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IMPACT OF SUBSTRATE THICKNESS ON THE REFLECTION COEFFICIENT PERFORMANCE OF MICROSTRIP PATCH ANTENNAS FOR 5G SYSTEMS

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Abstract
This paper presents the performance analysis of a proposed hexagonal Microstrip patch antenna by varying the substrate thickness (hs) within the range of 0.4–0.8 mm. As the thickness of substrate changes, the reflection co-efficient S_{11} has been improved significantly. While at hs = 0.6 mm gives the best performance with a minimum return loss of -42 dB, compared to -3.5 dB, -9.44dB, -13.4dB, and -9.73dB for other thicknesses. Furthermore, the Voltage Standing Wave Ratio (VSWR) analysis indicates near-ideal impedance matching at hs=0.6 mm, with a value of 1.01, while values of 4.95, 2.01, 1.54, and 1.96 are observed for other thicknesses. The radiation pattern exhibits stable directional characteristics with reduced back radiation and consistent side-lobe behavior. The proposed antenna achieves a maximum gain of 8.35 dB, making it suitable for wireless communication applications, particularly in modern high-frequency systems such as 5G.

1. INTRODUCTION

Accumulative application latency and increasing bandwidth requirements account for improvements in communication standards. Next-generation communication standards, such as fifth-generation (5G) wireless networks, are expected to support significantly more wireless connections to power existing and new applications such as social networking, HD video streaming, rich web browsing, and real-time gaming [1]. Microstrip patch antennas (MSPA) are widely used in wireless communications due to their small size, low cost, low profile, and ease of manufacturing [2].

They find applications in satellite communications, WLAN, Wi-Fi, ISM devices, IoT, RFID, mobile networks and future 5G technology.

Despite these advantages, traditional MPAs have limited bandwidth and low gain, which limits their use in high-performance, high-speed wireless systems [3].

Therefore, extensive research has been conducted to improve the radiation properties, including the gain, making it an active research field [4]. Substrate characteristics and surface wave losses in dielectric layers often limit the gain of rectangular Microstrip patch antennas. The high dielectric constant substrate allows the creation of compact structures. However, it tends to limit the field and generate surface waves, leading to reduced radiation efficiency and consequent gain [5]. Parasitic components, electromagnetic band gap (EBG) configuration, superstreets and multilayer structures serve as conventional gain enhancement techniques.

2. Microstrip Patch Antenna:

A Microstrip patch antenna is a thin planar antenna consisting of a metal patch mounted on a dielectric substrate with a ground plane underneath [6].Designed similar to a printed circuit board (PCB) for easy integration, it provides a compliant package for applications such as GPS, Wi-Fi, and 5G.

However, they have drawbacks such as reduced gain and limited bandwidth, which are often resolved through design changes such as slots and metamaterials.

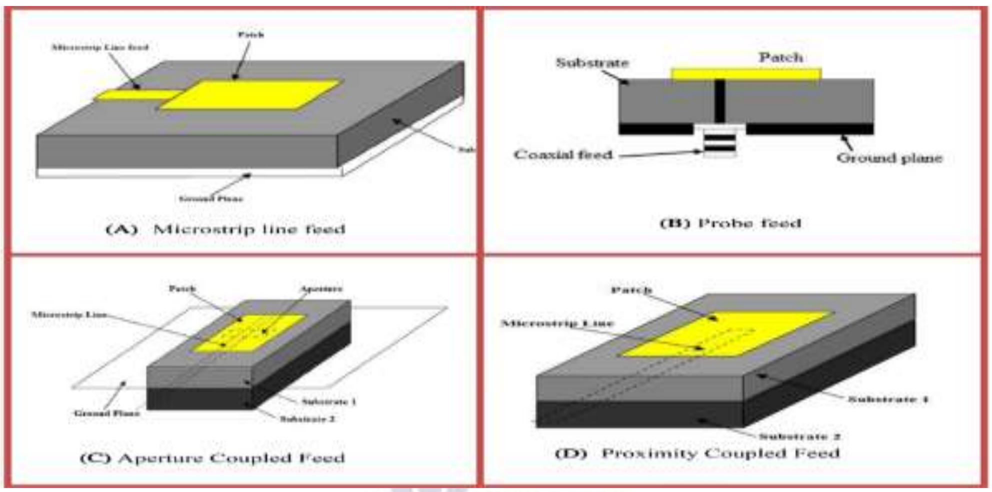

Fig: 1 Microstrip Patch Antenna

This assembly includes critical elements such as the light emitting plate, dielectric substrate, ground plane, and power feed mechanism. Although Microstrip patch antennas have advantages such as compact size, low profile, concentrated radiation, and cost efficiency, they also have disadvantages such as reduced efficiency, cross-polarized signals, and limited power control capabilities [7].

