COMPREHENSIVE SURVEY OF MICRO STRIP ANTENNA DESIGN FOR WIRELESS AND 5G APPLICATIONS

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ABSTRACT

Micro strip patch antennas (MSAs) are a fundamental component in modern wireless communication systems, offering advantages such as low weight, low profile, ease of fabrication, and versatility in resonant frequency and radiation characteristics. This paper delves into the design considerations, advantages, and disadvantages of micro strip patch antennas, focusing on various feed techniques. The basic structure of an MSA consists of a radiating patch and a ground plane separated by a dielectric layer. Different shapes of patches, including rectangular, square, dumbbell, circular, triangular, elliptical, U, H, and E shapes, are explored for their impact on bandwidth enhancement. The dimensions of the microstrip patch, such as length, thickness, and height of the dielectric, play a crucial role in determining the antenna's performance. The dielectric constant of the substrate, ranging from 2.2 to 12, significantly influences the bandwidth, efficiency, and radiation pattern. Proper selection of substrate material emerges as a critical task to overcome the limitations of micro strip antennas, including low gain, low efficiency, and high return loss.

Advantages of MSAs, such as their low weight, low profile, ease of fabrication, and adaptability to various applications, are discussed. However, their operational disadvantages, such as low efficiency, high Q, poor polarization, and narrow bandwidth, pose challenges. Different feed techniques, including micro strip line feed, coaxial line feed, aperture coupling, and proximity coupling, are examined, each presenting its unique set of advantages and drawbacks. The importance of achieving impedance matching for optimal power transfer and radiation pattern is emphasized. The paper concludes with an overview of the various feed techniques, highlighting their fabrication complexities, bandwidths, and radiation characteristics. Understanding the trade-offs associated with different design choices is essential for engineers and researchers working on micro strip patch antenna development, ensuring the efficient integration of these antennas into diverse communication systems.

Keyword : - *Micro strip Patch Antennas, Dielectric Substrate, Antenna Feed Techniques, Bandwidth Enhancement, Impedance Matching*

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1. Introduction

In its basic configuration, a micro strip patch antenna consists of a radiating patch and a ground plane, with a dielectric constant isolating them, as illustrated in Fig1.1. The patch is typically crafted from conducting materials like gold or copper, and various shapes, each with distinct advantages, are available [3]. Feed lines and the micro strip antenna (MSA) radiating patch are commonly photo-etched onto the substrate. To streamline calculations, analysis, and performance evaluation, the MSA patch is typically considered in shapes such as rectangular, square, dumbbell, circular, triangular, elliptical, or other regular forms, as depicted in Figure 1.2 [6]. Notably, U, H, and E shapes are particularly significant. The use of these shapes can enhance the bandwidth of the conventional rectangular micro strip antenna, with improvements ranging from 4.81% to 28.71% for U shape, 28.89% for E shape, and 9.13% for H shape, making the E shape antenna the most effective [23].

The length (L) of the rectangular microstrip patch is standard, usually falling within $0.3333\lambda_0 < L < 0.5\lambda_0$, where λ_0 is the free space wavelength. The patch is designed to be very thin, ensuring $t << \lambda_0$, where t represents the thickness of the MSA patch [2]. The height (h) of the dielectric typically ranges from $0.003\lambda_0$ to $0.05\lambda_0$, and the dielectric constant of the substrate (ε_r) is generally between 2.2 and 12 [2]. Metallic patches are commonly fabricated using photolithographic etching or mechanical milling processes, contributing to a construction process that is relatively simple and cost-effective, mainly involving the substrate material. Despite the advantages of being lightweight (especially for thin substrates) and durable, the radiation efficiency of patch antennas tends to be lower compared to some other antenna types, typically ranging between 70% and 90 %.

