost-effectiveness, and manufacturability, providing a viable solution for next-generation wireless communication systems. Future research may focus on optimizing the design for broader bandwidth and further miniaturization to meet the demands of advancing technology.

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