Microstrip patch antennas are widely used in wireless communications due to their small size, slim design, and easy integration into a variety of devices.

These antennas have many advantages that make them suitable for a variety of applications such as mobile devices, wireless routers, satellite communications, and radar systems. Read on as we explore the definition of microstrip patch antennas, their design, and the benefits and applications that make them an integral part of modern wireless communications systems [8].

2.1Challenges in reflection co – efficient Performance in MPA:

The performance of hexagonal Microstrip patch antennas is often limited by substrate properties and losses due to dielectric surface waves [9].High dielectric substrates allow for compact designs, but often limit the field and induce surface waves that reduce radiation efficiency and achievable gain. This study describes the design of a hexagonal patch antenna and increases the substrate thickness from 0.4 to 0.8 to analyze the gain and s-parameters of the patch antenna [10].The goal is to improve antenna gain and c0 reflectance, and therefore effective performance, while maintaining an operating frequency of 50 to 75 GHz for V-band applications.

3. Methodology of Hexagonal MPA:

The proposed hexagonal patch antenna is designed using CST software and provides desirable results in terms of S11, VSWR, bandwidth, directivity, and antenna gain [12].

The parameters of the hexagonal patch antenna are shown in Table 1.

Parameter	Calculated Value(mm)
Width of ground	16.737
Length of ground	14.8
Height of ground	0.025
Height of substrate	0.4,0.5,0.6,07,0.8
Width of patch	6.7
Length of patch	4.8
Width of feed line	1.35
Gap b/w patch & Feed line	1
Insert feed line	1.5
Radius of patch	4.65

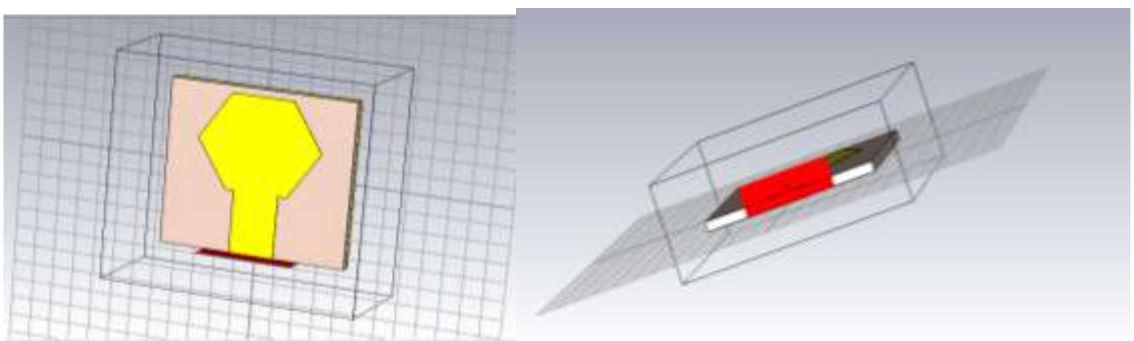

Fig: 2 and 3, Proposed Hexagonal patch Antenna

The following formula determines the spot width: Here, "fo" is the operating frequency and "εr" is the dielectric constant of the substrate.

$$W = \frac{c}{2fr\sqrt{\frac{Er+1}{2}}} \longrightarrow (1)$$

This formula is used to calculate the width of the patch antenna.

The effective permittivity εr (eff) is then calculated using equation 2.

$$E_{reff} = \frac{Er+1}{2} + \frac{Er-1}{2}\left(1+12\frac{h}{w}\right)^{-0.5} \longrightarrow (2)$$

The antenna's width and length, both mostly measure in millimeters while the thickness of substrate show by h_s

$$L_{eff} = \frac{C}{2f_o\sqrt{Eeff}} \longrightarrow (3)$$

$$\Delta L = 0.412h\frac{(Eeff+0.3)\left(\frac{W}{h}+0.264\right)}{(Eeff-0.258)\left(\frac{W}{h}+0.8\right)} \longrightarrow (4)$$