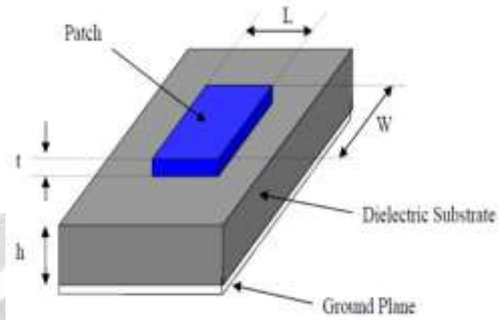

Fig 1.1 MSA with rectangular patch

Various substrates can be employed in the design of microstrip antennas, with their dielectric constants typically falling within the range of $2.2 \leq \varepsilon_r \leq 12$. Optimal antenna performance is often achieved with thick substrates having a dielectric constant at the lower end of this range. Such substrates offer improved efficiency, larger bandwidth, and loosely bound fields for radiation into space, albeit with the trade-off of a larger element size. In microwave circuits, the need for entangled bound fields necessitates minimizing unnecessary radiation and coupling, leading to a preference for thinner substrates with higher dielectric constants. However, these substrates tend to be less efficient and have relatively low bandwidths due to increased losses.

The selection of the proper substrate material is a crucial task in microstrip patch antenna design. Overcoming the inherent limitations of microstrip antennas, such as low gain, low efficiency, and high return loss, is facilitated by choosing appropriate substrate materials. The permittivity of the substrate emerges as a critical parameter in controlling the bandwidth, efficiency, and radiation pattern of the patch antenna. Substrate materials exhibit two fundamental properties: dielectric constant and tangent loss. Achieving optimal antenna performance requires a careful selection of materials that balance these properties.

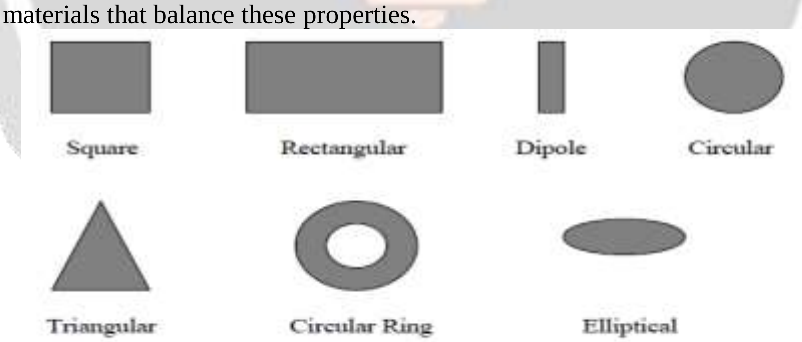

Fig 1.2 different design of patch

Microstrip patch antennas predominantly emit radiation due to the presence of fringing fields between the patch edge and the ground plane. To achieve optimal antenna performance, it is crucial for the dielectric to have a thick substrate with a low dielectric constant. This configuration enhances efficiency, provides a larger bandwidth, and improves radiations [4]. However, a thicker substrate generally results in a larger antenna size. Designing a significant and efficient microstrip patch antenna requires careful consideration of dielectric properties. While higher dielectric constants can be employed for this purpose, they often lead to reduced efficiency and a narrower bandwidth. Therefore, a delicate balance must be struck between the dimensions of the antenna and its overall performance. This balance is crucial to ensure that the antenna meets desired specifications without sacrificing key performance metrics.

Table 1.2: Advantage and Disadvantage of Micro strip Antenna

Feature	Advantages	Disadvantages

Weight and Size	Low weight and profile	Low efficiency and power
Versatility	Versatile in resonant frequency, cross-polarization, and design	High Q (sometimes exceeding 100)
Manufacturing	Simple and less expensive manufacturing using modern technology	Poor polarization and scan performance
Mechanical Robustness	Mechanically robust when mounted on hard surfaces	Spurious feed radiation
Compatibility	Compatible with MMIC designs	Very narrow bandwidth (typically a fraction of a percent)
Adaptability	Adaptive elements can be added for variable frequency, impedance, polarization, and radiation pattern	Desirable narrow bandwidths in some applications (e.g., government security systems)
Enhancement Methods	Methods like increasing substrate height, using cavities, and stacking can enhance efficiency and bandwidth	Surface waves introduced with increased substrate height, leading to unwanted power loss
Quality Factor (Q)	High antenna quality factor (Q)	Low efficiency and narrow bandwidth associated with high Q
Power Handling	Problems with low power handling capacity can be addressed by using antenna array configuration	Surface waves can be minimized using photonic band gap structures