The Length of the patch antenna calculated by the following method

$$L = L_{eff} - 2\Delta L \longrightarrow (5)$$

The following formulas used to calculate the ground and substrate size by the given formulas

$$W_g = 6h + W_p \longrightarrow (6)$$ [13]

$$L_g = 6h + W_p \longrightarrow (7)$$

3.1 Feed line technique of (MPA):

MPAs are gaining importance in various communication fields. Patch antennas have an inherently narrow bandwidth. Various methods have been developed to improve bandwidth. Several factors influence the effectiveness of an antenna. Feeding is a method where excitation is delivered via direct or indirect contact to enable the patch to radiate) the unique types of feed line methods for microstrip patch antennas outlined below:

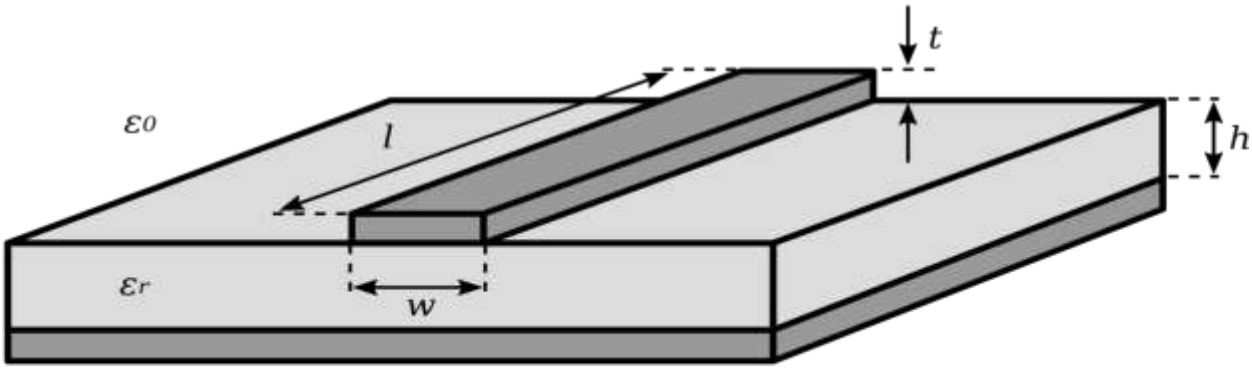

Fig: 4 Feed line technique of patch antenna

This power delivery method is simple because it allows for simple design, simple modeling, and impedance equalization. However, as the dielectric substrate thickness increases, surface waves and stray radiation also increase, leading to a decrease in antenna bandwidth. This type of power delivery method involves attaching a conductive strip directly to the end of the microstrip patch as shown in Figure (4) [15].

The patch is wider than the conductive strip. Because the power supply can be etched onto the same substrate to form a planar structure, no additional matching components are required, and patches can include inserts that provide effective impedance matching.

4. Result and Discussion of Hexagonal Patch Antenna:

The suggested hexagonal microstrip patch antenna was created and tested to function in the V-band (40–75 GHz) for wireless communication systems using CST Microwave Studio. In terms of radiation properties including return loss, VSWR, bandwidth, gain, and impedance matching, the simulation findings validate outstanding performance. A return loss (S_{11}) of –42 dB was found at a resonant frequency of 58.9 GHz, indicating little reflection and almost perfect impedance matching. With a Voltage Standing Wave Ratio (VSWR) of 1.01, there was little mismatch between the antenna and the feed line network, allowing for effective power transmission. Below are the results of the proposed hexagonal antenna with different substrate thicknesses:

4.1 Reflection co – efficient (S_{11}):

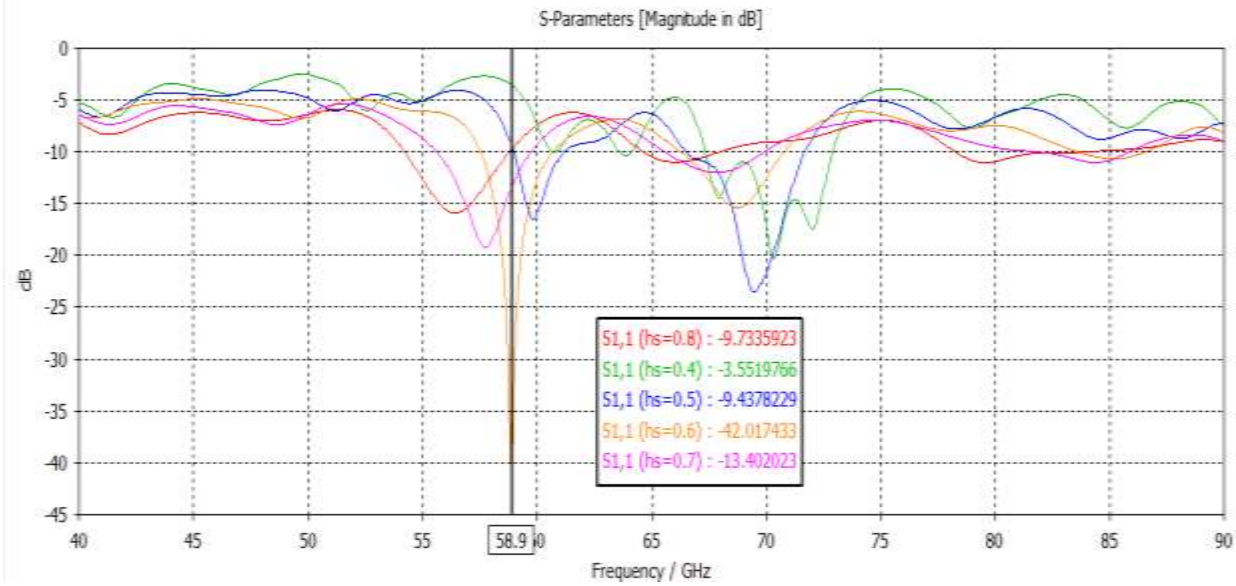

Fig: 5. The reflection co – efficient factor of proposed antenna less than – 10 dB

The results of the simulation demonstrate a clear effect of substrate thickness on the antenna's impedance matching characteristics. By varying the substrate thickness (hs), the prototype hexagonal microstrip patch antenna's return loss performance was examined. The substrate thickness in this study was gradually increased from 0.4 mm to 0.8 mm, with 0.6 mm yielding the best results. The observed return loss was −3.5 dB when the substrate thickness was changed to 0.4 mm, indicating poor impedance matching and increased power reflection. The return loss reduced to −9.44 dB with a thickness of 0.5 mm, suggesting better matching than in the previous case. At Hs = 0.6 mm, antenna performance significantly improved with a return loss of −42 dB, indicating excellent impedance matching and reflected power at the resonant frequency. However, the return loss fell to −13.4 dB when the thickness was increased to 0.7 mm, and it further lowered to −9.73 dB when the thickness was increased to 0.8 mm. These results unequivocally show that 0.6 mm is the ideal substrate thickness for the proposed hexagonal antenna, resulting in optimal impedance matching and maximum radiation efficiency. As the substrate thickness increases, changes in fringing fields, surface wave excitation, and the effective dielectric constant are the primary causes of the performance variations. Therefore, choosing the right substrate thickness is essential to improving the suggested hexagonal microstrip patch antenna's overall performance.