3. Different Feed Techniques

Various methods can be employed for power feeding in microstrip antennas, with the four most renowned configurations being microstrip line, coaxial probe, proximity coupling, and aperture coupling [11]. Microstrip patch antennas can be energized through numerous methods, categorized into two types: contacting and non-contacting. In the contacting method, RF power is directly fed to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is employed to transfer power between the microstrip line and the radiating patch. Regardless of the feeding technique, ensuring proper matching between the feeding source and the antenna is crucial. This matching is essential for transferring maximum power and achieving a better radiation pattern.

3.1Microstrip line feed

In this microstrip feed technique, a narrow strip of conductor is directly connected to the edge of the microstrip antenna patch. The conducting strip, though small in width compared to the substrate's dimensions, offers the advantage of allowing the feed to be placed on the same dielectric, providing a planar structure. The primary objective of the various cuts in the patch is to match the impedance of the feed line to the microstrip antenna (MSA) patch without the need for additional matching elements. This is achieved by carefully controlling the cut position in the MSA patch. Consequently, this method offers a straightforward feeding scheme with easy fabrication and simplicity in modeling, as well as impedance matching.

However, as the thickness of the dielectric substrate increases, there is a concurrent rise in surface waves and unnecessary feed radiation. This escalation negatively impacts the antenna's bandwidth. Additionally, the feed radiation contributes to undesirable cross-polarized radiation.

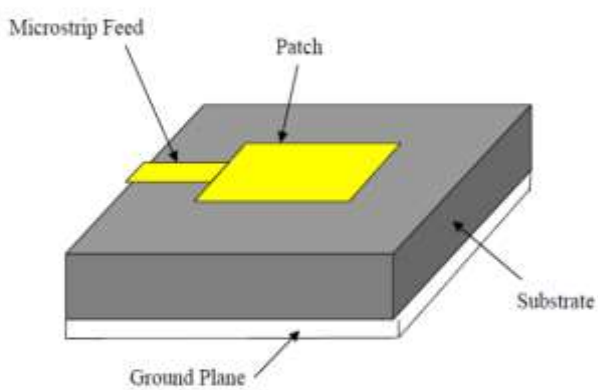

Fig. 1.3 MSA with micro strip feed

3.2 Coaxial line feed

The coaxial feed, also known as probe feed, is a commonly employed technique for supplying energy to microstrip patch antennas. In this configuration, illustrated in Fig. 1.10, the inner conductor of the coaxial connector or probe extends up to the dielectric radiating patch. Simultaneously, the outer conductor remains disconnected from the ground plane of the microstrip antenna.

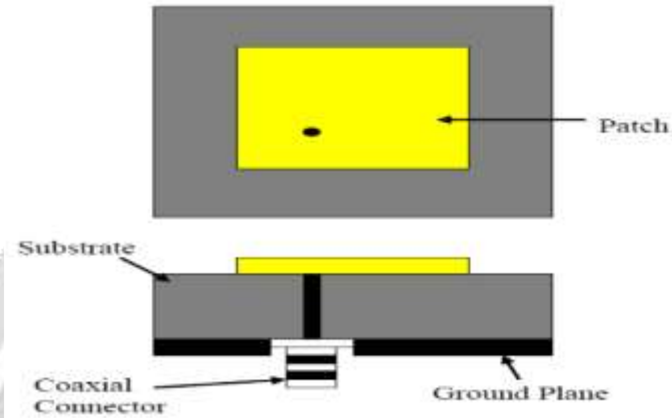

Fig 1.4 MSA with coaxial feed

The advantages of the coaxial feed scheme lie in its flexibility, allowing the placement of the feed at any desired location inside the patch to match the input impedance of the micro strip antenna. The fabrication of this energy feed method is straightforward and comes with low unnecessary radiation. However, its major drawback is the provision of a narrow bandwidth, and it poses challenges in terms of modeling. This method is not suitable for thick dielectric substrates since it requires drilling a hole in the substrate to reach the patch, and the connector extends outside the ground plane. Additionally, for thicker substrates, the increased probe length induces more inductance, leading to matching problems between the feed and the patch of the micro strip antenna. As discussed further below, non-contacting energy feed techniques in micro strip patch antennas address these issues [7].

3.3Aperture coupling

In the aperture coupling energy feed technique for microstrip patch antennas, the patch of the microstrip antenna (MSA) and the microstrip feed line are isolated by the ground plane, as illustrated in Fig. 1.5. The coupling between the patch and the feed line is achieved by creating a slot or aperture in the ground plane. This method allows for independent analysis of the energy feed mechanism and the radiating element. Typically, a high dielectric material is used for the bottom substrate, and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. While this approach has some drawbacks, such as being challenging to fabricate and providing a narrow bandwidth, it offers moderate spurious radiation and ease of modeling [7].

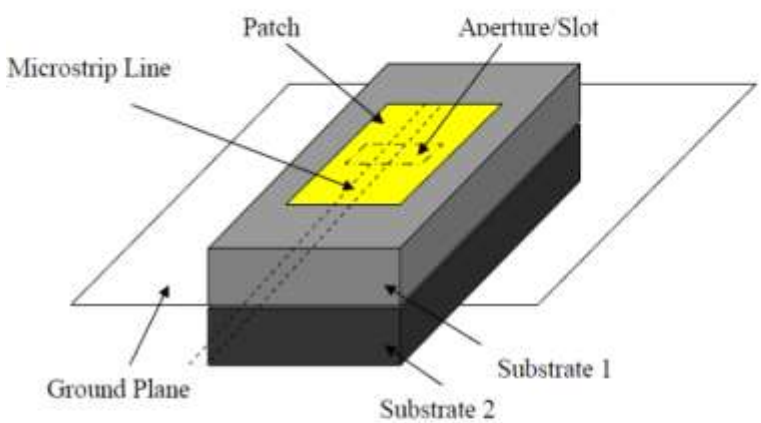

Fig 1.5 MSA with aperture coupling

In the aperture coupling energy feed technique for microstrip patch antennas, the coupling aperture is typically centered under the patch, contributing to lower cross-polarization due to the symmetry of the configuration. The effectiveness of coupling from the feed line to the patch is influenced by factors such as the shape, size, and location of the aperture. The presence of the ground plane between the patch and the feed line minimizes spurious radiation. Typically, a high dielectric material is employed for the bottom substrate, while a thick substrate with a low dielectric constant is used for the top substrate to optimize radiation from the patch.
Despite its advantages, this feed technique has significant drawbacks. Fabrication is challenging due to the involvement of multiple layers with different dielectric properties, leading to an increased thickness of the antenna. The aperture coupling also results in a narrow bandwidth. While it is considered the most difficult of the four methods to fabricate, it is somewhat easier to model and exhibits moderate spurious radiation. The aperture coupling involves two substrates separated by a ground plane, with a microstrip feed line on the bottom side of the lower substrate. The energy is coupled to the patch through a slot on the ground plane, allowing for independent analysis of the energy feed mechanism and the radiating element [7].

3.4Proximity coupling-

The electromagnetic coupling scheme, also known as proximity coupling, involves the use of two dielectric substrates. In this configuration, the radiating patch is positioned on top of the upper substrate, while the feed line is situated between the two dielectrics, as illustrated in Fig. 1.6. This feeding technique offers notable advantages, including an overall increase in the thickness of the microstrip patch antenna, which helps eliminate unnecessary feed radiation and provides a high bandwidth, reaching up to 13%. Additionally, this scheme allows for the use of two different dielectric media, each with a distinct dielectric constant – one for the patch and another for the feed line, facilitating the analysis of individual performances.

While proximity coupling boasts the highest bandwidth, reaching up to 13 percent, and is relatively easy to model with low radiation, its fabrication presents some challenges. The length of the feeding stub and the width-to-lineratio of the patch can be adjusted to control impedance matching in this configuration

[7].