4.2 VSWR (Voltage Standing Wave Ratio) of Proposed Antenna:

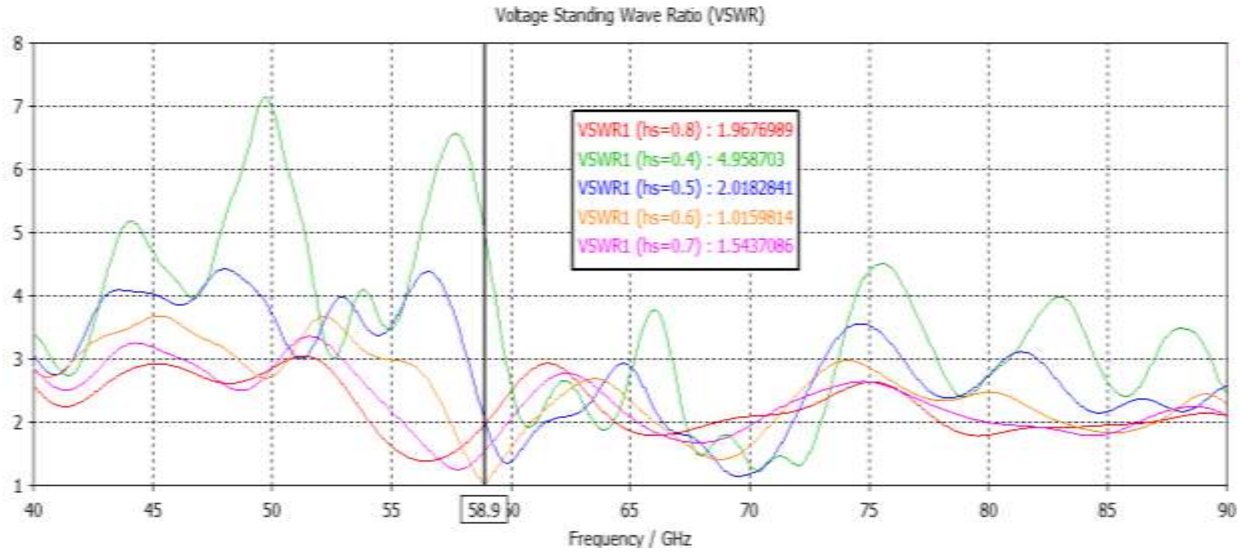

Fig: 6 VSWR of proposed antenna observed in between 1 and 2

The suggested hexagonal microstrip patch antenna's VSWR values were assessed by varying the substrate thickness from 0.4 mm to 0.8 mm. The primary derisory impedance matching, the VSWR, was 4.95 at 0.4 mm and increased to 2.01 at 0.5 mm. At hs = 0.6 mm, an exceptional impedance matching with a practically perfect VSWR of 1.01 was noted. The best substrate thickness is 0.6 mm, while further thickness increments to 0.7 and 0.8 mm produced VSWR values of 1.54 and 1.96, respectively.

4.3 Radiation pattern of Proposed Hexagonal Patch Antenna:

A consistent and nearly directed broadside characteristic in the radiation pattern of the suggested hexagonal microstrip patch antenna indicates current radiation perpendicular to the patch's surface. Strong directivity and well-developed side lobes are evident in the well-defined primary lobe with minimal side and rear lobe radiation. The antenna's robust radiation characteristics and applicability for cutting-edge wireless communication systems are confirmed by its maximum gain of 7.33 dBi.

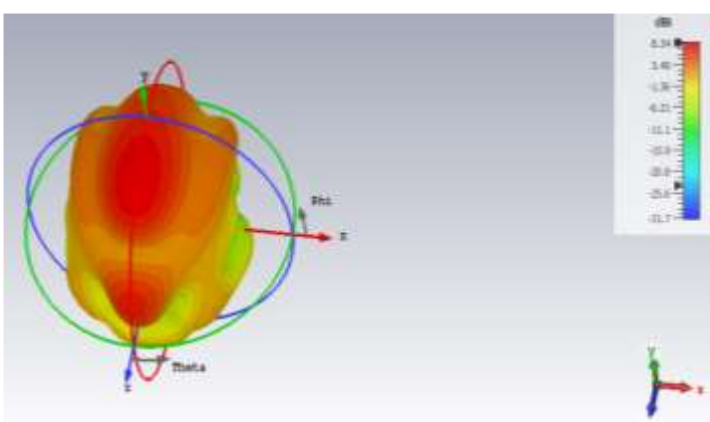
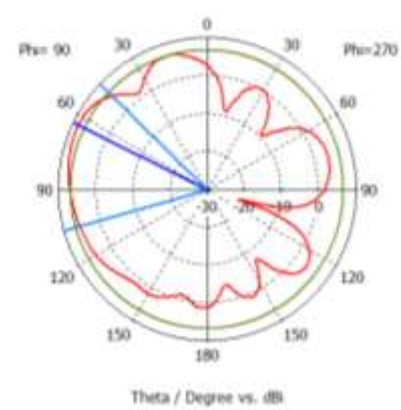

Fig: 6 and 7 represent the radiation pattern of proposed hexagonal patch antenna

All outcomes of proposed Hexagonal microstrip patch antenna given table -2:

Parameters	Results
Reflection co – efficient (S11)	−42 dB
VSWR	1.01
Gain	7.33dBi
Directivity	8.35 dB

Conclusion

For wireless communication applications, a prototype microstrip patch antenna with excellent performance and small size was effectively developed. At a resonance frequency of 58.9 GHz, the antenna showed remarkable impedance matching with a VSWR of 1.01 and a significant return loss of −42 dB. In terms of directivity, gain, and S-parameters, the suggested design outperformed the reference models. With a gain of 7.33 dBi and a directivity of 8.35 dB, it is shown to have excellent radiation efficiency and targeted signal transmission. These results demonstrate the exceptional applicability of the suggested antenna layout for high-data-rate transmission for wireless communication systems, particularly in complex millimeter-wave applications.

Future Work

Future research could concentrate on increasing gain, directivity, and radiation efficiency to enhance performance in (mmw) millimeter-wave applications. Experimental testing and real-world production are required to verify simulated results. High-frequency losses may also be decreased by enhancing feeding methods and substrate composition. Beyond the current 5G networks, these developments will enable high-data-rate wireless communication systems in the future.

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