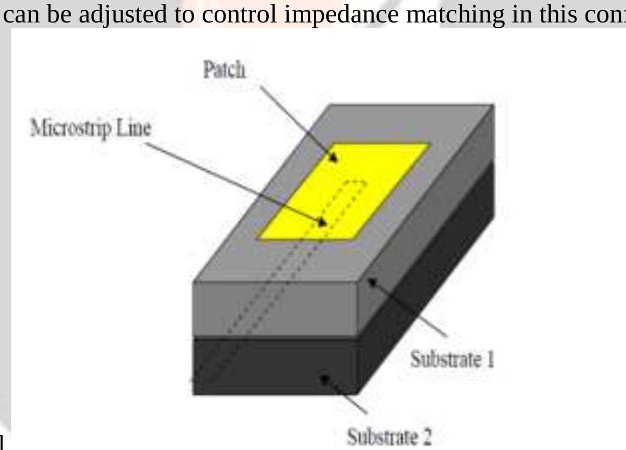

Fig 1.6 MSA with proximity coupling

Table 1.2: comparative Survey

Author Name	Focused Areas	Suggestion
Kishk, A. A. 1979	Fundamentals of Antennas	Utilize ANSI/IEEE Standard Test Procedure for Antennas (ANSI/IEEE Std 149) to enhance understanding and testing methodologies.
Balanis C A, 1997	Antenna theory analysis and design	Consider incorporating recent developments and trends in microstrip antennas to update the analysis and design principles.

Debatosh, G. 2003	Broadband Design of Microstrip Antennas: Recent Trends and Developments	Explore the integration of modern broadband design trends into microstrip antenna development for improved performance.
WATERHOUSE R.B. 1999	Stacked patches using high and low dielectric constant material combinations	Investigate the potential benefits and challenges of stacked patches with different dielectric constants for antenna design.
Garg R, Bharti P, Bahl I & Apisak I, 2001	Microstrip Antenna design handbook	Provide comprehensive guidelines and insights for microstrip antenna design, considering practical applications and challenges.
D. Orban and G.J.K. Moernau. 2009	The Basics of Patch Antennas	Update with the latest advancements in patch antenna technology, including any revisions or new findings in patch antenna basics.
Natalia K. Nikolova. 2010	Modern Antennas in Wireless Telecommunications	Explore modern antenna technologies beyond microstrip antennas and their applications in wireless telecommunications.
www.antenna-theory.com	Microstrip Antenna - Feeding Methods	Provide detailed information on various microstrip antenna feeding methods to aid researchers and practitioners in choosing appropriate techniques.
Sainati, R. A. 2010	Design, Analysis and Optimization of CAD of microstrip antenna for wireless applications	Investigate the optimization of Computer-Aided Design (CAD) tools for microstrip antennas, emphasizing wireless applications.
Won Jung, C. and De Flaviis, F. A. 2005	Dual band antenna for WLAN applications by double rectangular patch with four (4) bridges	Explore the effectiveness of dual-band antennas with specific design features, such as double rectangular patches and four bridges, for WLAN applications.
Roddy, D. and Coolen, J. 2004	Electronic Communications. 4th Edition	Incorporate the latest advancements in electronic communications, especially those related to antenna technologies and applications.
David M. Pozar, 1992	Microstrip Antennas	Update with recent developments in microstrip antennas, considering changes in technology and design principles.
Jieh-Sen Kuo, Cui-Bin Hsieh, and Ching-An Lai, 2002	Gain enhancement microstrip antenna with slots loaded in the ground plane	Investigate the impact of slots loaded in the ground plane on gain enhancement in microstrip antennas, incorporating the latest findings.
K. M. Luk, K. F. Tong and T. M. Au, 1993	Offset dual-patch microstrip antenna	Explore the design and performance characteristics of offset dual-patch microstrip antennas for specific applications.
C. Y. Huang, J. Y. Wu, and K. L. Wong, 1998	High-gain compact circularly polarized microstrip antenna	Investigate the design and performance aspects of high-gain compact circularly polarized microstrip antennas for practical

		applications.
R. Coccioli, W. R. Deal, and T. Itoh, 1998	Radiation characteristics of a patch antenna on a thin PBG substrate	Explore the radiation characteristics of patch antennas on thin Photonic Band Gap (PBG) substrates and their potential advantages.
Weihua Tan, Zhongxiang Shen, Zhenhai Shao, and Masayuki Fujise, 2005	Gain-Enhanced Microstrip-Fed Cavity-Backed Slot Antenna	Investigate the gain enhancement in microstrip-fed cavity-backed slot antennas, focusing on the design aspects and practical implications.
Saeed I. Latif, Lotfollah Shafai, and Cyrus Shafai, 2013	An Engineered Conductor for Gain and Efficiency Improvement of Miniaturized Microstrip Antennas	Explore the use of engineered conductors to improve gain and efficiency in miniaturized microstrip antennas, considering practical applications.
A. K. Arya, A. Patnaik, and M. V. Kartikeyan, 2013	Gain Enhancement of Microstrip Patch Antenna using Dumbbell-shaped Defected Ground Structure	Investigate the use of Dumbbell-shaped Defected Ground Structure for gain enhancement in microstrip patch antennas and its optimization.
A. Boualleg, N. Merabtine, 2005	Analysis of radiation patterns of rectangular microstrip antennas with uniform substrate	Explore the analysis of radiation patterns in rectangular microstrip antennas with a uniform substrate, considering different substrate materials.
K. Praveen Kumar, K. Sanjeeva Rao, V. Mallikarjuna Rao, A. Somasekhar, C. Murali Mohan, 2013	The effect of dielectric permittivity on radiation characteristics of co-axially feed rectangular patch antenna: Design & Analysis	Investigate the impact of dielectric permittivity on the radiation characteristics of co-axially fed rectangular patch antennas, emphasizing design considerations.
B.-K. Ang and B.-K. Chung, 2007	A WIDEBAND E-SHAPED MICROSTRIP PATCH ANTENNA FOR 5–6GHZ WIRELESS COMMUNICATIONS	Explore the design and performance characteristics of a wideband E-shaped microstrip patch antenna for wireless communications in the 5-6 GHz range.
Atser A. Roy, Joseph M. Môm, Gabriel A. Igwue, 2013	Enhancing the bandwidth of Microstrip patch antenna using slots shape patch	Investigate the use of slot-shaped patches for enhancing the bandwidth of microstrip patch antennas, considering practical applications and optimizations.

4. Conclusion

In conclusion, the study of micro strip patch antennas (MSAs) reveals a nuanced interplay between design choices, advantages, and challenges. The fundamental structure of an MSA, comprising a radiating patch, ground plane, and dielectric substrate, forms the basis of its performance characteristics. The choice of patch shape, dielectric material, and substrate dimensions directly influences key parameters such as bandwidth, efficiency, and radiation pattern. The investigation into various shapes of patches, including rectangular, square, dumbbell, circular, triangular, elliptical, U, H, and E shapes, underscores the impact of geometry on enhancing antenna performance. The consideration of dimensions such as patch length, thickness, and dielectric height emphasizes the delicate balance required to achieve optimal results. The dielectric constant of the substrate emerges as a critical factor, with careful material selection proving instrumental in overcoming inherent limitations.

While MSAs offer advantages such as low weight, low profile, and ease of fabrication, their operational challenges include low efficiency, high Q, and narrow bandwidth. The study of different feed techniques—microstrip line feed, coaxial line feed, aperture coupling, and proximity coupling—provides insights into the trade-offs associated with impedance matching, fabrication complexity, and bandwidth. Each feed technique presents a unique set of advantages and disadvantages, and the selection depends on specific application requirements. The quest for achieving impedance matching for optimal power transfer and radiation pattern remains a constant theme throughout the discussion, underlining its crucial role in MSA design. In essence, this exploration of microstrip patch antennas underscores the need for a holistic understanding of their intricate design considerations. Engineers and researchers must navigate through the multitude of choices, considering trade-offs and constraints, to harness the full potential of MSAs in the ever-evolving landscape of wireless communication systems. The continued advancement in MSA technology promises innovations that address current limitations, making microstrip patch antennas an indispensable component in modern communication networks.

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